The Success Story of the Photonics-Related Curriculum Concept Developed in the Engineering Study Program from Undergraduate to Graduate

Asta Tamulevičienė*[a], Tomas Tamulevičius[a], Sigitas Tamulevičius[a]
[a]Faculty of Mathematics and Natural Sciences, Physics Department, Kaunas University of Technology, Studentu str. 50, Kaunas, Lithuania

ABSTRACT

Lithuania is recognized as a laser-tech cluster and therefore the Materials Engineering and Nanotechnologies study program carried out at the Kaunas University of Technology is tempting to address the competencies required by the beneficiaries. Students are introduced to Optics and Laser technologies via three recently revised dedicated courses that have theory lectures, practical tasks, and laboratory works. The endeavor starts at the basic level like geometrical optics, light interference, diffraction, etc. going through modern optics covering optical devices and processes, and finalizes with a deeper understanding of topics covering nonlinear and ultrafast laser optics, plasmonics, and laser material processing. The study program is unique in a way that it provides double degree diplomas both in Physics and Materials Engineering fields. Considering the challenges and needs of the laser-related industry in Lithuania the courses in Optics were adapted to include fundamental and applied research-based topics along with problem-based learning tasks directly related to the real-life problems that expand the content of the classical textbooks. Lab work tasks are performed at university research laboratories employing the state-of-the-art femtosecond laser, laser micromachining workstation, and transient absorption spectrometer allowing students to get familiar with the locally produced photonics products. Hands-on experiences with contemporary technologies together with a critical amount of fundamental knowledge in photonics later on stimulate students seeking a job position in the laser/optics-related industry in Lithuania. The feedback from the students shows that the problem-based learning approach and teamwork allow students to get a better understanding and more in-depth knowledge of the field and teaches soft skills expected by employers.

Keywords: Optics Education, Photonics, Laser technologies, Problem-based Learning.

1. INTRODUCTION

Kaunas University of Technology (KTU) is the biggest technical university in Lithuania and among Baltic countries[1]. The deep connections with the industry located around Kaunas and different parts of Lithuania allow adapting study programs to keep up with the industry and student needs. The physics department at the Faculty of Mathematics and Natural Sciences (FMNS) just last year celebrated its 100th anniversary, so it has deep traditions in educating undergraduate, graduate, and Ph.D. students in the field of physics[2]. Historically, studies in Kaunas are more oriented toward a combination of physical sciences and materials engineering. This allowed proposing the multidisciplinary studies “Materials Engineering and Nanotechnologies” where students receive double degree diploma in Physics and Materials Engineering. Students taking these studies receive a broad field of competencies that allow them to be confident and competitive when seeking job positions in a variety of enterprises situated around Kaunas and its region or throughout the country and abroad. Historically, Optics related courses were always included in the curriculum, as the important fields in Physics. The tremendous progress in laser-related technologies worldwide, namely the development of high peak power lasers, and related peripherals, as well as their emerging application were recognized by the Noble Prize in Physics in 2018[3]. Ultra-fast laser micromachining and femtosecond time scale resolved spectroscopies went through the transformation from custom build researcher equipment to the turn-key systems daily used in the industry. It imposes the need for a deeper understanding of ultrafast lasers, their components, related applications, and technologies. That enquired reevaluation of the courses given in the Optics field in the current curriculum. Additionally, the interest from laser companies was heard as due to fast growth in the field they stated lacking specialists. The laser industry in

*asta.tamuleviciene@ktu.lt

Seventeenth Conference on Education and Training in Optics and Photonics: ETOP 2023,
edited by David J. Hagan, Mike McKee, Proc. of SPIE Vol. 12723, 1272322

Lithuania counts more than 25 years of history, and now more and more companies related to laser development are established every year and are linked together with universities preparing the specialists via the Laser Association of Lithuania[4]. The association connects different companies working in the fields of Short & Ultrashort pulse lasers, Laser systems for science & technology (*i.e.*, Light Conversion, Ekspla, Quantum Light Instruments, etc.), Laser Technology Equipment & Workstations (*i.e.*, Workshop of Photonics, Femtika, etc.), Optical Coatings (Altechna Coatings, Optonas, Optoman), Optomechanical Components (Standa, Eksma Optics), Laser Products and Services (Brolis Semiconductors, Holtida, Direct Machining Control). Such expansion of the field demanded the transformation of the courses related to optics in undergraduate and graduate study programs. Aiming to keep up with the progress and teach relevant topics current curriculum with revised theoretical background, lecture material as well as new laboratory works and practical tasks was proposed including new teaching methods as problem-based learning activities.

2. SELECTED PATH FOR THE REVISION OF OPTICS-RELATED COURSES

Students studying at the FMNS at KTU have 9 European Credit Transfer and Accumulation System (ECTS) credits for the courses related to the optics field, namely Optics (3 ECTS) and Phenomena of Modern Optics and Nanophotonics (PMON, 6 ECTS). Later on, after finishing their Undergraduate studies, they can choose a Graduate program "Materials Physics" where an additional course Applied Optics and Photonics (AOP, 6 ECTS) is given. Such a curriculum is now for at least 5 academic years. These courses are taught and supervised by the research group "Applied Optics and Photonics" established at the FMNS. The theoretical basis for these topics covered was carefully revised not to repeat between different courses but to provide in-depth knowledge in the field. The relation between the courses can be illustrated with the simplified diagram depicted in Fig. 1 which resembles the one found in B. E. A. Saleh and M. C. Teich book Fundamentals of Photonics[5], where authors explain how optics can be taught using different concepts describing light starting from ray optics and finishing with quantum optics. In our case, this diagram shows the knowledge development of our students through their studies at FMNS.

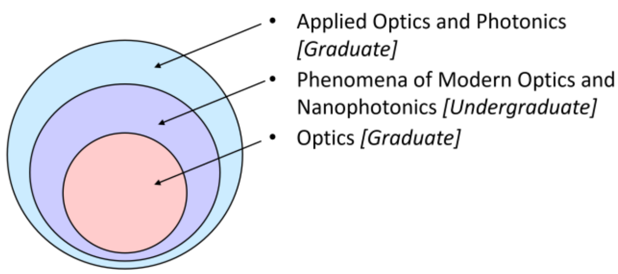

Figure 1. Relation of the Optics courses in the Undergraduate and Graduate programs at the FMNS in KTU.

Topics covered in the three courses are listed in Table 1. As one can see, the curriculum in all courses has the same track – students participate in the theoretical lectures, work on practical tasks, and do the experiments in laboratory. Lectures are given every week, whereas practical problem-solving class and laboratory class is given every second week.

To encourage learning during all semester but not only before the deadlines as the mid-term and final exams, every lecture starts with a short online quiz to remember the topic discussed last time. Figure 2 illustrates the slide during the lecture and on the right side, one of the possible quizzes is provided (student view in Socrative[6]). Teachers can use online tests for tracking class attendance and student activity when it is compulsory. An experience of a few years and anonymous course evaluation indicated that students usually are keen to participate in the quizzes using their smart devices.

Another important issue in the courses is the effective communication channels and convenient teaching material exchange with the students. At KTU all the study material from the modules must be accessible for students via Moodle[7] course page. On the course page, one can put the lecture material as a pdf file or recorded video along with laboratory work descriptions, problems for practical tasks, etc. Additionally, self-evaluation tests are created for each topic, and

Table 1. Information about the topics covered in the different courses through undergraduate to graduate studies programmes.

"Optics" [Undergraduate]	"Phenomena of Modern Optics and Nanophotonics" [Undergraduate]	"Applied Optics and Photonics" [Graduate]
» Evolution of optics; » Light as waves, rays, photons; » Propagation of light; » Geometrical optics; » Superposition and coherence theory; » Polarized light; » Light Interference; » Diffraction of light; » Fourier optics; » Optical instruments and detectors	» Introduction to the Fundamental Ways of Describing Light Properties Required for Description of Modern Optical Phenomena; » Electromagnetic Optics; » Polarization Optics; » Optical Properties of Regular Nanostructures and Photonic Crystals; » Guided-Wave Optics; » Statistical Optics; » Resonator Optics; » Light Interaction with Atoms, Molecules and Crystalline Materials; » Laser Amplifiers; » CW and Pulsed Lasers; » Acoustooptic Modulators; » Electrooptic Modulators; » Introduction to Nonlinear Optics and Ultrafast Optics; » Introduction to Nanooptics and Plasmonics	» Peculiarities of the Light description - Selected Chapters; » Lasers and Their Working Principles - Selected Chapters; » Nonlinear Optics; » Ultrafast optics; » Applications of Nonlinear Optics and Ultrafast Optics in Spectroscopy; » Laser Interaction with Materials and its use for Micromachining Applications; » Nano Optics and Plasmonics
Time distribution in the course (in academic hours, a.h.)		
Lectures: 32 a.h. Practical: 8 a.h. Laboratory work: 8 a.h. Independent work: 32 a.h.	Lectures: 32 a.h. Practical: 16 a.h. Laboratory work: 16 a.h. Independent work: 96 a.h.	Lectures: 32 a.h. Practical: 16 a.h. Laboratory work: 16 a.h. Independent work: 96 a.h.
Tasks and evaluation in the course (influence on the grade, %)		
Midterm exam 30% Lab work examination 20% Problem-solving task 20% Final Exam 30%	Midterm exam 35% Lab work examination 20% Problem-solving task 10% Final Exam 35%	Midterm exam 35% Lab work examination 20% Problem-solving task 10% Final Exam 35%

students can perform self-evaluations before examinations to check their understanding of the topic. These Moodle courses also serve as repositories of student reports and online examination platform which was exploited during the pandemic years. It is also a place to communicate between students and students with the teacher, leave feedback on the course, etc.

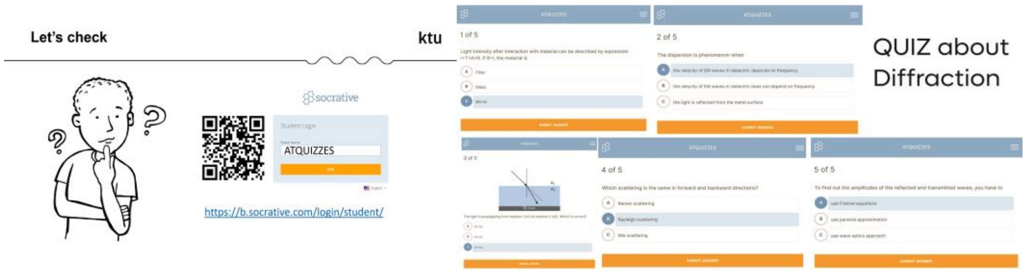

Figure 2. An interactive quiz to check the understanding of the material given during the lectures in the Optics course.

Students in the undergraduate study program have Optics course in the 3rd year, so up to this point they have participated in the courses of Classical Physics (Newtonian Mechanics, Oscillations, Thermodynamics) and Physics 2 (Geometrical optics, Light-matter interaction, atom physics). In Physics 2 course students have considerable time periods allocated for labworks and perform conventional experiments to get familiar with light propagation via lens (ray optics), diffraction and interaction with material (refractive index determination), etc. At the time when they come to the Optics course, they already have some background knowledge and can expand their knowledge in a broader view.

Specifically in optics-related courses, labworks are performed in high-level scientific labs (not with the standard laboratory setups to check some general phenomena) at the Institute of Materials Science of KTU[8]. It is mainly a research-oriented university department providing open access to technological and analytical facilities for conducting research-based studies at the university. It has a specialized optical laboratory equipped with continuous wave and pulsed lasers, a laser micromachining workstation, transient absorption, UV-Vis-NIR, and FT-IR spectrometers, a spectroscopic ellipsometer, etc. Labworks are performed in small teams, and students are supervised by the teacher of the course and an engineer or Ph.D. student working in the lab. The cooperation of experienced staff and young researchers (Ph.D. students) ensures more attention and supervision in case of help is needed during the labworks as well as allows for nurturing future academic staff and at the same time encourages students to choose scientific careers after their graduate studies. The list of labworks is provided in Table 2.

Table 2. Labworks performed in the courses

Course	No.	Titles
Optics	2	Spectrophotometry and the Beer-Lambert-Bouguer Law; Spectral Analysis of Optical Filters
PNOM	4	Determination of Laser Beam Quality Factor; Investigation of Laser Attenuator; Determination of Brewster Angle Employing White Polarized Light; Determination of the Light Coherence Length Through the Spectral Analysis
AOP	4	Characterization of Laser Diode; Determination of the Material Ablation Threshold with a Femtosecond Laser; Investigation of Surface Plasmons Polaritons; Autocorrelator

The number of students per team depends on the size of the class enrollment. Teams are created either by students preference or by blind grouping, it depends on the course teacher. It is aimed to form groups of 3-4 students both for labworks and for problem-solving tasks. Last year's experience indicated that teams were working more efficiently when students already knew each other, have similar interests, and were eager to collaborate for achieving the best solution for the problem. Such activities in teams allow to find a common word with international students from other countries as usually each year some students join under an exchange program for a semester and increasing number of students from abroad choose full studies at KTU.

As the labworks are performed in teams, students must hand in a single report done by the team. Using Moodle platform, we provided a possibility for students to review other teams' reports (act as reviewers). It was a great help for the teacher as students evaluated the reports very maturely, substantiating their evaluation without simply putting either an excellent mark (10 points) or a fail mark (<5 points). At the same time understanding that the work will be evaluated by the other students in the class motivated students to provide more mature reports. The grade provided by the students serves as a guideline for the teacher and the final evaluation comprises two parts, namely 50% is the report evaluation, and 50% is the written defense where questions related to the topic of the labwork are asked. Both need to be evaluated positively. Working in a team teaches students not only hard skills like working with dedicated equipment but also soft skills like teamwork, communication, and collaboration. It is very important nowadays to strengthen the ability to work in teams, especially after pandemics as more and more students prefer to work individually.

As the study program is interdisciplinary, the labworks in the courses are also related not only to the explanation of the physical phenomena, but also showing the application possibilities. For example, in the Optics course, labworks are performed with simple equipment, like an optical spectrometer, but it allows students to prepare solutions for the measurements and using measured data find the concentration of the unknown solution, or select the filter for the defined application (bandpass, Notch filter, fluorescence measurement, etc.). In the master-level course (AOP), some of the labworks are performed with a femtosecond laser and micromachining equipment. Safety issues are also important in these courses, so students get an introduction to laser safety in the optics lab before performing labworks as well as protective means like Certified Laser Safety Glasses.

Another step in the improvement of the courses was the introduction of new software used for modelling light path in optical components (OSLO EDU[9]) and new teaching methods to engage students in the field of optics via solving small real-world problems. After studying literature[10-12] and communicating with internal Educational lab department colleagues[13] we came up with the solution to implement problem-based learning activities in all three optics-related courses. Such a unified system allows us to keep track of this field and correlate problems between different courses. One example of the problem is depicted in Fig. 3. Students select the problems from the list or are allocated randomly. Problems are provided in the first weeks of the course and students are developing the solution for the problem and consulting with the teachers till the end of the semester. Solutions to the problems are presented to all class during the seminar as an oral presentation. During practical class, discussions on the progress are taking place every month. Students from the same team are anonymously evaluating the work of each team member including their own input, whereas the final presentation and quality of the following discussion are evaluated by other teams and the teacher. We have observed that students are very polite and sincere when evaluating each other and especially are critical to themselves.

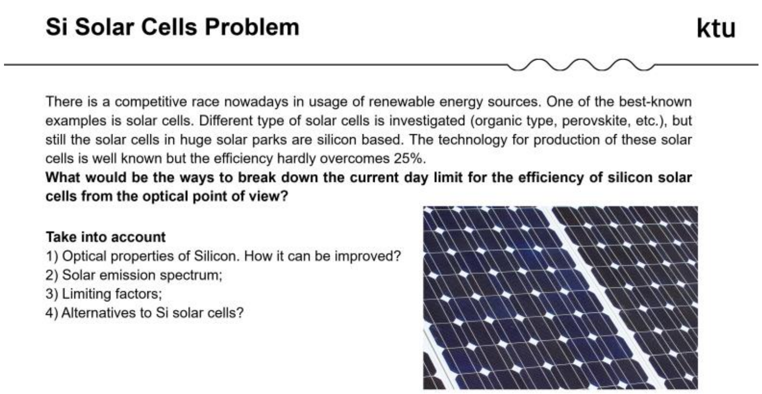

Figure 3. An example of PBL task in Optics course.

In Graduate level courses students are encouraged to exploit the given tasks to prove the equation given during the lecture or in printed material, few examples are given in Fig. 4. One example was to obtain the extinction curve of the metallic sphere carrying localized surface plasmon resonance when the dielectric permittivity of the nanoparticle and surrounding were provided. Students have the flexibility to choose the measures how to solve the task. Some uses Microsoft Excell, others prefer writing their scripts on Matlab.

60-70% of the final mark of the course are accumulated by passing mid-term and final exams. During quarantine due to COVID-19 pandemic, these assessments were performed online using Moodle platform in the form of quizzes with multiple-choice questions and open questions. After the pandemic, the assessments are performed exceptionally in a classroom and mainly with open questions. Students receive multiple questions from topics covered during the course and they have the possibility to choose one question out of two covering the similar topics. Such an approach for knowledge testing proved to be a good strategy as most of the students pass from the first approach and the distribution of the grades usually resembles close to normal distribution.

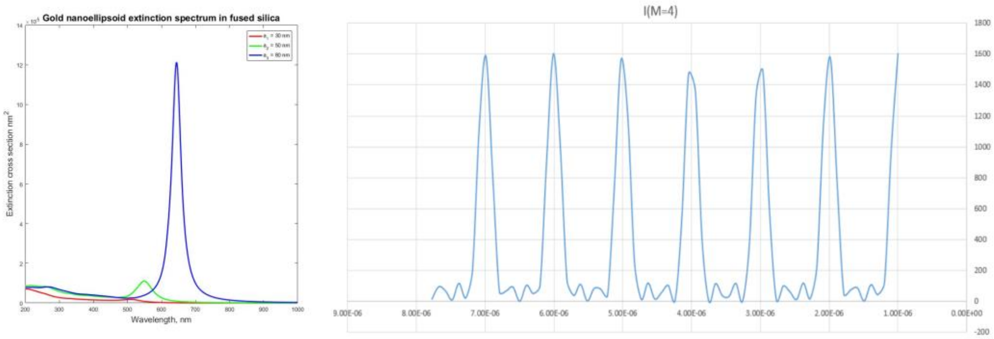

Figure 4. Examples of student provided solutions for the tasks in AOP course: on the left – extinction spectrum of gold nanoellipsoid, on the right – mode locked laser (number of modes - 4).

Courses are also a good dissemination channel to introduce activities of an existing university research group "Applied Optics and Photonics"[14]. It helps to attract students to join ongoing research activities. The research group focuses on activities related to laser application for different purposes including micromachining of different materials, nanoparticle synthesis with femtosecond laser pulses, transient absorption spectroscopy of nanomaterials, etc. We also attract students to perform research in Optics field via competitive funding, when Research Council of Lithuania[15] funds the student sumer practices or research activities during the semester. We have numerous examples when students, after taking one of the mentioned courses and joining the research group continued performing their final undergraduate, graduate, or Ph.D thesis on a similar topic or decided to seek a career in an Optics related enterprise. They find work positions in prestigious laser-tech companies in Lithuania, such as Light Conversion, Altechna, Workshop of Photonics, Femtika, Optonas, Brolis Semiconductors, etc.

We supported the student initiative to establish Optica Student Chapter at KTU[16]. Students from this organization actively participate in outreach events for pupils and families (science shows like Researchers Night, Day at Parents' Work, Spaceship Earth, etc.) promoting awareness and interest in the field of Optics and attracting future students to studies at the KTU. The student chapter also contributes to organization of the annual international conference-school "Advanced Materials and Technologies"[17] that is taking place in Palanga, Lithuania where the members participate in the poster section themselfs and participate in an evaluation of the best poster presentations in the respective field as well as contribute with the dedicated prize.

3. CONCLUSIONS

The student-oriented activities introduced in the optics-related courses allowed for reaching student satisfaction in the interdisciplinary study program Materials Engineering and Nanotechnologies at the Kaunas University of Technology. We managed to combine the fundamental background with hands-on experiments in the laboratory and the inclusion of problem-based learning allowed students to easier understand how the topics covered in theory lectures can be applied to solving everyday problems. Efforts in the preparation of attractive lecture material, laboratory works, and problem-based learning tasks were awarded by positive students' feedback, including the evaluation of teaching quality and attractiveness of the tasks. Finally, the evaluation and positive feedback from our industry partners proves the good orientation of selected path in the education at KTU.

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