A Survey of Lens Design Courses

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ABSTRACT

In an attempt to determine what other teachers of lens design teach, I constructed a short questionnaire and sent it by e-mail to a wide range of schools that are listed in the SPIE's "Optics Education 1997." I wanted to see what commonality there was between lens design courses and where the emphases are placed. This paper describes the types of courses that are taught, their content, the approaches used, and the tools the teachers used to introduce a fairly narrow technical subject to novices.

1. THE INSTRUMENT

I constructed a short questionnaire that could be sent my e-mail to as many institutions as I could determine might be teaching a specialized course in lens design. The list was generated by evaluating the program descriptions and specialties for all the institutions listed in SPIE's *Optics Education '97.* Those programs with no listed e-mail addresses were not included. I also described the study in one of the SPIE listservers and received some requests for questionnaires, which were sent. The text of the message is given here.

I am interested in the choices that teachers of lens design make when constructing a course on the topic. I would like to see how much commonality there are between lens design courses and where the emphasis is placed. If you teach a lens design course I would appreciate if you would respond to the questionnaire below and send it by e-mail to doshea@prism.gatech.edu. If you are not teaching the course, but know who does, I would ask that you forward this message to that person.

I have tried to keep the questionnaire short and to the point so that it requires only a small amount of time. Please feel free to comment at the end of the questions or add any information that you think is relevant to the teaching of lens design.

Don O'Shea

Questionnaire for teachers of courses or units on lens design at college or university.

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The course
What is the name of the course?
How many students take the course each year?
How long has the course been given?
What is the length of the course?
Hours per week? For how many weeks?
How many hours per week are the students expected to spend on the course?
How often do you or someone on your faculty teach it?
Is there a separate course in geometrical optics given?

Its contents
Estimate the percentage of the course spent on the following topics.
The total of all topics including the additional topics at the end should add to 100%
Percent on fundamentals?(stops, pupils, windows)
Percent on predesign?
Percent on discussion on programs?
Percent discussion of classic designs?
Percent on optimization?
Percent on aberrations
Percent on tolerancing?
Percent on additional topics (please list topics briefly)?
TOTAL 100%

Approaches
Do you use y-ybar?
Do you use a matrix approach?
Do you use y-nu traces?
What type of design evaluations are used (rank in the order of importance)?

Siedel
Ray intercept
Spot diagram
MTF

Applications discussed
List specific lens designs discussed in detail
List specific system designs discussed in detail

The tools
What text do you use?
What program(s) do you use? Is there a primary program?
What is the most important aspect of a design program for students?
Additional comments

Thank you for your time.
Don O'Shea

2. THE RESPONSES

Initially 46 questionnaires were sent out and another four were requested, but only two would qualify as university or college programs. Therefore, the inquiry pool was 48 institutions. Of these, 15 were in the US, 2 in North America, 11 Chinese institutions, 19 in Europe, and 1 in Australia. Almost all of those who responded were from the US. As I learned during a subsequent visit to China, there is usually one e-mail address per institution and unless the correct person is present, the messages can be discarded. In very few instances did I get notices of non-delivery. Unless there as a specific need to identify an institution, I did not do so. I did not feel it was necessary or wise to identify each institution with each response. In most cases the aggregate serves.

2.1 The course

Eleven persons responded to my request to fill out the questionnaire and I filled out one myself. Two of the respondents were from the same institution, but both courses, while different, qualified as lens design courses. Two of the respondents were from Europe. So the coverage in the US was quite good, perhaps because of the ease of receiving and sending e-mail. Although the data is most representative of US institutions, it should be useful to others who are considering the establishment of a lens design course.

The course goes by a number of names and in a number of cases incorporates more that just the design of lenses, as is obvious from the list given in Table 1.

Table 1. List of courses incorporating lens design.

Optical Design (3)	Engineering Optics
Lens Design (2)	Introduction to Optical Design
Optical Design, Fabrication and Testing	Optical Design Workshop
Optical System Design	Design of optical systems
Computer Aided Optical System Design	

The courses are given annually in two-thirds of the cases, the balance are given biannually to an average of 12 students per course. These courses have been given for as long as 80 years ago, in the case of London's Imperial College, or as short as one that was established this past year. The average is about 20 years. The total amount of instruction averages a total of 50 hours with students expected to work an additional 12 hours per week. All the courses have substantial use of computer laboratories, however, and, as anyone who has ever sat down to do a design knows, the amount of time devoted to design exercises is considerably more than this. All programs have a separate geometrical optics course.

2.2 Course content

The emphasis in each of the courses varies with institution. Table 2 lists the percentage devoted to each of the topics listed in the questionnaire. At the bottom of the table gives the average percentage for each of the sections. Institution K, being a European institution, divides the course differently, putting all of the practical material into a laboratory that takes up 50% of the the course.

Table 2. Percentage of course devoted to various topics.

Institn.	Funds	Predsgn	Progs	Designs	Optimiz	Aberrns	Tol.	Add'l Topics
A	40	8	12	1	4	20	1	14
B	10	10	10	20	30	10	10	0
B'	10	5	5	10	9	30	1	30
C	15	15	10	10	5	20	5	20
D	10	20	10	30	10	10	5	5
E	10	5	10	10	5	10	5	45
F	10	10	10	15	10	20	10	15
G	20	13	3	16	10	16	6	16
H	5	10	5	20	10	30	10	10
I	12	15	15	15	18	15	10	0
J	30	10	10	10	20	20	0	0
K	12	2	5	10	4	17	0	50
Avg.	16	11	9	14	12	18	6	14

In four of the programs, the additional topics take the form of a final design project or set of projects. Other topics covered are:

scanners, spectrometers.
Gaussian beam propagation, eyepiece design, diffractive optics, IR imaging.
optical materials and manufacture.
radiometry, Gaussian beams, polarization.
non-classic systems-HOES, gradient index,Fresnels

These topics tend to reflect the interests of the course instructor, as they should.

2.3 Approaches

The approaches toward initial descriptions of the systems vary, but not as much as the distribution of topics. Two of the courses used y-ybar approach (one indicating: "Absolutely!"), three said they used it somewhat, and seven replied that they did not use it at all. The numbers were exactly the same for the use of the matrix approach. The majority of the courses, 8 of 12, used y-nu traces for initial layout. These approaches in teaching lens design have been discussed from time to time, but in terms of illumination, the peak always falls in the far infrared. That is, in these discussions more heat than light is generated.

I asked the respondents to rank order four different types of image evaluation (Seidel, ray intercept, spot diagram, and MFT). Two respondents indicated that Seidel coefficients had been addressed in earlier courses and were not used in the current course, so that they could not be included in the ranking. In other cases they indicated two or more were used on an equal basis. I dropped from the average those which considered Seidel coefficients as prerequisite evalution that was not used in the course being described. Those that were considered equal were given equal rank with adjustments to those ranked below them. The average rankings for the four image evaluations were

Table 3. Ranking of Image Evaluation Approaches

Evaluation type	Average Ranking (1 = Highest)
Ray intercept	1.6
Seidel	2.3
Spot diagram	2.3
MTF	2.4

Although ray intercept curves were invented to enable lens designers to provide graphic evidence of system performance at a time when computation was at a premium, they still are used by most teachers at their primary technique for evaluation. I think this is probably because the method is multidimensional expressing not only the magnitude of ray error and the content of third order aberration but also the amount of vignetting present.

The specific sequence of lens designs that are used in most of these courses is: singlet, doublet, Cooke triplet, and Double Gauss. After that there is a good deal of variation. A number of teachers branch into reflective and hybrid systems (Cassegrain, Richey, and Schmidt). One teacher begins with a pinhole camera, others include aplanatic doublets, anastigmats, singlets with aspheres, landscape, achromats (including HOE's and GRINs), eyepieces, Fourier transform lenses, laser diode collimator, and the eye.

Many of the teachers include specific system designs, mainly the telescope and microscope, but other systems also covered by one or more of the respondents are photolithographic steppers, projection displays, spectrographs, laser scanners, gradient index systems, flying spot telecine. In one graduate level course, there is detailed design of four types of lenses, two chosen by the instructor, two chosen by the student. Another course has more emphasis on lens design, since the instrumentation is covered in the previous course. Some of the applications explored in detail included viewers for visualization, infrared imaging, laser beam propagation in cavities, photolithography, displays, scanners, refractive and fiber systems (*e. g.*, coupling lenses, microlenses)

2.4 Tools

The textbook used by various teachers was in some cases supplemented by some notes generated specifically for the course. Table 4 lists the number of times that various texts were listed in response to a query as to the textbook used in the course. Note that there are more than 12 citations. This is because some instructors included texts that were used as reference as well as for teaching. Two texts by Richard Ditteon[1] and by Robert Shannon[5] are listed although they have just been published. This is in anticipation of using the text in the future by three of the respondents, two of them are the authors.

Table 4. Citations of texts used in courses

Author	No. of uses cited
Ditteon[1]	1
Kingslake[2]	2
Malacara[3]	1
O'Shea[4]	4
Shannon[5]	2
Smith[6]	3
Welford[7]	1
Zschommler[8]	1
Supplements	6

The other tool of the teacher of lens design has to employ is a ray tracing program. This type of program traces rays through a specified set of surfaces, thicknesses, and refractive indices and evaluates the quality of image with a number of methods, several of which were listed above in the section on Approaches. The program can then, with a default or constructed error function, attempt to optimize the design. Many can provide tolerancing information, radiometric evaluations, and exchange interferometric information with fringe analysis programs. Insight into designs and the tradeoffs that must be made can be gained through a judicious use of these programs as teaching tools. Thus the selection of the program by an instructor is determined by his or her perception of what is required by the students to gain the facility needed to take the principles presented in the course and apply them to new problems.

Table 5. Ray tracing programs

Program	No. of uses cited
Code V	8
OSLO	5
Sigma 2000	1
ZEMAX	5

Table 5 lists the frequency that programs were cited in the survey. Again, note that the total citations is greater than 12, since some programs use more than one program in their instruction. The majority of the schools use Code V, but OSLO and ZEMAX are respectably represented. Sigma 2000, being a program from Europe currently is not used in any of the US schools. Because of the number of US schools in the survey, it would be incorrect to portray this as an accurate distribution of ray tracing programs in courses on lens design.

The comments on the most important aspect of the student use of a design program provide additional insight to the use of the programs. Three of the respondents, all of which use ZEMAZ as their primary program, mentioned ease of use as an important aspect. But this was also true for a user of an OSLO. As might be expected for anyone who has used these programs, no one cited ease of use as an attraction for Code V. As one respondent put it:

> "My first impulse is to say ease of use, but since we have been successfully using Code V for years that is obviously not the right answer. Actually, there are two important considerations. Since our students are eventually going to be looking for jobs, I think being able to put familiarity with the industry standard software (Code V) on their resume is important. The other consideration is availability. The students need to have easy access to the software. The ideal situation would be to give each student their own copy. Again, this doesn't happen with Code V, but until this year we have had the software on a mainframe which

the students had easy access to. This year, our computer center moved the software to a SunStation which has caused considerable problems."

Several others expressed the following ideas:

"To see the aberrations; understand how straightforward it is to calculate them with modern software; to understand the various forms of output."

"Comprehension of the use and limitations of design programs. Most students will not go into design, but they should understand the fundamentals. The course has prepared many students for a career in design, and a larger number for a career in optical engineering."

"I want them to learn the design process not just the program mechanics."

"the ease of getting the optimization to do its thing, and then graphical output."

Finally, one of the respondents indicated that an important aspect of the program for the students was that there was support for the program by a Teaching Assistant. I didn't think to ask the question about program support, but this is an excellent idea. If there is a student around who has already taken then course, then hiring them as a Teaching Assistant to handle the day-to-day problems that can crop up with any lens design program makes a great deal of sense and can save an instructor time.

2.5 Additional comments

I requested additional comments and, aside from some personal messages, got the following:

"I have two main goals:
"1. Understand paraxial optics, mainly through the y-ybar diagram. Chapt 1,2,5 of O'Shea plus Shack's y-ybar notes.
"2. Aberrations: What are aberrations? Familiarization with the Seidel aberrations. Wavefront aberration polynomial. Ouptut from optical design programs: spot diagrams, wavefront maps, PSF, MTF, rimray, field curves,.... Paraxial optics as a coordinate system for ideal imaging from which we measure our aberrations."

"I am not at all happy with our course as it currently exists and I plan major changes when I have time. One problem is that our Computer Aided Optical Design course is designed as a follow-on to the two undergraduate courses. Graduate students coming to [this institution] from other colleges really do not have the background in geometrical optics to make the most of this course. I'm going to try to develop some remedial exercises to try to bring them quickly up to speed. Also, we don't have a really good textbook for this course. Kingslake was a marvelous text before computers began to dominate the design process. Now it is woefully out of date."

"We are finding it difficult to get studentships because of political issues at the semi-national level, so our course is under threat, but, who knows, that might change now (as of yesterday). And (b) My Optical Design course is not appreciated by my non lens design colleages, they say it is too hard-core for the current generation of students (ie non whizzy and softwarey enough), and anyway "Who needs all those optical designers?"."

3. SUMMARY

I did not feel that I can set down a list of conclusions based on this survey. My purpose, after all, was to see what others were teaching lens design, how they were doing it, and what they were emphasizing. I think I have accomplished this. I hope it will give those who are teaching lens design and those who are contemplating such a course some idea of what is currently taught and how it is taught. We will continue to look for better texts, better tools, and to incorporate our interests into these courses.

Note that nothing in this survey covered the computer hardware that was used. This was intentional. Computers are so fast these days that the speed has virtually no effect on teaching lens design. As a matter of fact, there may be too much speed. Bob Hopkins, who taught lens design at the Institute of Optics, once told me that he really appreciated the mainframe computers (probably once the bother of cutting your own card deck had vanished) because they took sufficiently long to calculate an optimization that he had time to think about what he wanted to do next. That is something not given to today's teachers or their students.

4. ACKNOWLEDGEMENTS

I would like to thank all of my respondents: Warren Blaker, Russell Chipman, Richard Ditteon, John Greivenkamp, John Harlander, Duncan Macfarlane, John Maxwell, Duncan Moore, Jannick Rolland, Robert Shannon, and Erdei Gabor.

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