Development of Laboratories with Virtual and Real Elements for Better Preparation of Telecommunications Engineers

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Structured Abstract

BACKGROUND
Industry demands graduates with better preparation and greater knowledge. Such a situation challenges universities to find better ways to enable students to develop into highly efficient engineers. At the National Autonomous University of Mexico, we partially solved the problem of achieving the main objectives of engineering laboratories under limited laboratory space and timetable, thus enabling students to become highly efficient engineers. This has been achieved by combining real "hands-on" exercises with computer simulations and other virtual activities, such as the use of educational resources available in the internet. Our approach and results might be of interest to educators of different subjects relating to electrical, optical and telecommunications engineering.

PURPOSE
The purpose of this paper is to present the design procedure, the content and assessment results of laboratories that we developed for some optional subjects of the Telecommunications Engineering course (academic major, major concentration). Previously, none of these subjects had a parallel laboratory.

APPROACH
We elaborated, implemented and evaluated new laboratories for three optional subjects of the Telecommunications Engineering course: Optical Devices, Quantum Devices, and Audio and Video Encoding. The elaboration of the laboratory content and protocols was performed by means of an iterative procedure comprising design, analysis, and optimization of the content.

RESULTS
In the iterative design process, we received strong feedback from students and educators that ensured the laboratory efficacy. We combine in-person laboratory sessions with relevant computer-based and internet-based educational activities that our students perform under adequate guidance outside the formal timetable.

CONCLUSIONS
Properly designed laboratories with real and virtual elements are efficacious in enabling students to become highly efficient engineers, while such laboratories require much less in-person laboratory time than traditional "hands-on" engineering laboratory. The design procedure described in this paper could be helpful for educators of distinct engineering careers, in particular for those who wish to establish new laboratories for optional engineering subjects.

KEYWORDS
Engineering laboratory, hands-on laboratories, alternative learning environments, telecommunications engineering

Introduction

Industry demands graduates with better preparation and greater knowledge. Such a situation challenges universities to find better ways to enable students to develop into highly efficient engineers. Good laboratories are extremely important in providing students with practical skills and knowledge relevant to their field of study. However, it is difficult to complement all engineering subjects, in particular optional subjects with respective teaching laboratories, as the available capital investment, training staff and other resources are usually limited. For example, only 40% of the core engineering subjects and less than 20% of the optional subjects of our Telecommunications Engineering course (academic major, major concentration) at the National Autonomous University of Mexico have respective teaching laboratories. Virtual and remote laboratories based on the use of computational resources and the Internet are frequently considered as a solution to this problem (Peterson and Feisel, 2002, Feisel and Rosa, 2005, Chen, Song and Zhang, 2011). In particular, Muthusamy, Kumar and Syed Abd Latif (2005), and Basher and Isa (2006) express the view that remote and simulation laboratories provide real world relevant laboratory experimentation at a fraction of the cost of traditional instruments. Also, D'Andrea and coauthors (2007, 2008) present successful cases of implementation of remote microwave and telecommunications laboratory. On the other hand, Morris (2003) emphasizes potential problems relating to software, websites, and a high cost of specialized software that might be needed for successful simulations and remote laboratories, and high maintenance cost of such a software that may be far in the excess of the initial hardware cost. This correlates with the opinions of Balamuralithara and Woods (2009), Cuartero-Olivera and Pérez-Navarro (2009), and Chen, Song, and Zhang (2011), who highlight that establishing both remote and simulation labs require additional space, substantial financial support and technical assistance, and availability of expertise to change and develop the simulation software following changes of syllabus.

At the same time, many authors (e.g., Feisel and Rosa, 2005, Cuartero-Olivera and Pérez-Navarro, 2009) agree that students must have some hands-on experience with real instruments, equipment and processes relating to their career and further research are needed to determine the most efficient way to bring this about. That is, virtual and remote laboratories are not a *panacea* as they cannot substitute real laboratories and “hands-on” experiments. Whenever it is possible, we must benefit from the particular special features of distinct kinds of laboratories - hands-on, remote and simulated, and combine them.

Regretfully, there are few case studies and few recommendations on how to combine in some optimal way the real and virtual engineering laboratories. At the National Autonomous University of Mexico, we partially solved the problem of enabling students to become highly efficient engineers under limited laboratory space and timetable. We achieved this by implementing new laboratories for several optional teaching subjects that previously did not have laboratories. The new laboratories combine some real “hands-on” experiments with simulations and other virtual activities, such as the use of educational resources available in the internet. Our approach and results might be of interest to educators of different subjects relating to electrical, optical and telecommunications engineering.

Purpose

The purpose of this paper is to present the design procedure, the content and evaluation results of laboratories that we developed for several optional subjects of the Telecommunications Engineering course, namely: 1. Optical Devices, 2. Quantum Devices, and 3. Audio and Video Encoding. These subjects are taught, among a dozen of other optional subjects, at the next to last 8th and last 9th semester of the course. We considered these three subjects together because all three deal with light, optics, images, signals etc. Previously, none of these subjects had a parallel laboratory, primarily because it was unrealistic to fit too many parallel laboratories in the timetable. The academy suggested that we share the laboratory time between several optional subjects during a 16-week long semester. Therefore, we needed to design laboratories that could allow us to achieve the desired learning outcome under a reduced in-person laboratory time, in comparison to traditional full-semester laboratories.

Approach

In order to meet the above conditions, we decided to reduce the in-person laboratory sessions while complementing them with computer-based and internet-based educational activities that could be done by students under adequate guidance outside the formal timetable.

The elaboration of the laboratory content and protocols was performed by means of an iterative procedure comprising design, analysis, and optimization of the content. We systematically collected data to monitor the success of laboratories in achieving intended learning outcomes for students. We intended to access student performance, instructional strategies, educational technologies, and learning environment. This was done at each iteration cycle so that we could revise and adjust the laboratory content and instructions. For assessment, we employed a pre-test/post-test comparison of learning as well as a questionnaire on student experiences of particular laboratories. In addition, evaluations by the instructors and professors in charge of the subject about whether the laboratory has met its intended learning outcomes were conducted on a regular basis.

Such a procedure has allowed us to develop and implement laboratories where firstly, students work in the virtual environment in order to get better knowledge of the particular learning topic. Also, the students perform computer simulations of the phenomena, processes, equipment etc. that constitute the subject of laboratory. Secondly, students work in the real learning environment - an in-person teaching laboratory. Thirdly, students return to the virtual environment once again, where they integrate the knowledge obtained in the virtual and real learning environments and thus deepen their knowledge of the learning topic.

Description of Design Procedure

Firstly, we defined the target learning objectives and the available environmental components: laboratory space, timetable, laboratory infrastructure, measurement instruments and computers, network accessibility and performance, students and professors, among others. Secondly, we defined a set of laboratories for each teaching subject and designed them as a subset of exercises related to the target learning objectives. Table 1 shows the teaching subjects and relating laboratories that were developed within the frames of this work.

Table 1: Teaching subjects and relating laboratories

Teaching subject	Laboratory
Optical Devices	Optical filtering
	Light dispersion
	Optical spectrometry
	Polarization of light
Quantum Devices	Optical radiation sources
	Optical radiation detectors
	Properties and applications of a He-Ne laser
	Properties and applications of a CO2 laser
Audio and Video Encoding	Image coding in JPEG format
	Principles of analogue and digital video
	TV signals
	Video coding in MPEG1, 2 and H264 format

We defined the following features of the laboratories: 1. Objective, 2. Type, 3. Basic content, 4. Laboratory equipment, materials and floor space required for hands-on activities, 5. Software required for virtual activities, 6. Time required for hands-on and virtual activities, 7. Academic staff: professors and instructors required for conducting the laboratory.

Then we elaborated new laboratory experiments as a subset of virtual and real hands-on exercises, implemented and optimized them by means of an iterative optimization procedure comprising analysis, re-design and adjustment of the exercise elements. We adjusted the content, sequence and extension of real and virtual exercises each semester by taking into account the results of the previous semester. This was done for about four semesters per subject on average, until the assessment showed that we were sufficiently close to our educational goals.

Exercise framework

All laboratories include real hands-on exercises and virtual activities: learning from the internet resources and performing computer simulations of the physical phenomena, technological processes, element performance etc. that relate to the laboratory topic. Some virtual activities can be performed as a pre-lab, while others can be performed before or in parallel to the real hands-on exercises. Other virtual activities can be performed as virtual post-laboratory. We distinguish the following activities:

– Preparatory activity: Investigation of the concepts and other topics related to the exercise, and solving the previous questionnaire. The laboratory protocols refer the students to the recommended textbooks and internet resources, such as free digital books, papers, YouTube animations and videos relating to the laboratory topic.

– Simulation exercise: Performing virtual experiment by using simulation software.

– Real hands-on exercise: Performing real physical experiments in teaching laboratory conditions.

– Post-laboratory: Drawing conclusions about the laboratory and completing a final questionnaire. Repeating or extending some exercises, if necessary. Completing of a report.

Laboratory example

Laboratory title: Polarization of light.

Objectives: To achieve that at the end of this laboratory the student will be able to identify different states of polarization of light, to demonstrate the ability to collect, analyse and interpret data from the polarization simulation software (namely, Polarization Tutor), to select and apply optical polarizers, to measure the states of polarization of light, and to plot and interpret the state of polarization of light on the Poincare sphere.

Theoretical background: Laboratory protocol provides the students with brief description of the polarization states of light, formalism employed for the description of the polarization states of light, representation of the polarization states of light on the Poincare sphere, optical polarization components and fundamentals of polarimetry. This is complemented with a list of recommended bibliography.

Materials and methods: 1. He-Ne laser, linear polarisation. 2. Two He-Ne lasers, unpolarised. 3. Optical linear polarisers. 4. Wollaston prism (polarization splitter). 5. Optical prisms, various. 6. Precision translation stages. 7. WEB Camera. 8. Computer with access to Internet. 9. "Polarization Tutor" – free specialized software for simulation of states of light polarization (We use free software in order to avoid some problems noted in the Introduction section).

Exercise 1 (Virtual): Studying the internet resources, such as free electronic books, articles, YouTube animations and videos about the polarization of light. Evaluating the relevance and usefulness of the internet-based material.

Exercise 2 (Virtual): Exploring the states of polarization of light.
Procedure and content: 1. Download Polarization Tutor - free simulation software. 2. Vary the horizontal electric field component (x-axis, E_x), vertical electric field component (y-axis, E_y) and phase (Figure 1). Observe how the Stokes parameters change. See different views: x-y plane, ellipse, and 3D. 3. Observe and identify different polarization states (linear vertical and horizontal, right and left circular etc.). 4. Observe the changes in the representation of light on the Poincare sphere, under variation of the state of polarization of light (Figure 2).

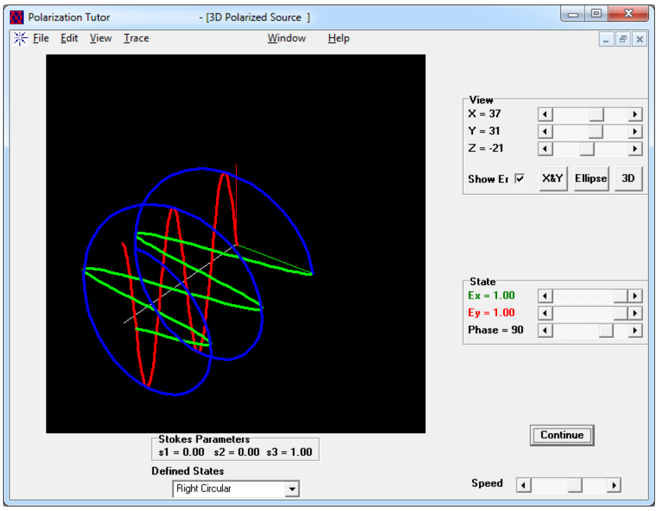

Figure 1: 3D view of the light of right circular polarization; vertical, horizontal, and total components

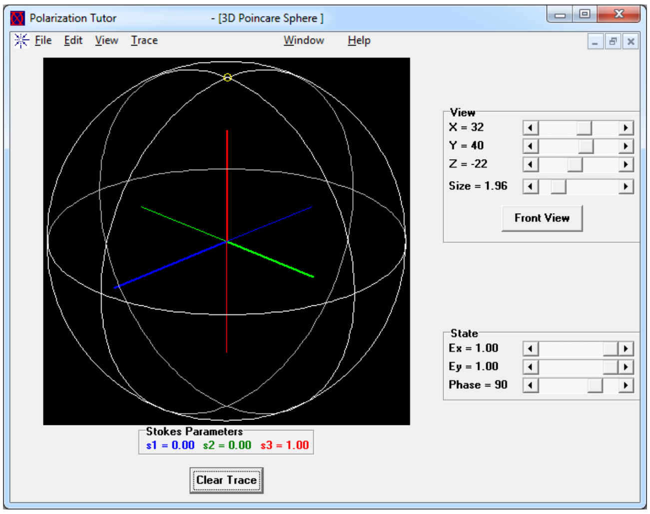

Figure 2: Representation of the right circular polarization of light at the Poincare sphere

Exercise 3 (Real, hands-on exercise): Experimental verification of polarization states.
Procedure and content: 1. Assemble the arrangement shown in Figure 3 by placing the optical elements at proper positions. Use the non-polarized He-Ne laser. 2. Investigate the effect of

each polarizer, by observing the light patterns at the screen. 3. Using the aforementioned material and equipment, assemble the configuration with the screen in between the two linear polarizers. Then investigate the effect of each polarizer. 4. Change the polarized He-Ne laser for a non-polarized He-Ne laser. Repeat the experiments described in 1 and 3. Investigate the state of polarization of light at different points of the arrangement. 5. Plot the state of polarization of light observed in each experiment on the Poincare sphere. 6. Interpret the results of each experiment.

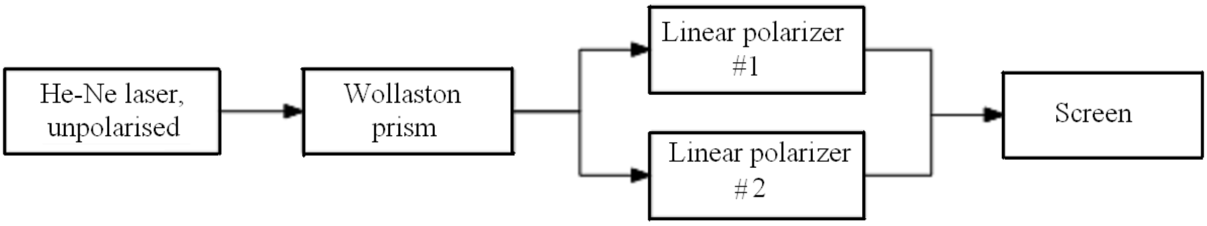

Figure 3: Schematic diagram of the arrangement used to evaluate the effects of polarization of light

Report content:
The report must contain the results of the simulations (numerical data and graphs), the results of hands-on experiments and their interpretation, plus the representation of observed polarization states of light on the Poincare sphere and detailed conclusions about the correlation between the simulated and observed behaviour of polarized light. In addition, the report must contain student's evaluation of relevance, quality and usefulness of the internet-based material that he or she consulted.

Recommended bibliography:
1. G. P. Agrawal, Fiber-optic Communication Systems, 3rd Edition, J. Wiley, 2002. 2. I. P. Kaminow, T. Li, A. E. Willner, Optical Fiber Telecommunications V: Components and Subsystems, 5th Edition, Elsevier, 2008. 3. J. P. Gordon, "PMD fundamentals: Polarization mode dispersion in optical fibers," PNAS 97(9), pp. 4541-4550, 2000. 4. Polarization Tutor, Free software, Agilent Technologies. 5. International Standard IEC 60825-1:1993/A2:2001, Safety of Laser Products. 6. American National Standard for Safe Use of Lasers, ANSI Z136.1-2007. 7. American National Standard for Occupational and Educational Personal Eye and Face Protection Devices, ANSI/ISEA Z87.1-2010. 8. Internet resources: the protocol provides the students with the list of about a dozen of animations and videos relating to particular exercises that are easily available on YouTube. The students have to evaluate the relevance and usefulness of the internet-based material in the final report.

Assessment

We assessed the effect of virtual exercises by comparing the performance of students who did virtual exercises and those of a control group who did not do them. We have found that the students who did the virtual exercises needed significantly less time (by a factor of 2 on average) to perform and interpret the hands-on exercises at the teaching laboratory. These students also got higher scores on a final written exam.
Besides that, we systematically assessed achievement of laboratory educational goals and learning objectives by measuring a student satisfaction by means of a questionnaire that was composed of a set of 22 statements:

1. The learning goals of each exercise are well established.
2. The content of the lab manual is well related to the theoretical class.
3. The theoretical background provided in the laboratory manual is just enough.
4. The laboratory content is well related to real world problems.
5. The instructions of the laboratory manual are clear and sufficient.

6. The recommended literature and internet resources are adequate for the purposes of the laboratory.
7. The simulation software is adequate for the purposes of the laboratory.
8. The experimental setup is adequate for the purposes of the laboratory.
9. There is good correlation between the pre-lab and in-lab exercises.
10. There is good correlation between the content of the simulation and hands-on exercises.
11. The virtual exercises prepared me well for the real exercises.
12. The computer simulations prepared me well for the real exercises.
13. The pre-test helped me to get prepared to the laboratory activities.
14. The post-test helped me to assess the knowledge that I acquired during the laboratory.
15. Writing a report has improved my communication skills.
16. Combining the virtual and real exercises, it was easy to conduct hands-on experiments, as well as to analyse and interpret data.
17. Combining the virtual and real exercises, I gained useful practical skills and theoretical knowledge.
18. At the end of this laboratory, I can identify different states of polarization of light.
19. At the end of this laboratory, I can collect, analyse and interpret data from the polarization simulation software.
20. At the end of this laboratory, I can select and apply optical polarizers.
21. At the end of this laboratory, I can measure the states of polarization of light.
22. At the end of this laboratory, I can plot and interpret the state of polarization of light on the Poincare sphere.

Also, we asked questions about the time spent on different exercises, performance of the instructors etc.

We used the following scale for rating the answers 1 - 22: a) strongly disagree (0), b) disagree (0.25), c) somewhat agree (0.5), d) agree (0.75), e) strongly agree (1).

At the first trial implementation of the Polarization of Light laboratory, the questionnaire average score was 0.54. We analysed the answers and used them as a feedback in the iterative optimization procedure that we noted above. We also took into account the suggestions of the educators. We adjusted the content, sequence and extension of real and virtual exercises, and proportion between them. This was done for several consecutive semesters, until the questionnaire average score reached 0.9. After that, a final version of the protocol has been approved and respective manual edited and sent to print. We also systematically assessed the student learning by applying and comparing the results of pre-tests and post-tests. However, a statistically significant in-depth evaluation has not yet been possible, because the content and instructions changed at each iterative cycle. In the next semester, more data will be collected from the students and academy, and the laboratories will be evaluated in more detail.

Conclusions

Our results indicate that, if properly designed, laboratories with real and virtual exercises are efficacious in achieving principal objectives of engineering laboratories, thus enabling students to become highly efficient engineers. Such laboratories require much less in-person laboratory time than traditional “hands-on” engineering laboratory, because virtual exercises prepare the students reasonably well for the real exercises. The design procedure described in this paper could be helpful for educators of distinct engineering courses (majors), in particular for those who wish to establish new laboratories for optional engineering subjects.

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