HINDSIGHT IS DIFFRACTION LIMITED

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Introduction

Most people would say that "hindsight is 20-20." We in the optics business say that "hindsight is diffraction limited." What of course we really mean by this cliché is that looking back always seems to make things clearer. In fact it is interesting to think about why in our society we study history. One of the really tangible reasons is that by studying the history of the past we can better prepare for, and to some extent extrapolate, into the future.

The intent of this paper is to take a look back through my own educational experiences, and then my industrial career in the optics field, with the goal of helping to define perhaps a little more clearly the structure and curricula of optics programs at BS and MS levels. One of the key areas to be addressed will be the distinction between training for a career versus training for a job.

Early exposure to optics

How do potential students first become interested in pursuing a career in optics? Many come in through associated fields which they began in college such as physics, electrical engineering, mechanical engineering, or others. Perhaps they were involved in a research project related to optics and found it exciting and challenging. And occasionally we find the "die hard" who was born with a lens in his hand rather than a silver spoon (I was one of these folks). Interest at an early age (high school or before) is often further heightened by science fair participation and other extracurricular activities such as astronomy, photography, and others.

But how valuable is it to become interested in optics at an early age?

My answer is that yes, it is beneficial to generate and early interest in optics. But no, it is by no means imperative. Some of the finest technical people I know in the field have come in "through the back door." But sparking an early interest generally results in a greater dedication and "grass roots" understanding of the specific field. But how can we generate this early interest in optics? Several ideas follow, and through the help and cooperation of educators along with our professional societies such as the SPIE and the OSA, we can indeed make some of these ideas happen:

- **"Optics Kits"** and associated lectures to high schools. These are kits with items such as a laser, lenses, holograms, and other items selected so as to elicit the interest of students. The OSA had such a kit in the Boston area some years ago, and members of the local OSA Section presented it to local high schools. And there are now other optics kits being promoted. I am confident that we generated an interest in our field to these students, and this form of early exposure of optics should be encouraged and further enhanced.

- **Science fairs.** Participation by our youth in science fairs is a fine way to be introduced to a field such as optics. But what can we do to foster such participation? Certainly the professional societies can sponsor awards at these events, and I urge this to be done. Indeed, I won an OSA award at a National Science Fair umpty ump years ago, and being an honorary member of the OSA for the following year was not only a thrill, but it definitely furthered my interest in optics.

- **Fostering hobbies** relating to optics such a photography astronomy, and others is certainly beneficial. And now I would imagine, lasers, fiber optics, and other fields are becoming legitimate hobbies to many.

Training for a job versus training for a career

The following is what Websters's Dictionary has to say about the words "job" and "career:"

> **job - A piece of work, especially a small miscellaneous piece of work undertaken on order at a stated rate. A specific duty, role, or function.**

> **career - A field for, or pursuit of consecutive progressive achievement, especially in public, professional, or business life. A profession for which one trains and is undertaken as a permanent calling.**

A "career" is typically thought of as being one's long term progression or advancement of their work assignments beginning after graduation and continuing over many years until retirement. On the other hand, a "job" is typically thought of as being one's specific work assignment at a given time. Thus if we train for a career, we must consider educating for as many of the long term challenges one will take on as is possible.

But should the students education prepare him or her specifically to perform well on the job, or should the education build s firm base or foundation in the field? In looking back, I must say "both," and this is important. The career training is of course most important, as it provides the foundation and development so necessary over the years.

But industry needs people who can do things - and right away. And this is where the job training comes in. Thus while a good background in mathematics, physics, and related subjects is certainly important, items such as listed below are important for the job:

- lab work
- problem solving
- exposure to real design and engineering tasks
- report writing
- presentations and design reviews

And while we're on the subject of job training, what can industry do for the newly hired graduate? The answer is clear: Do not give new hires a pile of manuals to read for two weeks. Instead give them something the very first day that they can "sink their teeth into." Overall, make sure that they feel good about their job - right from the beginning.

Some further comments are in order:

- **Guidance** to students is important. Especially as it relates to jobs and careers. I think that guidance councilors are sometimes far too remote from the real world of industry, and perhaps a colleges or universities guidance activities could be supplemented with industrial representation.

- Faculty as well as student **involvement in professional societies** such as the SPIE and the OSA is important. The visibility that a college or university will derive from such involvement will definitely aid in a students ability to secure a viable job. And further, when students attend conferences they can "rub shoulders" with people from all facets of industry. In fact, they may even get their first job through such an exposure.

- **Summer jobs** in industry are highly encouraged, and her is a grand opportunity for industry to help our students. Summer jobs show students what the "real world" is all about.

- **Industrial affiliate programs** whereby the college or university works in a cooperative way with industry can be most valuable top industry, the faculty, and of course to the students. This will take come financial commitment by industry, but the payoff is substantial. Often these programs include a means for direct faculty involvement with the participating company, and this is invaluable to all concerned.

Looking back, what was important

In looking back, three subjects come to mind, none of which are themselves "optics," but all three of which are imperative to yield a valuable career for a student. These are mathematics, electronics, and computers.

- **Mathematics** of course forms the basis of many if not all derivations in optics, and being at least somewhat fluent in math is imperative. And the word "fluent" is important.

- **Electronics** is now a way of life. Take SPIE for example: not only do we cover in depth "optics: in the classical sense, but electro-optics and opto-electronics. And in working with virtually any laboratory experiment or test today, electronics plays a vital if not indispensable role. But the training of electronics for optics people need not be to the same theoretical depth as for a EE major, but rather to teach the practical and useful aspects of the field.

- **Computers**. Most of live and breathe computers. But here I mean more than word processors, rather I mean the use of and interaction with computers as data taking and processing tools.

Laboratories and report writing

Labs are of course important. But their importance goes beyond the specific experiment and the associated problem solving, statistics, and other matters usually associated with a lab. Labs can be a fine vehicle with which to teach report writing and even giving presentations. Students often are not faced with their first traumatic experience of giving a presentation to their peers until they are in industry. It may be a good idea to have the students present on several occasions their lab report via a formal presentation - viewgraphs and all.

Thoughts for the professor

Lectures are vitally important to the student. Lectures should be cohesive and consistent. And suitable preparation is almost certainly the only way to achieve this. Many students take notes in class, hence blackboard material must be will planned. While a good text is helpful, distribution of lecture notes may be even better.

And practical examples of the subject at hand is most useful. These should be simple at first, with a gradually increasing level of complexity.

Teaching is somewhat like acting, music, or sports. Each time an actor goes out on stage the audience must be made to feel that the performance is just for them. And the best educators take this philosophy.

Subjects needing special attention

There are two specific subjects in the optics field that I believe need a special and enhanced level of attention at our colleges and universities, and these are radiometry (and photometry) and polarization. These are subjects that most people in the field claim to know something about, but most do not really have a good grasp or understanding of them.

- **Radiometry (and photometry).** I have seen far too many systems over the years that have failed to work properly because of radiometric short comings. Sometimes it is the units that scare people away (lux, candellas, and the like), but the bottom line is that radiometry is imperative to virtually any and all image forming or energy related optics requirement.

- **Polarization.** Polarization is one of those subjects that everyone knows something about, but few have a comprehensive grasp and working knowledge of the subject. And although we don't think about it, we are almost always working with light that is in some way polarized.

- **Coherence, speckle, and Gaussian beams.** These are all laser properties, and we are all working more and more with lasers. But the optical designer or engineer who understands his or her lens design or optical engineering likely does not have a working background knowledge of the effects of coherence, speckle, and Gaussian beams.

- **Basic geometrical optics.** Our field is so broad now that one can likely derive an advanced degree in optics without taking a class in basic geometrical optics. But geometrical optics is important to many areas of optics. Anyone who works with the manipulation of electromagnetic radiation needs some working knowledge of geometrical optics.

A real look back

The material at the end of this paper is included for interest only. It is from the University of Rochester Institute of Optics announcement of 1930-1931. Tuition was $300 a semester. The BS program was four years duration with an emphasis on industry and applications. Optometry was an option.

Summary and conclusions

I hope via this paper some ideas have been put forth both to colleges and universities as well as to industry that are useful. Education is like a sling shot: a large and intensive effort will hopefully launch the student in the right direction with suitable intensity.

Optics is heading into may exciting and challenging new directions. To keep our graduates up to these challenges we must:

- provide a good theoretical base
- provide good base in allied fields
- have well structured laboratories
- include many practical examples in class
- interact with industry
- keep lectures fresh and well planned
- have good notes and/or text

THE INSTITUTE OF APPLIED OPTICS, U OF R, 1930-31 ANNOUNCEMENT

- TUITION WAS $300
- STUDENT TAX OF $20
- FOUR YEAR DEGREE
- INDUSTRY/APPLICATIONS INTENSIVE
- OPTOMETRY WAS OPTION

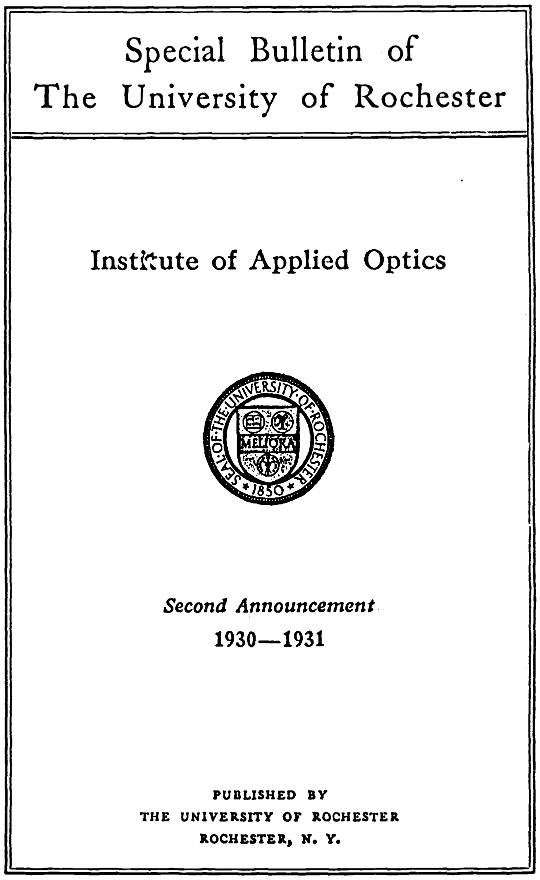

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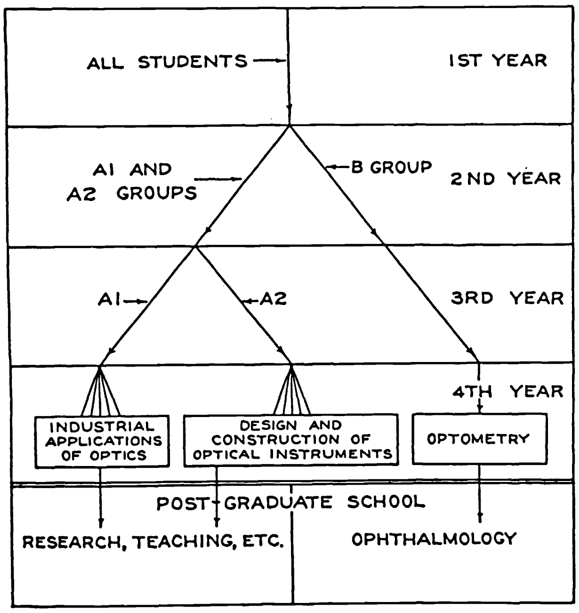
DIAGRAM SHOWING MAIN LINES OF TRAINING IN THE SCHOOL OF OPTICS



PROGRAM FOR THE FIRST THREE YEARS

Group A. Industrial Applications of Optics

Freshman Year

First Term	Credit Hours	Second Term	Credit Hours
Rhetoric 1	3	Rhetoric 1	3
German, French	3	German, French	3
Mathematics 1	3	Mathemtatics 1	3
Physics 1	4	Physics 1	4
Chemistry 1 or 11	4	Chemistry 1 or 11	4
Physical Education 1	1	Physical Education 1	1
	—		—
	18		18

Sophomore Year

German, French [1]	3	German, French [1]	3
Mathematics 5 (Anal. Geom. & Calc.)	3	Mathematics 5 (Anal. Geom. & Calc.)	3
Physics 4 (Physical Meas.)	3	Physics 4 (Physical Meas.)	3
Psychology 1	3	Psychology 1	3
Drawing 1	2	Drawing 2 (Descriptive Geom.)	2
Shop Work 1 (Machine Shop)	2	Optics 5 (Optical Shop)	3
Physical Education 2	1	Physical Education 2	1
	—		—
	17		18

Junior Year

French, German or Readings in German Optical Literature	3	French, German or Readings in German Optical Literature	3
Optics 1 (Physiological Optics)	3	Optics 1 (Physiological Optics)	3
Optics 2 (Geometrical Optics)	3	Optics 2 (Geometrical Optics)	3
Optics 3 (Intro. Phys. Optics)	3	Optics 4 (Application of Physical Optics to Instruments)	3
Optics 7 (Elem. Photography)	2	Optics 6 (Radiation Spectrum)	2
Elective in Group II.	3	Elective in Group II.	3
	—		—
	17		17

SENIOR YEAR
A1: INDUSTRIAL APPLICATIONS OF OPTICS
A2: DESIGN AND CONSTRUCTION OF OPTICAL INSTRUMENTS

Senior Year—Group A

As will be seen from the chart of the scheme of courses on page 10 Group A students, begin to diverge slightly in the third year but the divergence becomes much more marked in the fourth year where a special effort has been made to provide training for two main groups.

1. Group A1—Industrial Applications of Optics—designed especially to train technicians who ought to be familiar with the use of the optical apparatus employed in the many branches of applied optics such as those outlined in Optics 7–14.
2. Group A2—The Design and Construction of Optical Instruments—arranged to make available a thorough practical training to those interested in becoming designers of optical apparatus. Because of the close relations between the Institute and the sponsoring companies, the opportunities and facilities available in this field are unusual.

Senior Year

Group A1. Industrial Applications of Optics

No specific courses have been laid down for the Senior Year. Students will arrange their work in consultation with the professors. A list of courses which will be offered is given below, together with the total credit carried by each course, and students should choose enough work to accumulate 17 or 18 hours a term.

For the benefit of students desiring to take up specific branches of applied optics, the following suggestions are made to assist them in their elections.

(1) For industrial applications of optics.

Course	Term	Hours
Optics 7—Elementary Photography	I	3
Optics 8—Advanced Photography	II	3
Optics 9—Advanced Physical Optics	I II	6
Optics 10—Visual Sensitometry and Colorimetry	I II	6
Optics 11—Electricity	I or II	3
Optics 12—Spectrophotometry and Radiometry	I II	6
Optics 13—Polarimetry	I or II	3
Optics 14—Applied Spectroscopy and Interferometry	II	3

Group A2. Design and Construction of Optical Instruments

Mr. Henry Kurtz, Assist. Professor Kingslake, Mr. Fassin.

The complete time of students in this course will be assigned to

Optics 15—The design of lens systems.

Optics 16—The testing of optical systems.

Optics 17—The mechanical design of optical instruments.