

Govindjee, Who Revealed the Secrets of Photosynthesis and Inspired Five Generations of Explorers

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Received: 07-10-2023; Accepted: 22-10-2023

ABSTRACT

We present here, our thoughts on Govindjee's ideas for guidance of beginning students which is based on an article in Hindi, "*Prakash Sanshleyshran Kay Rahashyon Ko Ujagar Waley Preyrak Vaigyanik—Govindjee*" by Kapoormal Jain. The key points of this paper are based on Govindjee's life and his own philosophy by which the inherent source of his brilliant scientific achievements follows: (1) Adopt progressive ideas; (2) Study and share thoughts in order to gain understanding; (3) Explore career options while learning from the wonders of nature; (4) Build a strong background; (5) Be bold; (6) Dreams are made into reality when heart and soul meet in harmony; (7) Always keep the interests of society in mind; (8) Achieve deep understanding; (9) Develop a clear focus; (10) Move forward with new technologies; (11) Persevere and work diligently; (12) Conduct scientific investigations with integrity; (13) Publish effectively, persuasively, and creatively; (14) Focus on promoting respect; (15) Adopt an effective and engaging style; (16) Remember those who have been uplifting – Never forget; (17) Engage in mutual cooperation to achieve the big goal; and (18) Encourage colleagues with positive feedback!

Keywords: Louis N.M. Duysens, Rajni Govindjee, Robert Emerson, Krishnaji, Eugene Rabinowitch

INTRODUCTION

The botanist, Govindjee, has undertaken amazing research, uncovering the secrets of the process of photosynthesis in plants and this is one of the reasons that the world community calls him, Mr. Photosynthesis. A scholar of integrity, his greatest personal virtue is that he is like the rising tides of the seven seas, all who meet Govindjee are uplifted. Let us now see how we may receive guidance from Govindjee which may prove helpful in preparing us to elevate mankind. Figure 1 shows Govindjee wearing the glasses his professor Robert Emerson wore when teaching him the tricks and safety precautions of glass-blowing.

Adopt progressive ideas

Govindjee was born in Allahabad on October 24, 1932, to Visheshwar Prasad and Savitri Devi. As a child, Govindjee was greatly influenced by the progressive thoughts of his father, who was first a teacher in a college and General Secretary of the United Provinces (Uttar Pradesh) Teachers Association, and then he became the sales representative of the Oxford University Press (OUP), North India. Prasad was a scholar of Hindi, English, and Urdu. He considered all people equal and was against dividing the society into castes. These qualities of his father came in the form of '*Sanskar*' and that is why, like his father, Govindjee never believed



Figure 1. Govindjee wearing glasses that belonged to the late Robert Emerson. Although, this pose is for fun and frolic, there is a serious safety message here because the lenses are tinted for protection of eyes. Source: Govindjee's family archives

in the caste system and never used his caste-indicative surname *Asthana*. However, when Govindjee was only eleven years old, his father unfortunately passed away. See: Govindjee (2007). In those days, Govindjee's mother, Savitri Devi, was not in good health, thus, the responsibility of his upbringing was handed to his eldest brother Krishnaji. Later, Krishnaji became a professor of physics at Allahabad University though he always was the supreme role model for Govindjee. See: Govindjee and Srivastava (2010).

In this way, we learn from Govindjee to adopt progressive ideas.

Study and share your thoughts in order to gain understanding

Since his childhood, Govindjee had a very inquisitive nature. 'Why' and 'How' were on his lips about everything. His eldest brother Krishnaji was known to say that Govindjee had enjoyed arguing so much that he used to dislike those who shied away from vigorous discussions. Govindjee did not rest until that curiosity was satisfied.

Eager to know and learn new things, love to study and debate any subject.

Explore career options while learning from the wonders of nature

Govindjee attended Colonelganj High School and Kayastha Pathshala Intermediate College. In school, his teachers introduced him to the wonders of nature. He became so fascinated with the world of botany that he would spend hours gazing at the flowering plants growing in the school gardens. Even today, Govindjee is attracted to the foliage and flowers he sees on his daily walks through local parks in Illinois. Nature's process of making food by plants, photosynthesis, became so dear to him that he would be inspired to devote his career to it. Nature is, indeed, full of wonders and, it is thus, that we learn by carefully observing every incident that happens in it.

Nature opens the path to careers.

Build a strong background according to your true interests

Even when Govindjee was in school, he took great pleasure in reading many biology books to learn about flora and fauna. Moreover, he learned through practical work. Animals had to be dissected in zoology, however, this shook his confidence. Needless to say, Govindjee did not like zoology. On the other hand, his confidence in botany was boundless and became a most suitable career choice. An understanding of physics and chemistry was necessary in the study of this subject, too, and his attachment to physics was already there from his brother, Krishnaji. Fortunately, in college, he enjoyed lessons from faculty members including, Jalpa Prasad and M.L. Gaur, professors who recognized his talent and ignited his interest in biology and chemistry. They even gave Govindjee books from their personal libraries to study. In this way, he was given a robust and strong background that had prepared him for botanical studies.

When he joined Allahabad University and was elected as the General Secretary of the Botanical Society, Govindjee organized a seminar on the topic of, 'Reincarnation of Photosynthesis Research'. This special seminar was

presented by six students, each of whom played the role of scientists who made important contributions to photosynthesis. Its purpose was to bring before all the fellow students an era of photosynthesis research when many early discoveries were made. For example, Jan Ingenhousz, who wanted to understand the processes of how plants made food, made advances in photosynthesis that were of great importance. Results of key experiments by Ingenhousz established that this process is completed only in the presence of light. See Chapter 1 in Rabinowitch and Govindjee (1969). Since these discoveries were made in European countries, everyone wore costumes of that period. Govindjee played the role of Ingenhousz. The immersion to which Govindjee played this role won everyone's heart.

Take 'role-play' as a mode of study and inspiration.

Be bold

When Govindjee played Ingenhousz, he argued passionately that photosynthesis is essential for life on Earth. Leaves, the green part of trees, blades of grass, and green cells of other organisms, such as algae, all contain chloroplasts that have molecules of chlorophyll, by which photosynthesis takes place. These chlorophyll molecules absorb the blue and red parts of sunlight, thus beginning the process of photosynthesis. Plants grow by eating sunlight, converting water and carbon dioxide into carbohydrates, our food, while releasing oxygen into the air. During the debate at the above seminar, it seemed as if Ingenhousz, himself, had appeared! At the end of the debate he said on his part that, 'This process plays its most important role in keeping the Earth a living planet. It not only gives us food to eat, but it also gives us oxygen to breathe and keeps us alive.'

Be confident.

Dreams are made into reality when heart and soul meet in harmony

Govindjee was applauded for his role and, indeed, very happy. The program was so effective and heart-touching,

that all present fully participated in it. And so, after successfully playing this role, he started dreaming of becoming a scientist like Ingenhousz.

If the heart strings are found while performing live, then dreams take birth and and pave pathways to new careers.

Always keep the interests of society in mind

The question arose in Govindjee's mind that if the food making process were understood properly, then the problem of hunger could be eliminated from humanity.

During his studies at Allahabad University, Govindjee specialized in plant physiology. The head of the Department of Botany, Shri Ranjan, a former student of Frederick Frost Blackman, explained the *Law of Limiting Factors* and the *Dark Reaction* (Blackman's reaction) about processes that could affect the rate of photosynthesis, laying the foundation for Govindjee's future in photosynthesis. Then, Govindjee decided to go to the USA for graduate studies under Robert Emerson. In 1956, he was selected as a Fulbright scholar under the United States Cultural Exchange Program, and as a Graduate Fellow by the University of Illinois at Urbana-Champaign (UIUC). Finally, Govindjee received a PhD in Biophysics. See Govindjee et al. (2019); and for further information, see his website: <https://www.life.illinois.edu/govindjee/>.

Contribute to the greatest good.

Become immersed in every subject to achieve deep understanding

The preeminent scientist, Robert Emerson, was the first to recognize an 'Enhancement Effect' that led to the concept of two-light reaction and two-photosystems in photosynthesis. In this phenomenon, Emerson had observed that the rate of photosynthesis increased when orange-red light (650 nm) was added to far red light (700 nm). That is, when these two beams of light were added together, the overall rate of photosynthesis increased significantly, much more than what would have been achieved by separately shining the beams.

Govindjee understood from this effect that there are two photosystems (PSI and PSII) working in chloroplasts which cooperate with each other and generate oxygen. The reaction center of PSI was then known to be P700 by the work of Bessel Kok, while that of PSII was called P680. Govindjee had made an early suggestion for it, see Krey and Govindjee (1964), and started investigations in depth into the subject, with many research questions in mind.

Delve deeply into the subject.

Develop a clear focus

As a graduate student, Govindjee had enjoyed working with Emerson to understand the process of photosynthesis. Then, suddenly Emerson died in an airplane crash on February 4, 1959. Soon thereafter, under the direction of another internationally regarded scientist, Eugene Rabinowitch, Govindjee completed his PhD thesis on, 'Action Spectra of the Emerson Enhancement Effect in Algae.' See: Govindjee et al. (2019); Govindjee et al. (2021); and Govindjee (2023). During his research work, Govindjee found that a spectral form of chlorophyll *a* (Chl *a* 670) played a role in PSII, which has an important, although indirect role, in producing oxygen. As a consequence, Govindjee turned his full focus onto PSII. For his recent publications, see: https://www.life.illinois.edu/govindjee/recent_papers.html; for his latest review on PSII, see: Shevela et al. (2023).

Focus and move forward.

Move forward with new technologies

That Chl *a* has a role in the process of photosynthesis is known, but the problem before scientists at that time was that after the absorption of light at 680 nm, they wished to find out what further actions took place and how oxygen was generated. Since the whole process takes place very rapidly in different steps, Govindjee started by moving away from traditional techniques and chose *Absorption and Emission Picosecond Spectroscopy* and *Kinetics* as tools. He also looked at *Delayed Fluorescence*

(DF, also known as DLE for *Delayed Light Emission*) of Chl *a*, which provided information on some of the reactions of PSII. Then, he used it as a signature in forward reactions of the whole process of photosynthesis.

From the analysis of the spectrum and intensity of DLE, he identified the intermediate co-products formed during the process of photosynthesis and stated that PSII acts as a catalyst for the photooxidation of water and for the reduction of plastoquinone. Furthermore, and most interestingly, his laboratory discovered that *bicarbonate* has an essential role in the light reactions of photosynthesis. It is clear from his work that the idea that two water molecules get oxidized to give rise to one molecule of oxygen remains the best hypothesis, although bicarbonate may be somehow involved there; see e.g. Stemler and Castelfranco (2023).

Notably, his astonishing work on electron and proton transport processes was the result of investigating the extremely short-lived intermediates of picosecond duration (fluorescence life-time). He showed how new technologies can be used beautifully to understand the mysteries of nature. For an overview, see Govindjee (2019).

Adopt new techniques.

Persevere and work diligently

Govindjee worked as a post-doctoral Fellow, US Public Health, National Institute of Health, between 1960 and 1961. From 1961 to 1965, he served as Assistant Professor of Botany; from 1965-1969, Associate Professor of Botany and Physiology & Biophysics; from 1969 to 1999, Professor of Biophysics and Plant Biology; and from 1998-1999, he also served as Professor of Biochemistry, UIUC.

After retirement in 1999, Govindjee has been continuing onward as professor emeritus UIUC. He is currently interested in research to improve the efficiency of photosynthesis, as well as understanding and using changes in Chl *a* fluorescence to monitor the regulatory mechanisms of plants, algae, and cyanobacteria. He also

wants to bring to light, the history related to the research of photosynthesis and the scientists working in this field. See: https://www.life.illinois.edu/govindjee/recent_papers.html for tributes he has written.

The work ethic is the 'mantra' of life.

Conduct scientific investigations with integrity

In New Mexico, Los Alamos National Laboratory had organized a seminar on the topic of photosynthesis and there, the organizers stated, “*We all depend on 'photosynthesis' and photosynthesis depends upon Govindjee.*” Thus, his work has become his identity, a very high recognition, indeed. This was made possible only because of the highest level of integrity in science.

Integrity.

Publish effectively, persuasively, and creatively

It is important to note that Govindjee had developed, together with Don DeVault and William Arnold, the theory of thermoluminescence in plants and algae. Furthermore, Govindjee has written more than 600 research papers on various areas of photosynthesis, *from a photon to a plant*. In a career spanning 67 years, Govindjee has been working for and influencing many minds around the world through his various publications and scholarly exchanges, including with Nobel Laureates, scientists, physicists, graduate students, post-graduate fellows, business professionals, and even the general public. His writing is effective, inspiring, creative, and always persuasive. At the heart of his writings has been his academic articles, such as in *Scientific American*, and for example, *Role of Chlorophyll in Photosynthesis*, *Light Absorption*, *Excitation Energy Transfer*, and *Production of Oxygen by Plants*. See: Rabinowitch and Govindjee (1965); Govindjee and R. Govindjee (1974); Govindjee and Coleman (1990).

Govindjee is the founder of the series, *Advances in Photosynthesis and Respiration*, and of the *Historical Corner of Photosynthesis Research*, while his prolific

writing continues. Recently, in 2019, a book was written with Dmitry Shevela and Lars Olof Björn, *Photosynthesis: Solar Energy for Life*. His earlier published (some edited) books include, among others, *Photosynthesis*, *Bioenergetics of Photosynthesis*, *The Maximum Quantum Yield Controversy*, and *Molecular Biology of Photosynthesis*. See e.g.: Rabinowitch and Govindjee (1969); Shevela et al. (2019); Nickelsen and Govindjee (2011); and Govindjee (1975; 1982).

Be effective, inspiring, and creative.

Focus on promoting respect

Govindjee has been honoured, elected a Fellow of the American Association for the Advancement of Science in 1976, and a Fellow of the National Academy of Sciences (India) in 1979. In 1981, he was elected President of the American Association for Photobiology. In 2006, he received the Lifetime Achievement Award of the Rebeiz Foundation for Basic Research. In 2007, the International Society of Photosynthesis Research (ISPR) awarded him with its *Communication Award*. In 2022, Govindjee received the Lifetime Achievement Award of ISPR, one of the most prestigious awards in photosynthesis research. For this, see: Nonomura and Kumar (2022).

Action brings rewards.

Adopt an effective and engaging style

Govindjee is one of the most engaging teachers in plant physiology, molecular biology, and biophysics at UIUC. His style of teaching, explaining, and communicating is so effective and interesting that all are mesmerized. His lectures and seminars are often interwoven with stories, and they are enjoyable. He has taught various subjects, such as biology, bioenergetics, biochemistry, fluorescence spectroscopy, and photosynthesis. For fun, see him in Figure 2 after his seminar at UIUC.

Strive to engage students with a communication style that is effective and interesting.

Remember those who have been uplifting – Never forget

Govindjee believes that in discussion of his own research on photosynthesis, he enjoyed the best of times with Bessel Kok, C. Stacy French, William Arnold, and Louis N. M. Duysens, to whom he has written tributes. See e.g. Govindjee and Fork (2006) on French; Choules and Govindjee (2014) and Govindjee and Srivastava (2014) on Arnold; and Govindjee and Pulles (2016) on Duysens. He told others that the training he received from Duysens developed him as a biophysicist. He also remembers the teachers from his school and college days who sparked his initial interest in this field.

Always remember.

Engage in mutual cooperation

Increasing the efficiency of photosynthesis in the future quite possibly could eradicate hunger from the world.

This is a huge target and Govindjee currently is taking aim internationally with various scientists and organizations. See Figures 3 and 4 for photographs of some who had gathered for his retirement party in 1999.

At present, Govindjee is working with Ashwani Pareek (India), see e.g.: Wungrampha et al. (2019); Baishnab Tripathi (India), see e.g.: Kandoi et al. (2022); and Ya [David] Guo (China) on projects by which plant production may be improved. See e.g.: Pandiyan et al. (2021) and Yuan et al. (2022). Govindjee has a strong sense of teamwork. Figure 5 shows Govindjee with Ashwani Pareek and Figure 6 shows him with Baishnab Tripathy, both in India.

Endeavor to work together.

Encourage colleagues with positive feedback!

Preeminent scientific achievements, such as the Govindjees' enhancements of Emerson's observations,



Figure 2. Govindjee (center) at a Halloween party, held after a Plant Biology Colloquium, University of Illinois at Urbana-Champaign. Clockwise (from the left): Sachin Heera (wearing horse mask), Stuti Shrivastava, Ursula Idleman, Clayton Dilks, and Amy Marshall-Colon. October 15, 2015, Source: Archives of Marshall-Colon



Figure 3. A 1999 photograph of former research collaborators of Govindjee. Left-to-right are: Thomas (Tom) J. Wydrzynski^{##}, Alan Stemler; Jin Xiong; Teruo Ogawa (Japan); Paul Jursinic; Maarib Bazzaz^{##}; Govindjee; Rita Khanna; Barbara Zilinskas; Jack Van Rensen (The Netherlands); Irene Van Rensen; and Julian Eaton-Rye (New Zealand). Source: Govindjee’s family archives (^{##} Deceased)

are at the foundation of some of the greatest benefits to mankind and that is why one of them is known, today, as, “The Emerson-Govindjees’ Enhancement Effect” (Lichtenthaler et al. 2022). Here, he undertook research and taught from 1961 to 1999. He is proud of all his graduate students (see: <https://www.life.illinois.edu/govindjee/g/GraduateStudents.html>); and maintains hardcopies of their PhD theses in his office; see Figure 7.

Since 2007, UIUC has been conferring the Govindjee and Rajni Govindjee Excellence Award on students who have excelled in the biological sciences.

Encourage excellence.

Concluding Remarks

The virtues of the great photosynthetiker, Govindjee Govindjee, guide us to innovate with progressive ideas. Even on his 91st birthday this October 2023, Govindjee continues to be a source of inspiration for young and senior scientists, thus for example, we offer an excerpt of a personal communication from Roberto Espinoza Corral (15 Oct 2023): “I would like to start this letter by thanking you for your work and especially for all I have learned from you over the years. From you, a really great



Figure 5. Govindjee (Right) with Ashwani Pareek on a field trip in Rajasthan, India. Source: Ashwani Pareek’s Archives



Figure 6. Govindjee (Left) with Deepika Kandoi and Baishnab Tripathy at Jawaharlal Nehru University, New Delhi. Source: Baishnab Tripathy’s Archives.

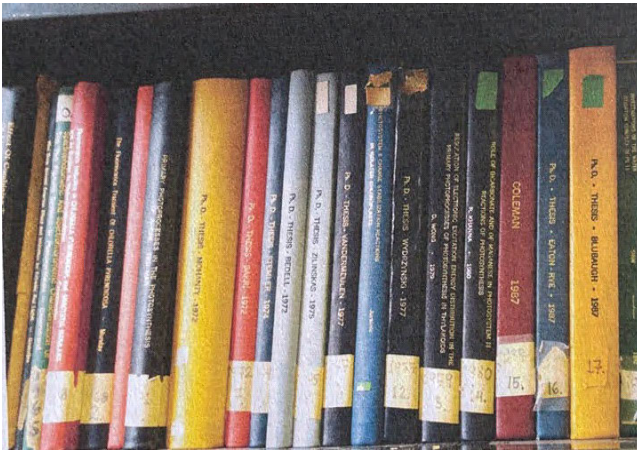


Figure 7. Theses of Govindjee’s doctoral students - all related to the mechanism of photosynthesis. Source: Archives of Rita Khanna

scientist, who significantly advanced our understanding of photosynthesis – from the red drop to the special role of bicarbonate in PSII – I had the pleasure of learning about your career during my PhD while learning about photosynthesis and how to interpret data generated using PAM on *Arabidopsis* leaves. Your papers that I had read led me to be curious about who was behind them; and I want to add that you have inspired me. While working at Michigan State University, I had the opportunity to attend a virtual lecture* you gave, and I hope in the future I could have the chance to meet you in person. I wish you the life you deserve after contributing so much to science and everyone in this planet, as photosynthesis is the basis of life.” (*For the lecture, see: <https://mcb.illinois.edu/news/2022-05-23/emeritus-professor-govindjee-delivers-2022-anton-lang-lecture>)

Inspirational tips that can help us achieve our goals are to learn from nature, give positive feedback, and elevate the quality of life as you **boldly** go where no man has gone before. We end this perspective on Govindjee by wishing him a happy birthday and by showing a recent photograph (see Figure 8), as this scholar of peace and light waves.

EPILOGUE

The editor of IJLS, Ashwani Kumar, recommends that readers visit the following websites to know more about Govindjee:



Figure 8. A photograph of Govindjee taken at his home in Urbana, Illinois. Source: Archives of Govindjee’s family

- i) <https://www.youtube.com/watch?v=OBKusHcjMzw>
- ii) <https://www.life.illinois.edu/govindjee/awardsandhonors.html>
- iii) <https://www.life.illinois.edu/govindjee/90th-birthday.html>

The editor further recommends two papers, Block (2022) and Kumar et al. (2021), for deeper glimpses of Govindjee’s life.

ACKNOWLEDGMENTS

AK thanks Ashwani Pareek (of NBRI) and Ashwani Kumar for invitations to write and submit this paper to IJLS. Most importantly, AK thanks Govindjee for reading it. The authors thank Roberto Espinoza Corral for sharing his kind note. The authors thank the Govindjee family for providing most of the photographs used here as they are different from those used by the late Kapoormal Jain (Bhopal, India) in his article in Hindi.

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How to cite this article: Kumar A, Nonomura A (2023) Govindjee, who revealed the secrets of photosynthesis and inspired five generations of explorers. *LS - An International Journal of Life Sciences*, 12(3):141-150.