

Teaching optics for other disciplines

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"Un homme éclairé est un homme libre"
Voltaire

ABSTRACT

In times where traditional curricula are questioned and multidisciplinary is encouraged, **optics** - in its broadest sense - is playing a very privileged role. In this paper we wish to illustrate this statement by analyzing how optics is infiltrating many related basic disciplines and many coming-of-age technologies, making it an exciting new field. By tempting to answer the questions : *What is teaching ? What is optics ? What are called other disciplines ?* we shall show how we strive to meet the expectations of students, industry and research labs. We shall report on our experience of teaching optics to small classes of electrical engineers and applied physicists, allowing to provide them with skills and insights much broader than the purely technical ones.

KEYWORDLIST

Optics, photonics, education, electrical engineering.

**1. INTRODUCTION : OPTICS AS AN OPPORTUNITY FOR
EDUCATION IN SCIENCE AND ENGINEERING ?**

How should we read the title of this invited paper ? With an exclamation mark, like an order ? With a question mark like an interrogation ? With a full stop, indicating self-assurance ? Involved in the teaching of optics for more than a decade and not being ourselves trained in optics during our studies, it is important for us, in this introduction, to first set the scene and address the real issues.

Do society, industry and research establishments require that professionals in "other disciplines" be educated in optics ? And, if the answer is yes, how should we proceed ? What should teaching be ? What kind of optics should be taught ?

Many elements to answering these questions can be found in recent publications about Higher Education in Europe [1], Education for Europeans [2] the Integration of Technology in European Education [3] and in the many references quoted herein.

All reach the same conclusions :

1. *There is an increasing gap between the economic and social realities and the output of our educational system.*
2. This mismatch is particularly noticeable in the way the *intellectual and behavioral aptitudes* of the learner are developed today.
3. Besides, there is great complain about the *lack of interest* of the youngsters for Science and Engineering, and great concern about the *dramatic decrease* of the number of students taking these disciplines.

4. Finally, all over Europe there is consensus about the need to increase the *motivation, curiosity* and *creativity* of students in Science and Engineering, and

5. to confront them with *multidisciplinarity, team work, industrial reality* and "*other cultures*".

All these issues have led in many a country to the questioning of the traditional curricula and to the elaboration of new ones.

We strongly believe that it is here that optics - taken in its broadest sense - can play an important role.

By its very nature optics is a field that should be proposed in the teaching programmes at every stage of the "Educational Chain"[2,3]. This is because so many natural and man-made wonders can be *shown*, and *seen*, and *explained* in simple terms ; also because so many futuristic questions about the nature of light and matter and their interaction remain unanswered. And as to applications, for boys and girls who like science-fiction, optics related components and systems seem within their reach. Nothing is more stimulating, because optics can be both *challenging* and *not too intimidating* at any age and at any stage of studies. This is particularly true at University level where optics offers unique themes to involve beginners in real science and real technology, and maintain this during all the study programme and beyond.

2. FROM OPTICS TO PHOTONICS

To answer the questions about what should be the content of optics education at University level, we should first specify what "Optics" means to us.

According to the respected McGraw-Hill's concise Encyclopedia of Science and Technology [4], Optics is "*narrowly, the science of light and vision ; broadly, the study of the phenomena associated with the generation, transmission and detection of electromagnetic radiation, in the spectral range extending from the long-wave edge of the X-ray region to the short-wave edge of the radio region*".

We fully agree with this definition, provided is added "*... and their applications*". However, most University Optics courses do not cover this extensive programme. Undergraduate programmes are devoted to topics like the Nature and Propagation of light (reflection, refraction dispersion, polarization, scattering, diffraction interference), Geometrical Optics and Optical Instruments, including the human eye [5]. In later stages, inspired by the "bibles" in Optics such as the invaluable book of Born and Wolf [6] or the very pedagogical work of Hecht [7] students immerse into the science of beam routing, beam shaping and imaging. These matters are extremely important, but much less exciting to young people than new (quantum) light sources, new detectors, new materials for transport, storage and display of information, modern holography, non linear optics, new medical applications, new material processing techniques, atom optics, etc. ... Most students seldom get a flavour of these topics which are related to the (quantum) interaction of light with matter, that beside their fundamental beauty have applications that infiltrate almost all aspects of our every day life. Or if they do they get it at the end of the day as "Sundry topics from contemporary optics".

This conservatism in the presentation of optics has many implications, among which, e.g. the fact that the available optical design software is not treating the source and detector aspects on the same footing as the propagation issue. But there is more. There is a *deficit in interest* in this important discipline. The recent selection round of the EC-TMR (Training and Mobility of Researchers) programmes[8] can illustrate this statement. Of the 248 networks submitted to the Physics Panel, only 38 projects explicitly mentioned Optics (P04) as a discipline relevant to the project. Thirty three (33) other projects were related to optics in its broadest sense, but were not recognized as such by the project leaders !

The six to eight (P04) projects that finally have been short listed for funding were in their vast majority, connected to other (sub)disciplines of physics, chemistry, mathematics, life sciences and engineering. They all are examples of *transdisciplinary* programmes where young professionals with different majors have to combine knowledge and efforts to be successful, often in collaboration with industry. A perfect illustration of what we stressed in the introduction ...

This new type of dialogue has to be prepared early enough. The old image of boring or difficult optics has to be brushed up. A possible way to show that scope and content of optics education has been adapted to new needs is to give it a novel name. In Brussels, following Laurin Publishing co. we decided to call it **Photonics** [9].

Selected topics in Photonics should be taught to students in other disciplines such as electrical and mechanical engineering, telecommunications, computer science, material science, physiology, medicine, ... and of course, physics !

And, reciprocally, to favor cross fertilization, aspects of the above mentioned specialties should be taught, by specialists, to photonic students. There is much work to be done in European Institutes of higher education ! At the University of Brussels, we started the experiment in 1993.

3. PHOTONICS AT THE VUB

Electrical engineers (EE), who are specialising today in information technologies and in related fields like electronics, photonics, telecommunication and computer science, will become key players in this challenging industrial environment. The changes induced by the information revolution are much faster than many people realise and in general, education curricula and teaching methods do not adapt fast enough. What is more, for a long time in Belgium, important curriculum revisions were impossible, since engineering study programmes, dating from the beginning of the century, were dictated by law. In 1993 legislation changed and allowed far more freedom to the universities in determining their own educational programmes. As before the student in spe must still pass an entrance examination with a strong emphasis on mathematics before being allowed to follow the academic engineering educational programme. The studies then take five years: two years to become bachelor and another three years to obtain the masters degree. Finally the new law also limits the average contact time between the student and the academic staff to 25 hours per week and the maximum study time to less than 1800 hours per academic year. This has the aim of both rationalising the teaching time-tables and to provide the student with more time to develop his or her abilities in self-learning and self-assessment.

At the Faculty of Applied Sciences of the Vrije Universiteit Brussel (VUB), Belgium, we have immediately seized this opportunity for innovation . In October 1993, with the start of the academic year, we transformed our traditional engineering curriculum into an EE education system to train "renaissance engineers" rather than "short-term economic human resources"[10]. The most far reaching of these educational innovations has been integrated into our novel photonics curriculum.

During the first four semesters of the programme all students in engineering follow the same basic courses. These courses provide an in-depth training in mathematics, theoretical mechanics, physics, chemistry, electrical measurements, structural programming and numerical analysis. Following W. T. Cathey in his recommendations for optoelectronic education, *these core courses already contain some aspects of Optics and Photonics*. For instance, Maxwell's equations, their solutions in various media and the reflection and refraction properties of plane

waves are covered. The course on quantum physics contains many aspects of the quantum oscillator, of quantum wells and magnetic moments as well as first principles of solid state physics and the theory of induced emission and absorption. The chemistry course opens the way to material science, thermodynamics and information theory.

Besides education in basic knowledge and training in problem solving and practical skills, some courses already contain elements that stimulate both civic responsibility and a sense of service and commitment to the community. The course "Technology and society" for example focuses on the possible impact of technological developments on society and the environment. *It aims at helping the students to understand that inducing technological change also implies taking responsibility for the possible consequences.*

The examination system has been adopted in which assessment is designed to *confirm progress rather than to sanction failure*. Most of the tests are both written and oral and therefore interactive, which makes it possible to evaluate the students' personal competence, sense for critical thinking, and communication skills; that is their ability to think through a problem or a new situation and their qualities to convey their findings.

After the first two years the students can opt for one of the possible engineering disciplines. If EE is chosen, the programme continues during three semesters with a common training for all EE students, followed by 2 semesters of more specialised courses in one of four information technology sub-disciplines: electronics, photonics, telecommunication or computer science. The last semester of the five years training is then devoted to the graduate thesis work.

The core courses in the common trunk of the EE curriculum provide the future engineers with a strong education in basic electronics, circuit design, electricity, analog and digital signal processing, systems and control theory, informatics, electromagnetism, quantum properties of matter *and* light, material science as well as advanced mathematics. They also get an extended course on power electronics and electrical machines such as an introduction to telecommunication. Mechanical engineering, strength of materials and less-technical matters complete their general background. The curriculum balances theoretical courses and practical work. Many practical classes, often organised as co-ordinated mini-projects encompassing different theoretical courses, give the students the methodology and the skills to work with modern, sophisticated instrumentation and to experience and practice team-work.

During the next two semesters, while training in electronics is continued, the students opt for one of the sub-disciplines given previously. Students choosing to specialise in photonics follow *eight compulsory courses* in this discipline and in addition three extra-disciplinary courses, such as business administration, economics, languages or indeed any other courses of their choice given in the university. The other courses are elective and students are encouraged to take them in other disciplines.

In *Laser physics and technology* the students are given an in-depth treatment of the physics and design of gas, liquid, solid-state and semiconductor lasers, their beam characteristics and their diverse applications such as medicine, material processing, metrology and chemistry.

Following on from a previous course on *Electromagnetism* is a training in *Diffraction and Fourier Optics*. Besides theory it illustrates applications such as analogue optical image

processing and filtering, holography, gratings, and computer generated diffractive optical elements.

Physical properties of optical materials and artificial structures covers a.o. electro-optics, magneto-optics, and acousto-optics. Much attention is also paid to the behaviour of optical signals at surface boundaries, through layered media and in nonlinear materials. Special emphasis is put on applications of novel photonic materials such as liquid crystals for optical retardation and photorefractive crystals for holographic memories.

The goal of the course on *Computer aided design of optical and opto-mechanical systems* is to teach students, with the *aid of commercially available most advanced software packages*, how to design and evaluate optical systems like those found in mass products like bar-code scanners and compact disc players. The course e.g. is completed with a case study in which the students have to develop an original system, including a cost/quality evaluation of their different designs. *Displays, optical memories and parallel optical information technologies* contains material on the human visual system, on colour theory and the physics and technologies of displays. Current photonic technologies for the multimedia and computing environment are covered such as optical data storage, optical interconnects and digital optical processing concepts. In doing so we mainly focus on the motivation for developing such particular technologies and on the underlying novel physical concepts rather than trying to cover all the different present-day approaches.

The courses *Photonics I, II* are an introduction to *optical telecommunication*. In a first part of this course the physics of optical fibers, semiconductor light sources and detectors is covered as well as the basics of information theory and information transport. In the second part the principles of high capacity guided-wave optical telecommunication systems are treated in detail, emphasizing dispersion, soliton propagation, optical amplifiers, multiplexing schemes and optical network configurations.

Most far reaching in flexibility is the course *Hot topics in photonics*. Here, in the beginning of every academic year, the teacher determines, in dialogue with his students, the content of the course. The students then select a topic of their interest, deepen the subject and give a seminar. Moreover, in the framework of the same course, prominent scientists, engineers or industrialists are invited to give tutorials on recent developments in the broad field of EE. Examples of this year's topics are: organic materials for photonic switching, job and career opportunities for engineers, Si-Ge superlattices, dark solitons, GaN optoelectronics, Bragg gratings for sensing and telecommunication, VCSELs, etc.

Practical classes in photonics provide the students with a hands-on training in table-top photonic experiments. We have therefore equipped two laboratory rooms with the necessary electronic and photonic instrumentation. A paper presenting these activities can be found in [11] Another example of tasks, organised as a mini-project, encompasses different theoretical courses.

The last semester of the five years academic engineering training is devoted to the graduate thesis work. The topic can either be industrially or academically oriented. Here, semesterisation of the curriculum gives the students the opportunity to leave their home university and do this work abroad via a European Community student exchange programme such as ERASMUS, SOCRATES or LEONARDO. It is important that the future world citizens should experience mobility, other languages and different cultures.

For those incoming students who are not yet ready for this all-embracing experience, we have transformed our department into a micro-metropolis, where they can work together with researchers and professors from several Eastern and Western European countries. In whatever way the international dimension is accomplished, it is needed to help students to a practical understanding of how to communicate across cultural barriers, of how to learn from other points of view, and how to work and value diversity, as a tenure or as a graduate student.

4. CONCLUSIONS

1. In order to cope with the lack of interest for Science and Engineering and the new demands of society with respect to aptitudes and attitudes of academically trained people, traditional curricula have to be revised.
2. In particular, the content of standard optics courses should be reconsidered, in view of the impact of optics and photonics in the latest developments of science and technology.
3. Teaching *Optics and Photonics* to other disciplines is possible and not too expensive. We tried it at the VUB and it works. Photonic EE engineers are recognized as such by industry, in Belgium and abroad : most of our students have found jobs in their field of studies.
4. The key to success is teaching to small groups with adequate equipment and software packages and genuine multidisciplinary ; bring up physicists and engineers together in the teaching and research staff, working towards a coherent curriculum and interested in each other's tools research problems and teaching language.
5. Networking and mobility of staff and students is important. The *COALITION FOR OPTICS* and the *OPEN* networks could play an important role in this field.
And, of course, the ICO ! ?

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