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Some thoughts on the education of optical waveguide engineers

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1. Introduction

It is difficult to discuss education in optical waveguides in specific terms. Details of a course will depend on whether it is at undergraduate or postgraduate level, for technicians or as a form of re-education for practising engineers. The initial knowledge of the students is also of importance and this will depend on the country – the university systems in England and China, for example, will be rather different.

In view of these difficulties you may ask, therefore, why I should say anything at all about the topic and the answer to this question is twofold. Firstly I have been asked to say something – but this is only a necessary, and not a sufficient, condition. Secondly, there are a number of fundamental principles which can be proposed for the education of all engineers and others who apply their knowledge for practical purposes. I propose to concentrate on these fundamentals, leaving the discussion of specific proposals to other speakers.

2. The problem

In the solution of any electromagnetic-wave problem it is necessary to consider the boundary conditions as well as the fundamental principles. One of our boundary parameters is related to the fact that the input signal (student) is usually coherent (intelligent), with a good knowledge of basic mathematics and physics but having little idea of how, or why, such knowledge can be applied. This is because most science teachers in high schools were themselves taught pure science in school, more pure science in university, and then returned to school to teach pure science. This circular progression may be compared with a device in microwave engineering called a "rat-race", in which a large amount of energy travels around in small circles without doing any useful work.

For education in optical waveguides, these bright students, with a good grounding in basic mathematics and physics, must be given a sound education in Electronics, Communications, Materials and Devices, with some Optics and if possible some exposure to the problems of Design, Economics, Management as well as oral and written communications. In fact we must try to provide a balanced education and not a narrow technical one. The theory of this approach may be excellent but there is the severe practical constraint that time is always limited.

Furthermore, a university education is useless unless it enables a person to think and learn independently and also to tackle challenging engineering problems. A purely vocational training is of little lasting value, because a technology may change several times during a lifetime and it is necessary to keep oneself up-to-date. Thus we must provide a sound, fundamental starting base.

Unfortunately there is no simple method of measuring the effectiveness of the education we provide so there are likely to be as many opinions as there are pedagogues. The arguments of this section are summarised in Table 1.

Table 1. General educational requirements

Good understanding of	Electronics Communications
Some understanding of	Design Economics Manufacture Management
Some	Technology BUT Technology changes rapidly Fundamental Base is essential
How are the results measured?	

3. What does "Fundamental" mean?

Even if it is accepted that an engineer's education must be fundamental, what does this mean? It seems to me that the more rapidly a technology is changing then the more necessary it is for practitioners in the subject to have a sound knowledge of basic studies and the less valuable will be practical techniques which are usually ephemeral. To illustrate this point it is interesting to look at the time interval between the demonstration of a new idea or product and its commercial exploitation. Some examples are given in Table 2. Obviously the technology of optical waveguides is changing very rapidly and a good grounding in the *relevant* mathematics and physics is essential.

Table 2. Idea to exploitation

Telephone	56 years
Radio	35 years
Radar	15 years
Television	12 years
Optical Fiber Communication	10 years
Transistor	5 years
Laser Diode	4 years
Microwave Maser	3 years

However we must be careful not to confuse the different functions and motivations of the engineer and the scientist.

A scientist is interested in knowledge for its own sake – an engineer only in knowledge that can be used. A scientist accepts nothing that cannot be proved by theory or experiment and in a broad sense the length of time required to obtain that proof is immaterial. The engineer cannot know everything he needs to know and must compensate for his impatience by experience and judgement (see Table 3).

Table 3. ENGINEERING differs from SCIENCE

SCIENCE requires absolute knowledge	
ENGINEERS	rarely have complete knowledge and must compensate with experience and judgement

Both theory and experiment are equally important but if theory does not agree with experimental results then, providing the experiment is correctly carried out, it is the theory which is wrong and not the experiment. Usually the theory is applied to a greatly simplified, or imperfect, model. For example Marconi had to ignore all the advice and theories of his day otherwise he would not have pioneered long-distance radio communication. One suspects that if the Science Research Council had existed in his day, Marconi's application for a research grant would have been rejected out of hand.

4. Other factors

Creativity and innovation are important tools in the armoury of an engineer (see Table 4), and also the ability to model a physical system which might be quite complex. I don't know how to train an inventor but creativity and innovation, as well as modelling, can be stimulated and encouraged by the right kind of project work. Design concepts must also be introduced. Examples of how these factors can be treated are the design, followed by construction and test, of a receiver, transmitter or

Table 4. Important factors

Creativity and Innovation
Modelling
Project and Laboratory Work
Engineering Examples
Lectures by Practising Engineers
Industrial Experience

simple optical transmission system. Some of these activities can be carried out in groups of two or three students since the students can learn from each other and they must also learn to work as part of a team.

In addition to fundamental studies in optical waveguides, mathematics, electronics, communications, materials and devices we must also introduce some concepts of technology. This can be done in a number of ways, of which laboratory experiments form only one. There can be case studies of specific projects, such as the planning and subsequent operation of an optical fibre transmission system. It can be valuable to have lectures by experienced practising engineers talking about their work, but only if they are good speakers and devote sufficient time to the preparation of their material. A poor lecturer can be worse than having no lecture. This kind of material can easily be presented by recorded (or live) television programmes but it is always necessary to have questions from the students answered immediately by someone with expert knowledge.

Another way in which students can be brought face to face with industrial problems is for them to work in industry during their course. In my own Department about 50% of the students spend a year in industry before coming to the University. Others spend 5 months there before starting the final year of study. In every case the industrial part of the course must be carefully programmed if it is to have any real value.

A factor which is not usually discussed in the context of engineering education is the shaping of character (Table 5). It is certain that you cannot give courses on this topic but a lot can be done through contact with tutors, that is by assigning students to individual members of the teaching staff for guidance, and by giving responsibility to the students. Both individual and group projects can be useful in this respect.

Table 5. Character-training

Through:
  Tutors
  Responsibility
  Group Projects

5. The syllabus

Finally we come to the material which should be covered. As I have said above, the exact level and syllabus will depend on a number of different factors. However the approach I would take is to teach optical waveguide sciences as part of a broader course on communication engineering, since a large part of the application of optical waveguides will be in communications. Furthermore, optical waveguides are no different in principle from metal waveguides and coaxial cables – it is only that the frequency of operation is five orders of magnitude higher, whilst the bandwidth and loss are several orders of magnitude better.

Thus my syllabus (Table 6) would include basic electronics (including analogue and digital systems); quantum electronics; communication theory and systems; electromagnetic theory (including the relevant optics); materials, including not only fibre materials, properties and fabrication and integrated optics but also embracing a coverage of devices such as lasers, light-emitting diodes and detectors for all frequencies; and of course the relevant mathematics.

Table 6. Technical syllabus

Communications (Theory and Systems)
Electronics (Analogue and Digital)
Electromagnetic Theory
Materials (Electronic and Glass)
Some Quantum Electronics
Some Optics

I would suggest also that about 15% of the time should be spent on laboratory (i.e. experimental) work with this taking the form of both individual and group projects in the last year. Some experimental studies should include design, construction and critical evaluation.

6. Conclusion

Clearly the type and content of a course will depend on the background of the students. For example, experienced engineers and scientists from other fields who wish to embark on work in optical communications will require condensed, intensive and specialised presentations over a short period of time. Undergraduate and postgraduate students at the Master level need a different treatment. They have time for any deficiencies in basic mathematics and physics to be made good and to be given a broader education covering electronics, communications and some optics. The undergraduates in particular should receive an education going beyond technical subjects and covering complementary topics such as those outlined in Tables 1 and 4.