Reminiscences

Desert Flower, Sphere and Antique Optics Equipment (photo credit: Wyant College of Optical Sciences, University of Arizona).

Education in Optics—John's Way

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I came to know Prof. John E. Greivenkamp 30 years ago through his paper on interferometric fringe analysis for aspheric surface measurement, when he was affiliated with the Eastman Kodak Company. During those days, I was also involved in developing an automatic aspheric surface measurement system based on interferometric fringe analysis. John's ideas helped me a lot in my understanding of interferometric fringe analysis.

I then met John at the Optical Sciences Center of the University of Arizona in the early 2000s. He was happy to share his ideas on optical surface testing using interferometric methods, Shack–Hartmann sensors, etc., with me. Later, in several optical conferences, I observed John as an energetic force, fully engaged at all times. By then, he had already established himself as a successful educator. I was elected as a SPIE Board member in 2011, when I had a chance to witness an entirely different dimension of John's activities. By then, John had already completed many hours as an SPIE Board member and authored several SPIE journal articles and books, including the first of the popular *SPIE Field Guides*, for which he served as Series Editor.

John at the Spark Museum of Electrical Invention, Bellingham, Washington, during a 2014 SPIE Board meeting.

Later, in 2012, I invited John to the Utsunomiya University Center of Optical Research and Education (CORE). CORE was founded by me in 2007 with the purpose of promoting education and research in the field of optics. My vision was to develop CORE into a global center for optics education and research. The College of Optical Sciences (OSC) in Tucson, Arizona was our model, and the Dean of the OSC at that time, Prof. James C. Wyant, fully understood our mission and supported our activities. During John's stay at CORE, he delivered several lectures on optical measurement and the history of optics.

The most impressive of John's lectures that I remember was "The History of Telescopes and Binoculars," which he gave at the Utsunomiya Girls' High School. Most of the audience was high school girls who had no prior knowledge of optics. John started, "How do lenses work?" and then continued with the story of the invention of the telescope early in the 17th century, including an interesting incident on a telescope patent.[1] The story John narrated was the following: In the early 1700s, it was believed that chromatic aberration was very fundamental in its origin and could not be corrected. A Barrister in London named Chester Moor Hall had then thought of a solution: the achromatic doublet. In 1733 he commissioned two different opticians, Edward Scarlett and James Mann, to make one lens element each. By chance, both opticians subcontracted the work to the same man, George Bass. Chester Moor Hall then continued to keep his invention a secret. Around 1750, George Bass told John Dollond about the achromatic lens he had made, or at least the fact that different glasses have different dispersing powers. Dollond then began a series of experiments using different types of glass. Dollond's son, Peter, saw the potential commercial advantages and patented the invention in 1758 once they succeeded in making test lenses. Chester Moor Hall twice attempted to challenge the patent. He lost his case on the grounds that, 'the person who should be profited by an invention is the one who benefits the public by it, not the one who keeps it locked in his desk drawer.'

This was a landmark decision in patent law that remains in place to this day. Dollond went on to become the dominant manufacturer of telescopes in the late 1700s and early 1800s. In fact, the name *Dollond* became a synonym for *telescope*.

John also emphasized how difficult it was to make binoculars at that time. Toward the end of his lecture, he presented his collection of antique optics, including telescopes, microscopes, binoculars, etc., which are currently displayed in the Museum of Optics at the OSC. His lecture was so impressive that the girls pounded John with many questions and became involved in an active conversation, which is very unusual for Japanese girls. "What is light?" was one of the most serious questions raised, and John answered, "It is a very good question. Um. . . . Um. . . . A kind of wave, sometimes a particle."

John's lectures were always prepared with the ingredients necessary to stimulate a student's interest. He strongly believed that, once students' interest is piqued, there after they will continue to grow and explore unknown territories in optics with much ease. This was John's approach toward optical education, which I too practiced in my teaching profession and found to be extremely successful. John lived a life that reflected his commitment to optics and education; his life story is a model for many optical enthusiasts to follow.

Reference

1. F. Watson, *Stargazer: The Life and Times of the Telescope*, Da Capo Press (2005).

A Shared Passion for Optics Education: John Greivenkamp and Harrison Barrett

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John Greivenkamp was a passionate educator, recognized for his outstanding teaching by SPIE awarding him the 2017 SPIE María J. Yzuel Educator Award. John and I were mentored by another passionate educator, arguably one of the best in optical sciences, Dr. Harrison H. Barrett of the University of Arizona's College of Optical Science. Harry's impact on imaging science was largely due to his dedication to teaching and his mentoring of graduate students. His teaching extended far beyond the classroom, too. His questions at the microphone during a conference were known for being mini-tutorials that brought clarity and depth to the discussion. His many lectures at conferences and institutions around the world built a far-reaching community of imaging science enthusiasts. During his years at the University of Arizona, Harry taught more than 20 different courses and was the advisor for over 75 graduate students. When students would ask him whether they should work in industry, national labs, or academia, Harry would quickly tell them that it depends on how they personally measure success—as for himself, he kept score by the number of dissertations produced in his group, not by money.

Below are some of the lessons John and I learned from Harry Barrett regarding how to be an outstanding teacher, mentor, and influencer in imaging and optical sciences:

1. Keep teaching fresh. Harry brought great enthusiasm to each course he taught and put considerable effort into his preparations for each class. Regardless of the number of times he taught the material, he insisted on generating new teaching notes for each class to ensure that his presentations were fresh.
2. Be rigorous and strive for clarity. Harry brought rigor to all the courses he taught and the research he led. His books paid incredible attention to detail both in his

efforts to be comprehensive regarding the topics he covered as well as attention to minute aspects of notation. Harry was a master of theoretical information transfer, i.e., the science of determining what information is transferred through an imaging system. He was also a master of practical information transfer, meaning the practice of developing presentations, course materials, and publications that successfully transferred information to his audience.

3. Be inclusive. Harry's research group was one of the first to include women and other under-represented students. He was intentional in the way he shared his diverse, international network of colleagues and collaborators with us, too. Attending a conference with Harry was an invigorating experience, as he included his students in wide circles of scientific conversation and networking.
4. Students deserve second chances (and sometimes one or two more!) as well as the support to turn those defeats into success. I observed many students who, after experiencing failure with prelims or lack of success in working with an advisor, were offered not only a second chance by Harry, but also Harry's personal time spent helping to prepare the student for that next prelim round or research experience. The lifeline he offered to so many made the difference between their dropping out vs. going on to successful careers in optical science.
5. Give back. Harry and his wife Cathy generously established the Harrison H. and Catherine C. Barrett Endowed Chair in Optical Sciences for Cancer Imaging as a mechanism for supporting a faculty member with interests in cancer imaging. There were other ways in which Harry supported students, post-docs, and professional societies through generous donations. John Greivenkamp's own generosity in gifting scholarship funds and his optical instrument museum to the College of Optical Sciences are similarly inspiring and will have a lasting impact on future faculty and students at the University of Arizona.

Harry Barrett had great passion for his life's work as a researcher and educator. He was also a deep lover of life and adventure outside of work, traveling around the world and trekking across England, around Ireland, and up past Everest base camp with Cathy. He gave us a very real and alive example of living life to the fullest in and out of the lab. I see many, many parallels in John's love of optics, of the University of Arizona and SPIE, of students, of travel, and of his family. He learned from one of the masters!

Chamblant Lenses, Astigmatism, and Cylindrical Lenses

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A few years ago, John Greivenkamp and I collaborated on a small project. The project directly incorporated geometric optics and optics history and dealt with visual optics, all three areas of great interest to John. An ophthalmologist in Pennsylvania, who is also a historian, contacted me about a pair of spectacles which consisted of Chamblant lenses and wanted to study the optical properties of the lenses.

The Chamblant lens consists of two joined lenses and is named after a French optician, Marie-Nicolas-Joseph Chamblant (1772–1841). The lens had originally been developed by Pierre Galland (1757–1837), and it appears that Chamblant fabricated the lens and both of them received a patent for "mirrored glasses and heliophlogic and optical instruments made from a new system that destroys spherical aberrations and can be used for heating apartments and the melting of metals, etc."[1] An English architect, Thomas Stedman Whitwell (1784–1840), studied this lens and concluded that, "The most highly advantageous result of this new system of dioptrics is the complete destruction of the aberrations which arise from the sphericity of the lenses of the old system, and by which the images of objects are so very considerably deformed."[2]

An ophthalmologist sent me a spectacle pair that had Chamblant lenses (see 1st figure), and I procured biconvex lenses (reading spectacles) from a retail store. Basic measurements were made (such as power, curvature, etc.). Since I did not have a Fizeau interferometer, I sent them to John, who readily agreed to make other measurements. Based on our measurements, we concluded that the two lenses making up the Chamblant lens were of excellent optical quality, with better performance than mass-produced modern lenses, and the Chamblant lens was a cross-cylinder lens.

The discovery of ocular astigmatism opened up a whole new need for cylindrical lenses, but astigmatism was not routinely corrected until the late 19th century. In 1825 George Bidell Airy first described his own astigmatism and its correction by cylindrical lenses. In fact, it was Airy who named the condition *astigmatism*, a term suggested by his colleague William Whewell in 1846. It should be noted that Thomas Young had described his own astigmatism in 1801 but did not suggest a cylindrical lens to correct it; he recommended tilting a spherical lens. The first cylindrical lenses for spectacles prescription were developed in 1828 by John McAllister in Philadelphia. A brief timeline is shown in the table.

In a cross-cylinder, the cylinder axes of the two lenses are perpendicular to each other. In fact, George Stokes (1849) developed a cross-cylinder lens to correct his own astigmatism. The Stokes lens is a variable-power astigmatic lens comprising, in its standard version, two pure cylindrical lenses of equal but contrary power that rotate in opposite directions. The Jackson cross-cylinder is used in modern-day clinical practice to refine refractive correction.

Our results from the Chamblant lens project can be summarized as follows:

- Chamblant lenses show a small amount of residual astigmatism/cylinder with a smaller amount of coma. The residual cylinder is likely a result of the two surface cylinders having very slightly different radii. The tiny amount of coma was likely due to the two cylinders not being exactly at 90 deg.
- Chamblant lenses have about 5 wavelengths of residual cylinder (about 0.04 D), which not is clinically significant.
- The wavefront data showed no sign of spherical aberration correction. In fact, it is not practical to correct spherical aberration (SA) with spectacles. While you could correct SA for a straight-ahead gaze by adding an r^4 shape to the lens, as soon as the eyes

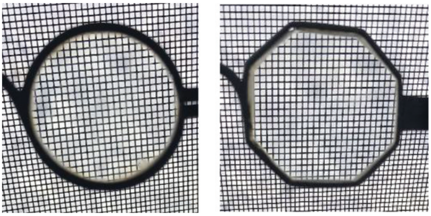
look even slightly to the side, significant coma will result. This is why even today we do not correct SA with spectacle lenses. SA correction with contact lenses can be used because the lens is "fixed" on the eye and the eye always looks through the same part of the contact lens. In general, a spectacle lens has an r^2 shape. When the eye's gaze moves away from straight ahead, prism results. The line of sight is deviated but by the same amount in both eyes. There could be an issue if the prescriptions for the two eyes were wildly different.

- There is no chromatic aberration correction.
- Spherical lenses have even slightly less residual cylinder.
- Clinically, Chamblant and spherical lenses are identical, and the user would see no visual difference (see 2nd figure).

Spherical aberration certainly exists in spherical lenses but, even in the early 1800s, it appears that grinding techniques were good enough to make it clinically insignificant; a spherical lens was about equal to a Chamblant lens in terms of quality—both were equivalent to a modern mass-produced reading lens. Chamblant lenses do nothing that spherical lenses do not do. We can think of absolutely no reason to make lenses that way. History has also proven this—the technology died almost instantly. So why should we study technical dead-ends? Knowledge of what worked and what didn't work gives insight into (and provides caveats to) further development of new technologies and therefore should be a part of science and engineering education.

This project incorporates John's varied interests in geometrical optics, visual optics, and optics history and provides a small example of his intellectual curiosity.

Spectacles with Chamblant lenses.



Imaging with (left) a spherical biconvex lens and (right) a Chamblant lens.

A brief timeline.

1722	Earliest mention of cylindrical lenses by John Marshall
1801	Young describes ocular astigmatism in his own eye.
1804	Galland sends a dissertation to the Athénée, a learned society, about "Heliophlogie," concerning the heating effects of lenses and mirrors described a new lens design later fabricated by Chamblant.
1813	Galland/Chamblant receive French patent for the "Chamblant" lens.
1815/ 1816	First mention of the use of these lenses in spectacles by Whitwell, in *Repertory of Arts, Manufactures, and Agriculture* (1816)
1824/ 1828(?)	Spectacles to correct astigmatism are developed by John McAllister.

1825	George Bidell Airy describes his astigmatism and correction with cylindrical lenses.
1846	Airy names the ocular condition as astigmatism.
1849	George Stokes develops a variable power astigmatic lens using cross-cylinders for astigmatism correction.
1887	Edward Jackson devices the cross-cylinder for subjective refraction, mainly in the cylinder axis and power refinement.

References

1. French patent, Arch. dep. des Deux-Sèvres, Fn-a 1513, Pierre Galland, Marie-Nicolas Chamblant, Patent of invention, Notice of the system of optics and heliophlogy, s.d. See also: Lamy, J. *Pratiques plurielles de la science: Pierre Galland de Cherveux, géomètre au début du XIXe siècle* (2012) Retrieved from https://journals.openedition.org/abpo/2328.
2. S. Whitwell, "Description of lenses of a square form stated to possess very considerable advantages over spherical ones," in *The Repertory of Arts, Manufactures, and Agriculture* Vol. XXVIII second series (1816) [In Number CLXIII of December, 1815 (pp. 13–19) London: Wyatt.]

Remembering John Greivenkamp

Larry C. Andrews
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I believe it was during the 1980s that I became a member of SPIE. There were only a handful of attendees at the first SPIE Orlando Conference I attended. Times have really changed since then.

I learned about SPIE's book publishing program during the mid-1990s from meetings I had with Eric Pepper, then the Director of Publications. He encouraged me to consider SPIE Press as my publisher if I had any ideas for writing a book, which I did. Later I worked with Tim Lamkins, then SPIE Press Manager, in the same capacity. During several discussions with Tim about writing a second edition of one of my books with coauthor and longtime friend Ron Phillips, Tim mentioned a new book series that SPIE Press was planning to launch. The series would be called *Field Guides*, and John Greivenkamp was to serve as the Series Editor.

Tim introduced me to John at one of the SPIE Symposia in 2002. The three of us sat around a table for some time, while John described in great detail his vision for the Field Guides. These were to be handy reference booklets of around 100 pages or so on a major field of optical science, with concise explanations of a particular topic provided in 1–2 pages. The books would have a spiral binding so that they could open and lie flat on a table for viewing without closing by themselves, as most textbooks tend to do.

John was a Professor at the James C. Wyant College of Optical Sciences at the University of Arizona. A project like this is something one might expect from a natural and seasoned educator like John. After listening to his enthusiastic vision of the *Field Guide* Series and hearing his suggestion that I write one in my area of expertise, I walked away knowing that I would write such a Field Guide.

John and I finished our Field Guides in roughly the same timeframe, and both were published in 2004 as the first and second in the Series. John's book was FG01 *Geometrical Optics* and mine was FG02 *Atmospheric Optics*. John later approved two more Field Guides that I wanted to write: FG18 *Special Functions* (2011) and FG22 *Probability, Random Processes, and Data Analysis* (2012), the latter with my coauthor Ron Phillips. John also accepted a second edition of my *Field Guide to Atmospheric Optics* (FG41), published in 2019.

My advice to new members of SPIE is to consider what knowledge you can pass along to your colleagues in the form of research papers and/or books. I've heard from many people over the years that "I can't write a book" or "I don't have enough time for that." **You can always make the time if you want**. Many of us have something to contribute to our particular area of expertise that will be useful to others. Don't be afraid to try—you might surprise yourself.

I didn't know John very well, having met him only a couple of times over the years. We lived on opposite sides of the country so our paths didn't cross very often. Nonetheless, I know that John Greivenkamp as Series Editor of the Field Guides provided a tremendous service to SPIE with this endeavor and an important and useful resource for the optical sciences community to enjoy for many years.

Getting the Word Out

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Providing an interchange of technical information within the optical engineering community is one of the most important functions of SPIE. In the early days, this interchange consisted of technical meetings and timely publication of the *Proceedings of SPIE*, the famous “yellow books.” Later, the *SPIE Press Field Guide* series, with John Greivenkamp as Series Editor, became another highly accessible source of information.

A personal example shows the role of SPIE in spreading technical information. Thermal stress in bonded doublet lenses arising from the different thermal coefficients of expansions in dissimilar glass types often leads to fracture. Unfortunately, analyzing the thermal stress is difficult. Stress singularities at the element edges make computer-based finite-element analysis inaccurate.

An alternative analytical method sometimes attempted was to use classical “bonded plate” theory, usually without success. While working as a consultant on the design of an optical system employing many bonded doublets, I found a number of mathematical errors in the bonded plate solution. Once these errors were corrected, the solution worked well in predicting thermal stress. Later, I mentioned this to Paul Yoder, my good friend, co-author, and former head of the SPIE Publications Committee. Paul’s immediate response was: “and you have not published?” I had signed a proprietary agreement when consulting, but this had long since expired.

So, in 2015 Paul Yoder and I published a joint paper on this topic: P. R. Yoder and D. Vukobratovich, “Shear stresses in cemented and bonded optics due to temperature changes,” *Proc. SPIE* **9573**, 95730J (2015). The paper presentation was well received, and, as we had hoped, it served to inspire further analysis of the problem, with a paper published by other workers in the field just a few years later. Our article is widely used and is a good example of the Society "getting out the word."

Photograph of a bonded doublet fractured by thermal stress [P. R. Yoder, Jr. and D. Vukobratovich, "Shear stresses in cemented and bonded optics due to temperature changes," Proc. SPIE ***9573****, 95730J (2015)].*

Optics at ICTP: Bringing Light to Students from the Developing World

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It is a great honor to contribute to this SPIE Field Guide as a tribute to John Greivenkamp, whom I always admired for his ability to chair difficult meetings that would have sent others scurrying away, and for getting to the point quickly and often (not, unfortunately, like what is about to happen here).

First: A little known fact is that I started out as a graduate student in optics but was lured away early-on to a low-temperature group with the promise of a trip to Europe. I was "easy," I know. Ironically, while I eventually moved to Europe and the International Centre for Theoretical Physics (ICTP-UNESCO) in Trieste Italy, I also ended up being lured back into the wonderful world of international optics, largely due to people like John Greivenkamp and one particularly persuasive person at SPIE who also introduced me to The Clancy Brothers. . .

In Trieste, in fact, I have had the good fortune to work closely with major optics organizations within our Trieste System Optical Sciences and Applications (TSOSA) board. TSOSA provides critical advice, oversight, and support for ICTP-UNESCO's many programs in optics education and training, and in particular the annual ICTP Winter College on Optics, which brings together many students and young researchers each year from dozens of countries in the developing world. The students learn about new trends in optics, but, just as importantly, can network with both lecturers and peers, and obtain a reprieve from often-discouraging scientific isolation. As a number of the countries represented in the College invariably have strained or no diplomatic relations, it also serves to support diplomacy through science. This isn't the sort of diplomacy practiced by foreign service professionals; rather, it is related to the building of mutual respect that comes from the close engagement of scientists and/or students from different countries, religions, and cultures in a common discovery process. The same concept applies at CERN, which was built on the premise of uniting the continent of Europe after it was torn apart by two world wars, and SESAME, which aims to unite the Middle East: SESAME scientists from different countries that are sometimes in conflict work together on a common goal and with a common passion—coming to a better understanding of one another not from the sharing of knowledge, but from the creation of it together.

Concerning the ICTP Optics Colleges, it is difficult to imagine a similarly *concentrated* collection of nationalities, where just about *everyone* is from someplace else. The students learn together, socialize together, and stay in contact through social media groups for years. And some fraction of them later will take leadership positions in their countries. This year, the College is being held entirely online for the first time, and it has been (it is going on as I write this) a fantastic learning experience. While personal relationships and understanding naturally face a larger impedance mismatch, it is abundantly evident that knowledge flows surprisingly easily over the fiber optic cables that connect us.

To help ignite the interest of younger students in science, the UNESCO Active Learning in Optics and Photonics program has reached well over 1000 physics teachers from over 60 developing countries to provide pedagogical updating on the teaching of optics and photonics in the first years of undergraduate and high school levels. The aim is to provide a better *conceptual* understanding of how light works using inquiry-based or active-learning techniques. The program has received generous base funding from SPIE for many years, and further support from other optics organizations including Optica and ICO.

Finally, at the early career professional level, the SPIE-ICTP Anchor Research program in Trieste has helped many highly selected young researchers from developing countries accelerate their career journeys, starting in Trieste. A few have used the experience to prepare successful grant applications for setting up low-cost, high-impact laboratories in universities where none had existed before. They all are self-starters and incredibly inspirational.

The ICTP Winter College on Optics: Applications of Optics and Photonics in Food Science, 2019.

Guided-Wave Photonics

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The field of guided-wave photonics (GWP) examines the phenomena associated with the confinement of light in composite structures comprising two dielectrics having distinct refractive indices. GWP has been the driving force behind landmark developments such as high-speed, long-range optical fiber communication (OFC) systems and photonic integrated circuits (PICs) for signal processing at optical frequencies. Optical fibers and photonic components have, unquestionably, revolutionized how we communicate and access information today.

My first encounter with this fascinating area was as a Royal Norwegian CSIR (NTNF) post-doctoral associate (1975–77) with the Electro-optics Group (ELAB) headed by Professor Kjell Bløtekjaer at the Norwegian University of Science and Technology, Trondheim (then called NTH). It was a pleasant coincidence that both Kjell and I had both been involved in research on electron transport in semiconductors and had decided to move on to this emerging S&T field around the same time. Since then, I have been indeed fortunate to have witnessed the tremendous growth of GWP and to have been a part of that growth.

There is a lesson here-sometimes, we are too committed to our field of study during, say, graduate school and become wary of stepping out of our comfort zones. However, from personal experience, I can attest to the fact that the rigor of graduate school goes a long way towards developing the ability to comprehend new concepts and empowers young researchers to switch to new fields and make remarkable strides therein. The bandwidth of knowledge and dissemination then can grow much broader for an educator, which eventually yields rich dividends. I never regretted this switch over! One of my primary tasks while at NTH was to characterize the index profiles of newly fabricated, high-silica, low-loss fibers.

I returned to India in the Fall of 1977 to join the Indian Institute of Technology (IIT) Delhi's Fiber Optics Group, which was led by a former SPIE Educator Award recipient, Professor Ajoy Ghatak, who was keen on starting a new laboratory for fiber optics. This was a great opportunity for building a new research laboratory from scratch. Our first efforts were to characterize telecom-grade optical fibers and, in the fall of 1980, succeeded in launching an IDP (Interdisciplinary) MTech teaching program in optoelectronics and optical communication jointly with EE faculty, who also developed the dedicated laboratory for communication aspects in their department.

The program ran successfully, with equal credits provided by each participating team, and became an excellent model for programs run jointly between multiple academic departments. Within a few years from its inception, it became one of the most sought-after MTech programs at IIT Delhi. We were possibly one of the first programs in the world to start a full-fledged masters' level interdisciplinary program.

From 1982–83, as an Alexander von Humboldt Fellow at the Fraunhofer-Institut für Physikalische Messtechnik (IPM) in Freiburg, Germany, I co-authored with my host, Prof. Ralph Kersten, a paper that proposed a collection of cutting-edge (at that time) topics along with experiments in the area of optical waveguides as a pedagogy. The paper was published in *IEEE Transaction in Education* **E-28**, 46 (1985). At the time, there was a general shortage of technical prowess among those trained in photonics (in India), and our collective goal was to empower graduating students to become successful professionals and to join a global talent pool, serving in both industry as well as in academia and national research laboratories.

Today, our alumni hold key positions in multinational organizations such as Facebook, Google, Infinera, Cisco, Bell Labs/Lucent Technology, NASA, Sterlite Optical Technologies India, Bhabha Atomic Research Centre (BARC), and the Indian Space Research Organization

(ISRO), to name a few. The Fiber Optics Lab at IIT Delhi also significantly expanded over the years under the mentorships of other colleagues.

Since then, GWP has made rapid strides during the last 50 years, so much so that data/signal transmission at 200–400 Gbps is now a reality, enabling overall transmission of Tbps per fiber cable. The emergence of critical scientific advances and exciting real-world applications provide boundless opportunities for educators and students in this field. I wish the community the very best in the years to come.

Reminiscences

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It is a privilege to write a short note on my experiences studying and teaching optics, to be included in this Field Guide. I had known Prof. Greivenkamp for more than 20 years through his research before I met him. In May of 2017, I received his invitation to author a physics Field Guide on any one of a variety of topics. I chose the topic of general optics and prepared material that included geometrical optics, physical optics, and quantum optics. Part of a lengthy review of the manuscript is quoted here: "The book is simply trying to cover too much material. It is trying to pack Born and Wolf, Goodman, Greivenkamp's *Field Guide to Geometrical Optics*, Saleh and Teich, and more into a 100-ish page overview of optics. As previously outlined, the FG Series is not structured for this use." During the preparation of the Field Guide, Professor Greivenkamp and I had email correspondence to clarify expectations. My regret is that, despite his advice and guidance, I could not translate the contents into the form expected of a Field Guide.

I recount here some of my experiences learning and teaching optics in India. I learned optics in the 1960s by studying *Principles of Optics* (Born & Wolf) and *Interferometry* (Candler), and I did raytracing through an optical system using a hand-operated Facit machine, which required the visualization and creation of a mental picture of what the equations represented. Setting up a Michelson or Twyman–Green interferometer to obtain a white-light fringe pattern required both skill and patience, although this was easy using Newton's ring experiment. *Principles of Optics* did not have separate geometrical and physical optics sections, and did not cover quantum optics. Later, I used books like *Fundamentals of Optics* (Jenkins & White) and *Geometrical and Physical Optics* (Longhurst), which had separate geometrical and physical optics sections. Now there are books devoted to geometrical optics and others devoted to physical optics.

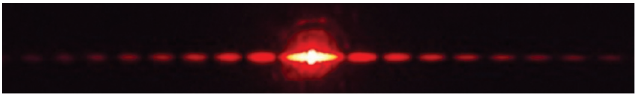
My learning experience was not optimal, which perhaps is reflected in my instruction style. I always placed emphasis on understanding the basics, and then on applying the knowledge thus gained for solving problems. Promoting entrepreneurship was never even considered.

Demonstration of some of the concepts and results became possible after the arrival of the He-Ne laser. Due to this laser, new topics evolved that would become full-fledged courses for degree programs in Optics. These new courses were, e.g., Holography and Hologram Interferometry, Optical Data Processing, Electro-optics, Speckle Metrology, and Fourier Optics. There was a renewed interest in optics, which became the science and technology that was driving innovation, and which continues to do so, although now it is considerably supported by software.

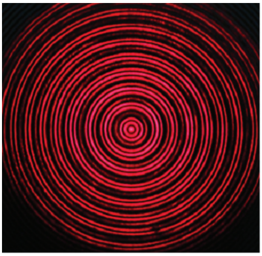
Additionally, with the He-Ne laser it became easier to demonstrate diffraction from various objects, particularly from a pinhole forming an Airy pattern. It was very easy to show the bright spot at the back of a round object when illuminated by a spherical or plane wave, the famous Arago spot (or Poisson spot or Fresnel spot). Also, to show that the diffraction patterns of a slit and a wire look similar is quite illuminating. I wrote a book entitled *A Course of Experiments with the He-Ne Laser*, which has a set of experiments that I conducted. This book became very popular in India.

Although a π phase change on reflection from a denser medium is aptly demonstrated in Newton's ring experiment when the surfaces are clean, I used Fresnel mirror interference to demonstrate the same. Most inspiring was to see the self-imaging phenomenon, in which a coarse grating is imaged by diffraction. I have used the He-Ne laser extensively in my classes to demonstrate interference and diffraction phenomena (see the photos on the next page).

The first photograph shows a diffraction pattern of human hair; the hair is plucked and held in the beam of a He-Ne laser. The second photograph shows a moiré pattern of a circular grating and its self-image in convergent light.



Diffraction pattern of a human hair.



Moiré pattern of a circular grating and its self-image in convergent light.

Mine has been a very satisfying journey, supported by my teachers, students, and colleagues. I am grateful to all of them.