AC 2010-2327: WEB-BASED INTERACTIVE VIRTUAL LABORATORIES FOR ELECTRICAL ENGINEERING AND MANUFACTURING EDUCATION

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Web-based Interactive Virtual Laboratories for Electrical Engineering and Manufacturing Education

Abstract

The paper presents a discussion on the characteristics and assessment of the incorporation of multilayered, highly interactive, simulation-based, integrated, and adjustable virtual laboratories for engineering and technology education in the areas of telecommunications and manufacturing. These labs are designed to enhance the understanding of technical concepts and underlying fundamental principles, as well as to help students master certain performance-based skills online. These virtual labs can be combined with related hands-on exercises to form hybrid laboratories to be delivered via either online or on-site teaching methodologies.

Virtual labs contain expandable sets of virtual experiments (VE), as well as relevant learning resources and assessment activities. Each VE focuses on a particular task and comprises such components as highly interactive main and auxiliary Java or Flash simulations, specific learning objectives, an experiment description, step-by step instructions for students, a worksheet, built-in lessons and technical manuals to facilitate "just-in-time" learning, embedded assessments, and other resources. An easy-to-use tool that enables instructors with no-programming experience to produce appealing and pedagogically sound interactive virtual activities is available as well. An example of a multilayered virtual lab on optical sensors is shown in Figure 1. Presented materials have been developed with partial support from the NSF.

I. Introduction

Computer simulation plays an important role in engineering programs by providing a learning platform that provides an efficient and effective way of teaching complex and dynamic engineering systems. A simulation-based teaching environment enables students to acquire experience and evaluate their previous results.[1]

Phenomenal growth in a wide spectrum of new and emerging technologies has led to increased demand for engineering and engineering technology graduates who understand the fundamental principles behind contemporary state-of-the art technologies, but also exhibit analytical, problem solving, and expert thinking skills. To address these growing industry demands, new technological tools and teaching methodologies need to be incorporated into engineering and engineering technology curricula. However, incorporation and implementation of state-of-the-art technological tools and equipment require considerable time and financial resources. Keeping curricula and labs current with the rapid change of technology poses another challenge for faculty. Engineering and engineering technology professors can address some of these challenges by using simulation and virtual experiments.[2] In addition to cost savings, simulation offers a number of other advantages, including the following:

- Allowing the user to modify system parameters and observe the outcomes without any harmful side effects.
- Eliminating component or equipment faults that affect outcomes.

- Supporting users progress at their own pace in discovery and understanding of concepts and issues.
- Enhancing the presentation of "dry" concepts by integrating theory and practice.

However, simulation is not a panacea for the problems of keeping curricula current, as it has some limitations too; for example, the use of software simulations of physical entities, such as electronic circuits, denies the user a chance to physically handle the circuit components or construct the circuit.[3] On the other hand, simulation has another major advantage in that a simulation is task- and learner-neutral; it models an object/system construction and operation or learning situation. Within simulation functionality, there are no restrictions on the student's actions. Thus, the advantages of simulation outnumber its disadvantages. In the areas of electrical and electronics engineering and technology and manufacturing technology, there are numerous uses for simulation, starting from simulation of electric circuits to complex tasks such as electromagnetic fields, networking, computer circuits, game programming, electron flow in semiconductors, and manufacturing process control and monitoring.

II. Incorporation of Virtual Labs and Simulation Experiments in Electrical Engineering and Manufacturing Education

The core components of all virtual labs discussed in this paper involve highly interactive and complex Java and Adobe Flash simulations using HTML/XML code and scripts. State-of-the-art graphical interfaces and realistic models of the simulations enable students to perform experiments that precisely imitate calibration and operation of optical sensors used in production lines. Allen-Bradley sensors were used as a prototype for these simulations. The set of the virtual labs, further described below, enables students to explore and compare three different optical sensing methods.

The virtual laboratories support technologies that can provide instructional opportunities in many modes, whether at a campus or school (traditional on-site teaching), at home (warm-ups, post-class tasks, or self-learning), in a corporate setting, or through distance learning. Realistic simulations enable learners to:

(1) Calibrate sensors and targets and observe how each parameter impacts the system performance.
(2) Analyze constraints between relevant parameters.
(3) Run "what if" scenarios to minimize risk
(4) Acquire data from virtual experiments for detailed analysis and comparison to actual operating conditions in a theory-to-practice approach (narrowing the understanding gap between theory and practice).

There are clear differences between a simulation, virtual experiment, and virtual laboratory**.** A simulation is task- and learner-neutral, i.e., it models a process, an object's or system's construction and operation, or a learning situation. Within simulation functionality, there are no restrictions on the user's actions. In contrast with a simulation, a virtual experiment is focused on a particular task. In addition to simulation, the virtual experiment includes specific learning objectives, scenario/assignment worksheet, assessment tool, and, most importantly, step-by-step instructions for students. Virtual experiments may also include optional auxiliary simulations, prerequisites, excerpts from interactive lessons and technical manuals, quizzes, and online reference resources. The student is expected to follow a set of step-by-step instructions to accomplish a particular educational assignment. Figure 1 shows the virtual experiment designed to enable students to explore the Diffuse Optical Sensing Method in detail.

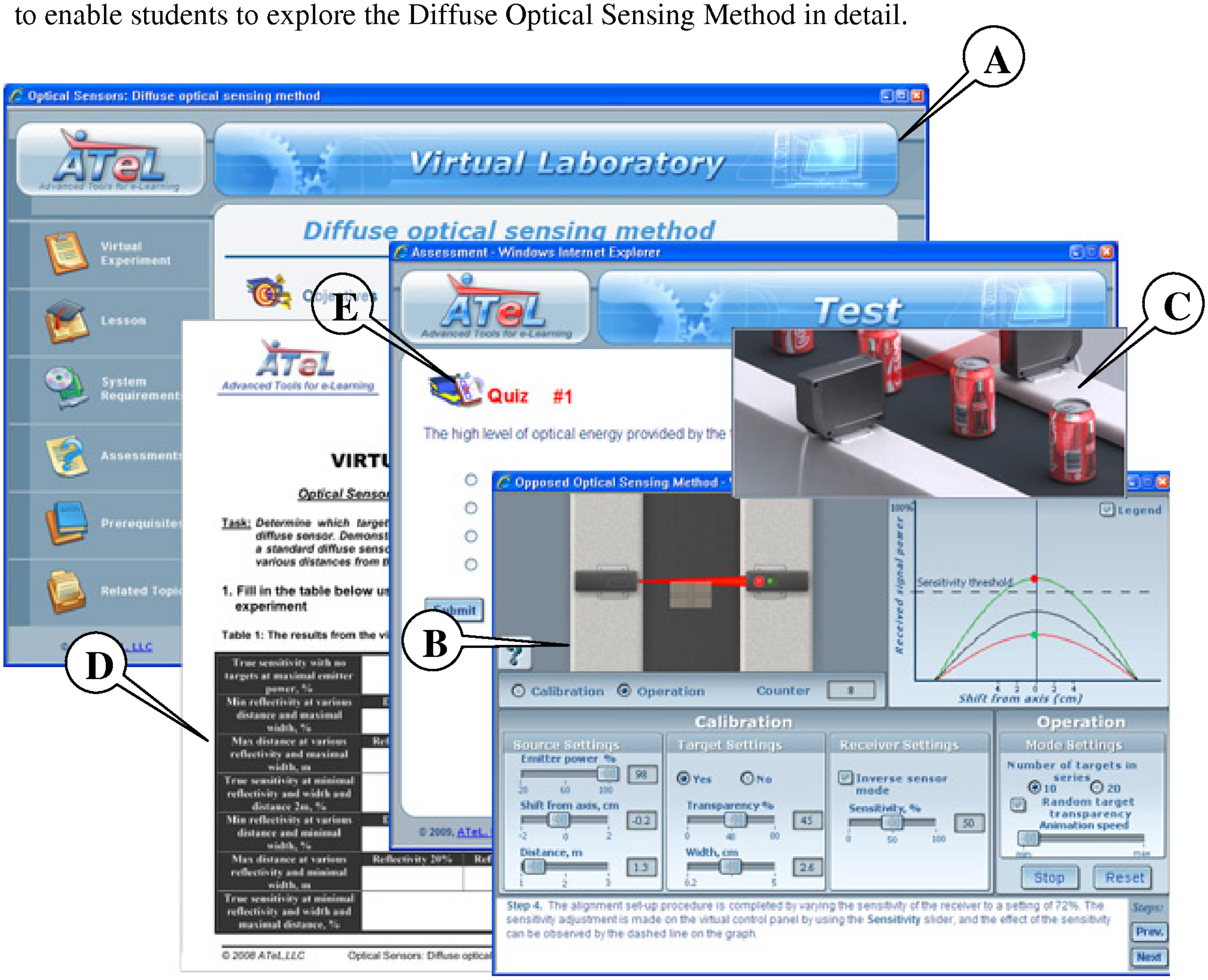

Figure 1: Screenshots of the virtual laboratory *Diffuse Optical Sensing Method*

By changing the system and target object parameters, students can learn how the size of a target can affect delectability and when target reflectivity is sufficient for detection by a standard diffuse sensor. They can also observe the effect of making sensitivity adjustments for objects at various distances from the target.

The main menu of the experiment (A in Figure 1) provides students with access to embedded resources, such as evaluation quizzes, lessons, and a system diagnostic tool.

First, students are presented with the specific learning objectives and experiment description. Then the simulation runs with step-by-step instructions for students underneath (B). The student is expected to follow these instructions to accomplish the assignment.

From within the experiment students may be asked to open a worksheet (D) to record acquired data and answer questions. The worksheet can be an Excel, .doc, or .pdf file formats and can be entered either online or manually on the printed-out worksheet. In addition the virtual lab includes control quizzes (E) that can be answered either online or with pen and paper.

The second lab, Opposed Optical Sensing Method, (also known as the thru-beam method) comprises a set of virtual experiments which help students to explore how this method is used for monitoring items on a production line and what parameters affect its performance. In this lab the light source—referred to as the transmitter or emitter—is aligned with the receiver, forming a beam which is broken by the target. The thru-beam sensors provide a high level of optical energy. Therefore, they are able to overcome lens contamination and/or misalignment, and they are capable of the longest scanning range of all optical methods. To fulfill the experiment assignment, students have to apply the proper alignment procedure to calibrate the sensor. They can vary such parameters as emitter power, alignment, and distance between light source and receiver; change size and transparency of the target; and make sensitivity adjustments. The diagram at the right in Figure 2 illustrates the impact of each parameter and the detection capabilities of the sensor.

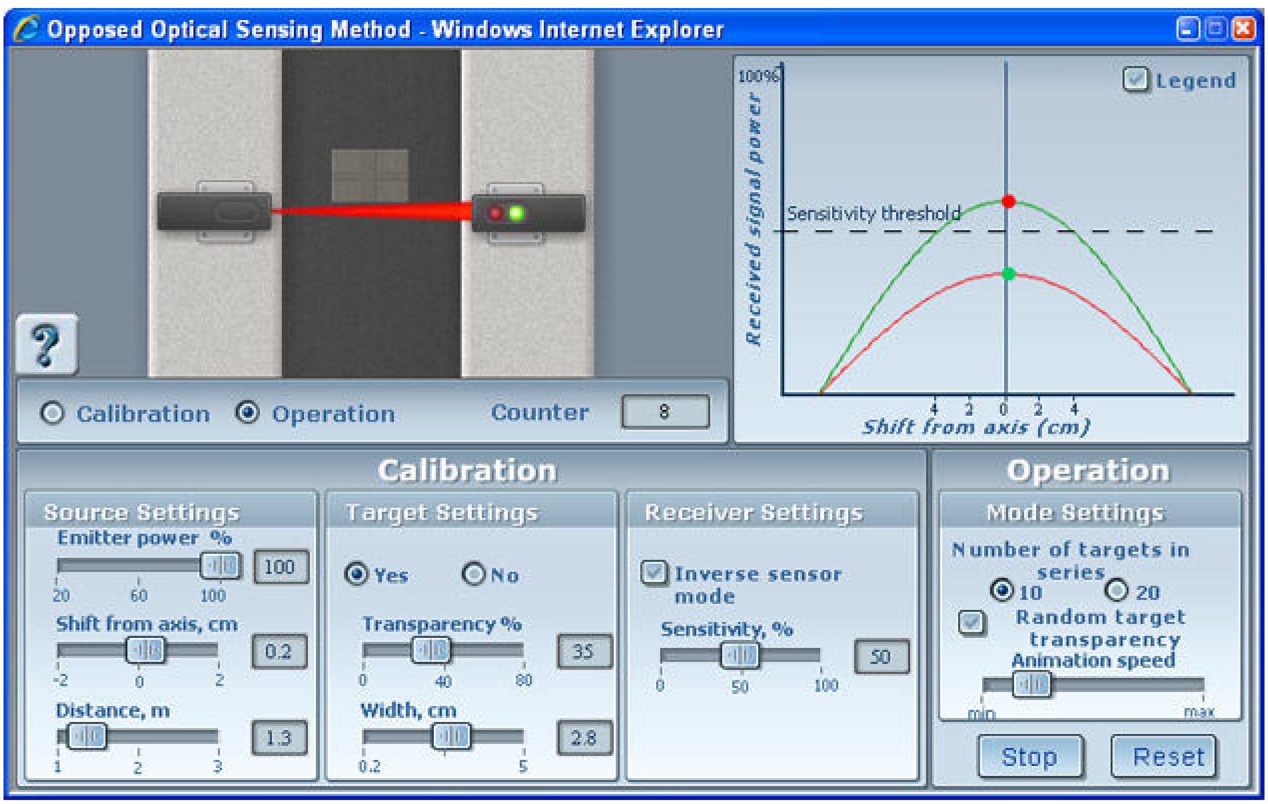

Figure 2. A screenshot of the virtual laboratory *Opposed Optical Sensing Method*

The third lab, Retro-Reflective Optical Sensing Method, was designed to enable students to explore this method and compare it to two other methods, to perform proper sensitivity adjustments, and to observe how these adjustments affect the detection capabilities of the retro-reflective sensor at various distances from the target. The lab also enables them to determine how various targets made from different types of materials at various sizes affect the detectability of the sensor. Figure 3 provides screenshots of this virtual laboratory. [4 & 5]

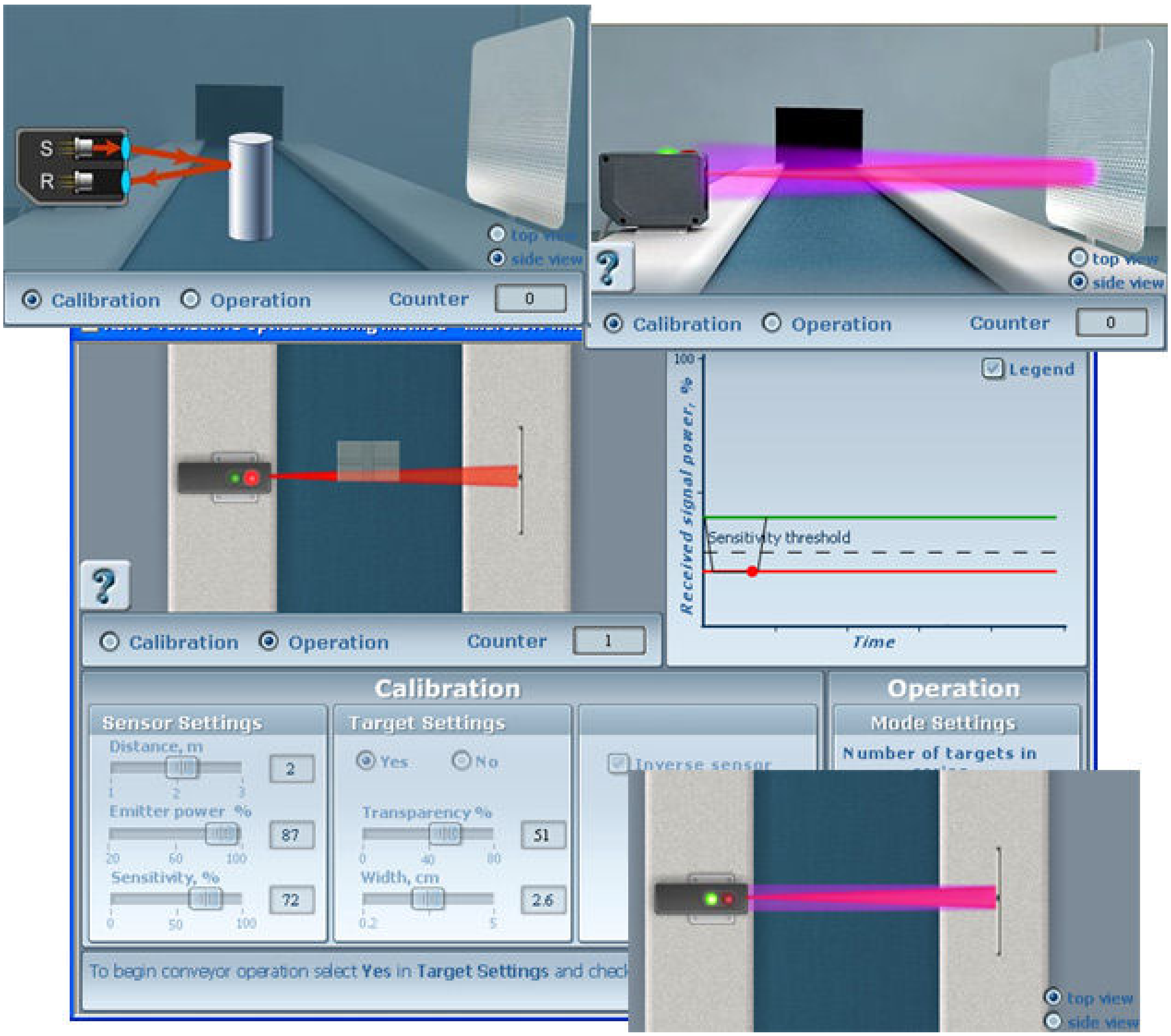

Figure 3. Screenshots of the virtual laboratory Retro-Reflective Optical Sensing Method

Virtual labs can also be linked with auxiliary simulations that help students explore the design and operation of the device components and learn underlying fundamental principles.

Screenshots presented in Figure 4 enable students to understand the design and operation of a Light Emitting Diode (LED) used as a light source in the optical sensors.

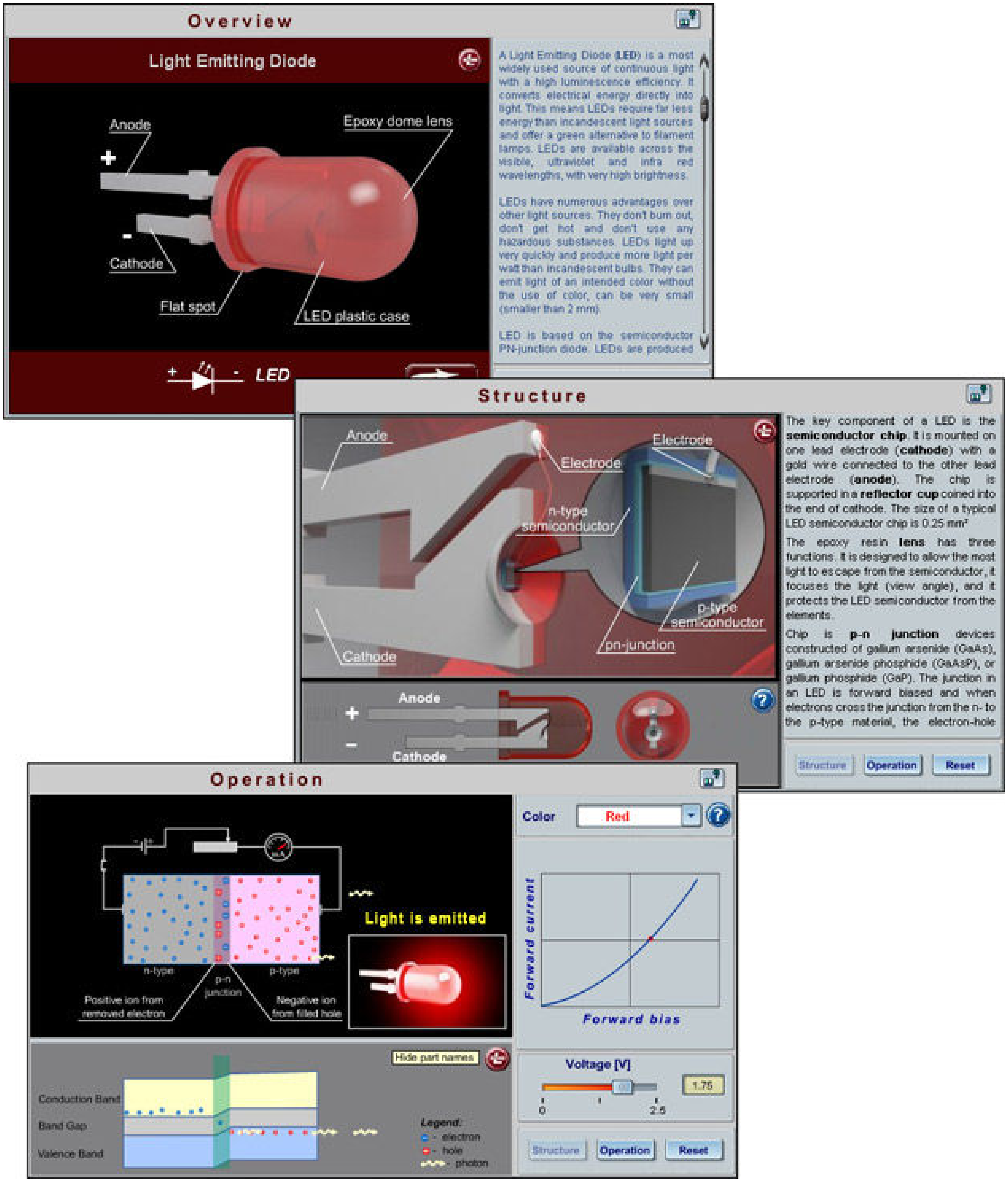

Figure 4. Screenshots of the simulation *Light Emitting Diode*

Some virtual laboratories facilitate a multilayered instructional approach. A multilayered virtual experiment is comprised of several interacting simulations. The main purpose of such an experiment is to bridge technical skills and the scientific knowledge base. An example of a multilayered experiment is presented in Figure 5. The lab enables students to achieve the following tasks:

- Assemble a Laser Diode to Fiber Coupling using different types of diodes, lenses, and fibers.
- Study the impact of various parameters on the coupling losses and collect virtual data.
- Explore the design and operation of the system components.
- Learn underlying fundamental principles.

Appendix A presents some of these experiments.

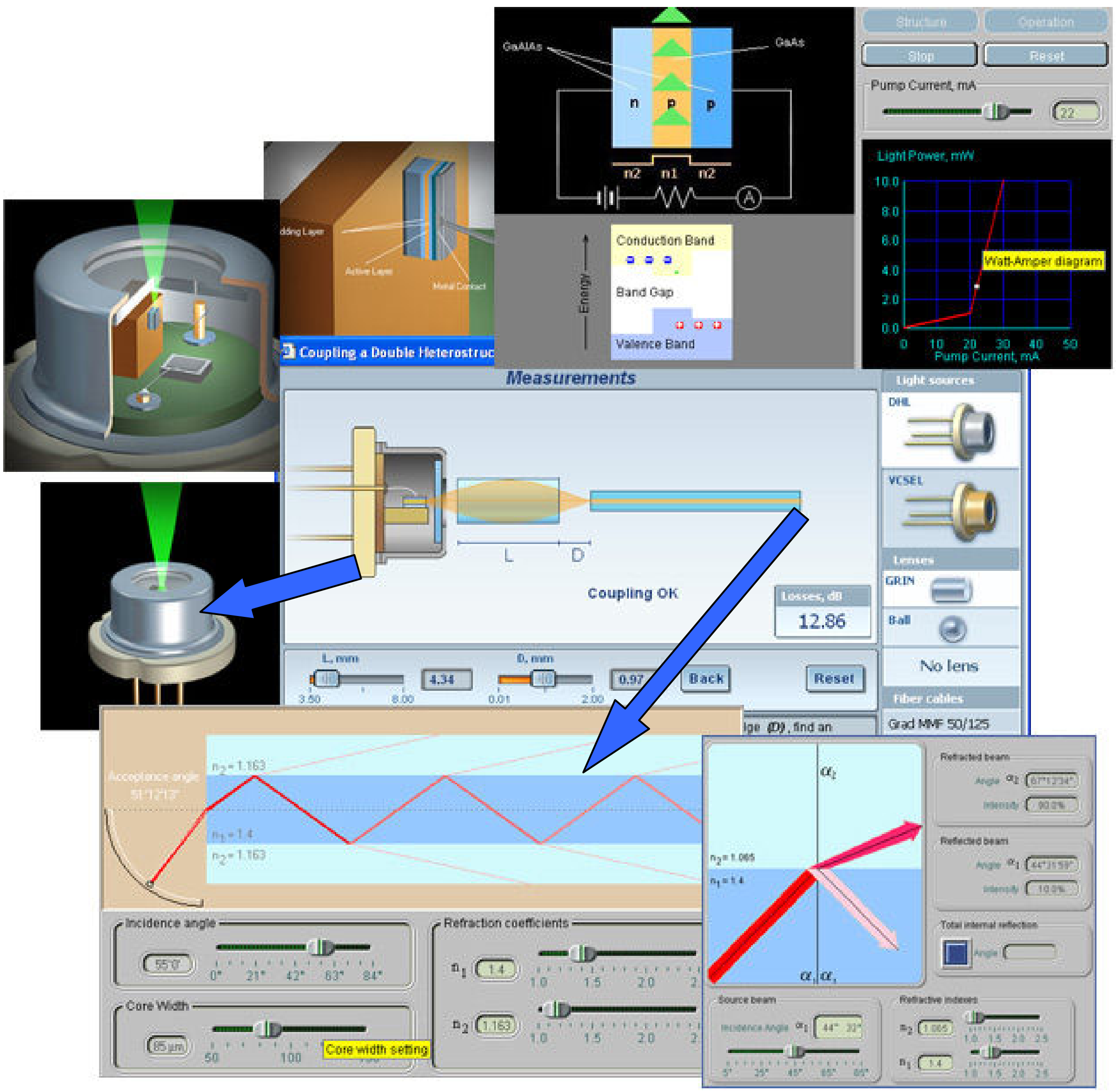

Figure 5: Laser Diode (LD) coupling to an optical fiber system.

III. Assessment of the Incorporation of Virtual Experiments and Labs into Wireless and Broadband Communication Courses

A number of simulations and virtual experiments based on ALSuite software have been incorporated into the Wireless Communications Engineering course (EET-380) and Broadband Communications course (ECET-425) at DeVry University, Addison, IL. (Sample experiments are presented in Appendix A). The students' assessments of ALSuite software-based experiments reveal that these simulations and virtual experiments provide a systems overview, and help students develop a good conceptual database. Students also believe that they are easy to use and their effectiveness is enhanced by interfacing them with external systems in order to provide a hand-on experience for users. Assessment results for the fiber optic experiments are presented in Appendix B.

Overall, ATeL simulation software proved to be very effective in implementing the laboratory objectives of the Wireless and Broadband Communications courses. Based on student feedback and assessment results, the software was more effective in promoting student learning when it was used in a hybrid (hands-on and simulation) mode. This fact is also supported by the findings of a recent research study conducted at DeVry University in Addison, Illinois. The study was designed to analyze the use of computer simulation design methods on student learning. The findings of the study suggest that simulation is effective when it is followed by hands-on activity to reduce the gap between theoretical knowledge and practical expertise. Students should be first exposed to theoretical concepts in the simulation environment, and then required to perform a hands-on activity. This approach ensures progressive and sequenced learning in the form of scaffolding, an aspect of cognitive apprenticeship. Furthermore, the findings suggest that in order to enhance student learning, the instructional design should consider three approaches. The first is to use simulation-based experiments in the first half of the course, followed by hands-on experiments in the second half (sequential design). The second approach is simultaneous use of simulation and hands-on experiments (parallel design). And the third approach is to use simulation and hands-on in an alternating mode (mixed design). All three approaches support a combinational approach or hybrid instructional delivery.[6]

Acknowledgement: The authors appreciate the assistance provided by Mr. Terry Bartelt, a retired electromechanical instructor at Fox Valley Technical College, who helped us in developing scenarios for simulations and virtual labs.

References:

1. Nahvi, M. *Dynamics of student-computer interaction in a simulation environment: Reflections on curricular issues.* IEEE Proceedings of Frontiers in Education, 1383-1386. (1996)
2. Cherner, Y.E., A. Karim, A. Khan, V. Rubanchik, and G. Mullett. *Using Simulation-based Hybrid and Multilevel Virtual Labs for Fiber Optics, Photonics, and Telecom Education,* in Proc. ASEE 115th Annual Conference, Pittsburg, PA (2008).
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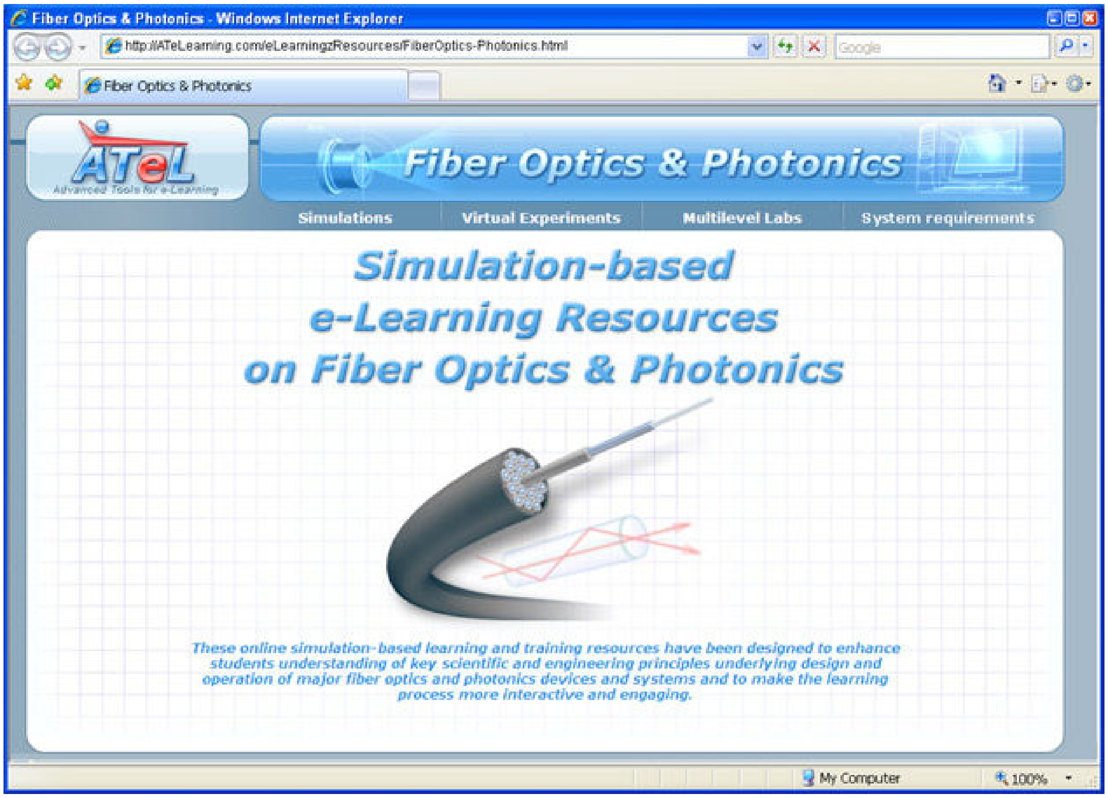
5. Bartelt, T. *Lab Manual for Bartelt's Instrumentation and Process Control*, Delmar Learning, 2006.

6. Taher, M. *Integration of Computer Simulation into Traditional Lecture-Lab Activities: Impact of Using Computer Simulation on Student Learning in a Technology-Based Course* (doctoral dissertation), Northern Illinois University, DeKalb, IL (2009)

The presented materials were developed with partial support from the National Science Foundation.

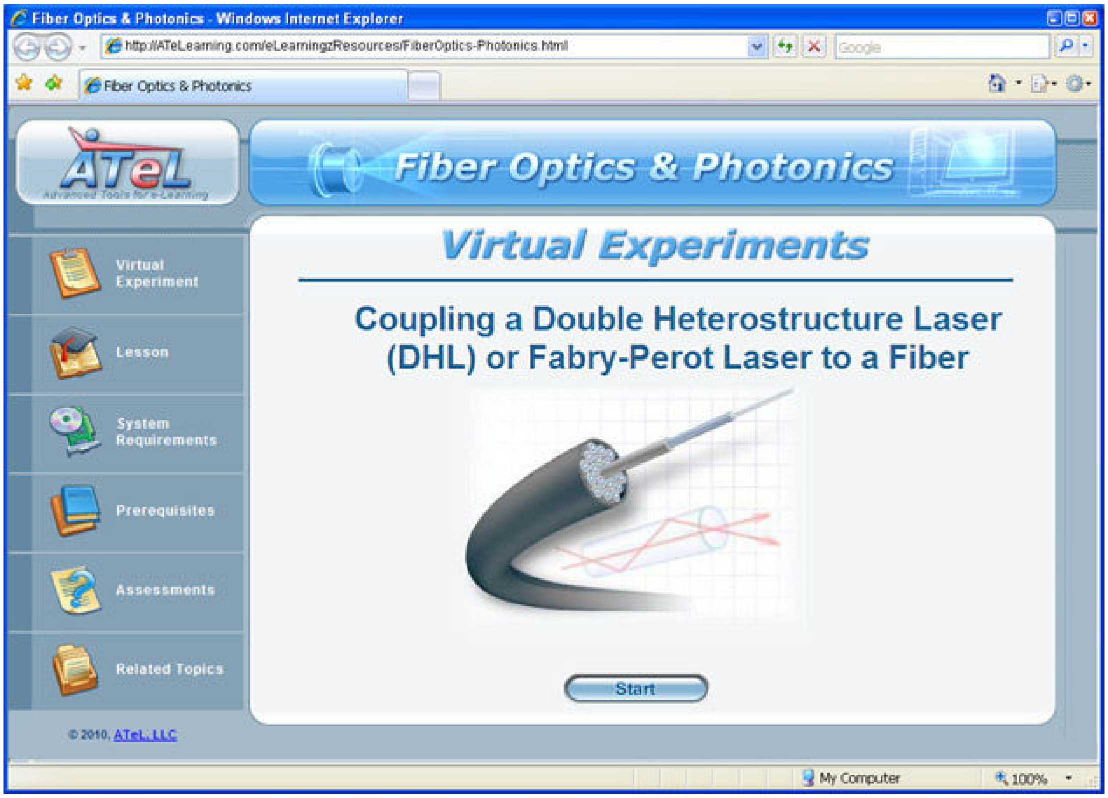
Appendix A

Sample Experiments



Experiment 1:

Coupling a Double Heterostructure Laser (DHL) or Fabry-Perot Laser to a Fiber

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Coupling a Double Heterostructure Laser (DHL) or Fabry-Perot Laser to a Fiber
Description
Modern optical communication systems use semiconductor laser diodes (LD) for transmitting light through optical fibers. Tiny laser diodes can easily be configured for coupling to the small-diameter cores of optical fibers. For this reason, laser diodes are widely utilized in fiber optic communication systems.
Efficient coupling of laser diodes to optical fibers using micro-optic components is required in almost every area of optical communications. Maximum power transfer is especially critical in long-haul fiber transmission systems.
This virtual laboratory consists of three parts.
Part 1
Part 2
Part 3
Assessment
In order to complete this lab you have to accomplish all three parts and then pass the assessment test. Click the Part 1 button to begin.
Back
Exit
Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
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Coupling a Double Heterostructure Laser (DHL) or Fabry-Perot Laser to a Fiber
Part 1
In this part you will couple the laser diode to each type of fiber without the use of a lens. Your results will serve as a control, so that, in Parts 2 and 3, you can see how much improvement can be made by using a lens with each type of fiber. Click the Launch simulation button to continue or Back to return to the previous page. Click the link below to print out a worksheet for the experiment.
Print PDF worksheet
Back
Simulation 1
Simulation 2
Exit
Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
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Virtual assembling a fiber pigtail:


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Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
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System Assembly
Select fiber cable type and press "Insert" button
L, mm
D, mm
3.50
8.00
0.01
2.00
Back
Insert
Reset
Step 3. Select Grad MMF 50/125 from the list of fibers and click Next twice.
Light sources
DHL
VCSEL
Lenses
GRIN
Ball
No lens
Fiber cables
Grad MMF 50/125
Grad MMF 62.5/125
Step SMF 8.3/125
NZDSF, DSF 10/125
Back
Simulation 1
Simulation 2
Exit
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Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
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System Assembly
To see optical diagram press the "Next" button
L, mm
D, mm
3.50
8.00
0.01
2.00
Back
Next
Reset
Step 4. Press the Next button to switch the simulation into the Measurement mode.
Light sources
DHL
VCSEL
Lenses
GRIN
Ball
No lens
Fiber cables
Grad MMF 50/125
Grad MMF 62.5/125
Step SMF 8.3/125
NZDSF, DSF 10/125
Back
Simulation 1
Simulation 2
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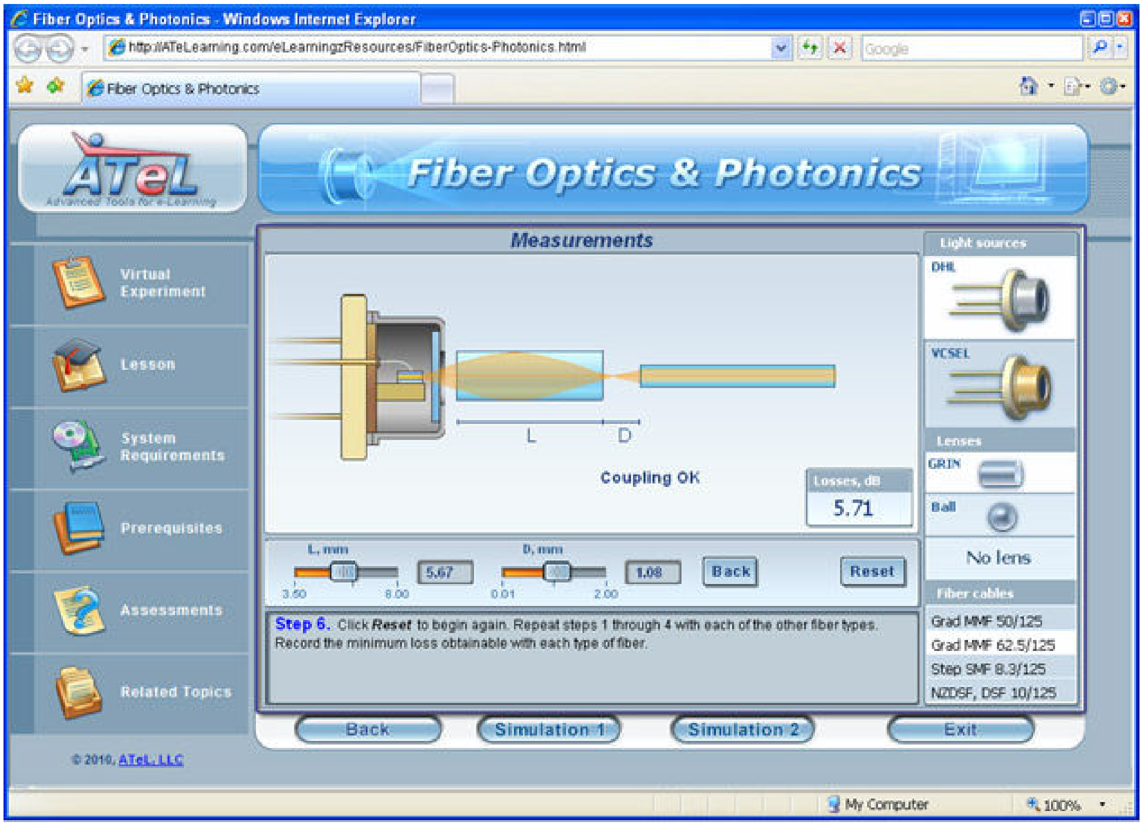
Examining the assembled pigtail:



Experiment 2: ***<u>Study of Dispersion</u>***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Dispersion laboratories
Description
This lab will introduce the two main constraints on transmission distance in fiber-optic systems: loss and dispersion. Loss is a function of the type of fiber and the wavelength used. Dispersion depends on both of these, as well as the source linewidth and the data rate.
This virtual laboratory consists of three parts.
Part 1
Part 2
Part 3
Assessment
Back
Exit
Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
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Dispersion laboratories
Part 1
LED (light-emitting diode) sources are almost always used with multimode fiber. We shall use two types of graded-index multimode fiber, with core diameters of 50 and 62.5 µm. LEDs are usually used with relatively low data rates over short distances, typically at a wavelength of either 0.85 µm or 1.31 µm.
Click the Launch simulation button to continue or Back to return to the previous page.
Back
Launch simulation
Exit
Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
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Prerequisites
Assessments
Related Topics
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Fiber Cables
Grad MMF 50/125
Grad MMF 62.5/125
Step SMF 8.3/125
NZDSF, DSF 10/125
Dispersion Limited Length
Light Sources
LED
DHL
SM DHL
Wavelength, μm
0.85 1.31 1.55
Data Rate
10
x10 x100 x1000
MHz
Mode Dispersion
414 ps/km
Chrom. Dispersion
-1.0 ps/(nm*km)
Band Width
1050 MHz*km
Cable Losses
0.66 dB/km
Reset
Start
intensity connection
Attenuation Limited Length
Step 1. Select a LED light source at a wavelength of 1.31 μm. Click the link below to print out a worksheet for this experiment.
Print out a worksheet
Next
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Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
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Fiber Cables
Grad MMF 50/125
Grad MMF 62.5/125
Step SMF 8.3/125
NZDSF, DSF 10/125
Dispersion Limited Length
105 km
Light Sources
LED
DHL
SM DHL
Wavelength, μm
0.85 1.31 1.55
Data Rate
10
x10 x100 x1000
MHz
Transmission length is 45.4 km, and is determined by attenuation limited length
Mode Dispersion
414 ps/km
Chrom. Dispersion
-1.0 ps/(nm*km)
Band Width
1050 MHz*km
Cable Losses
0.66 dB/km
Reset
Stop
intensity connection
Attenuation Limited Length
30 dB
45.4 km
Step 4. Note on the worksheet the linewidth Δ λ of the source. This value is displayed in the right panel Light Sources. Write into the table of your worksheet the dispersion and loss of the fiber. These are shown in the left panel.
Prev.
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Dispersion laboratories
Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
Part 3
Single-mode laser diodes (SM DHL) are used mainly for dense wavelength-division multiplexing (DWDM) systems, where several optical carriers are used, each independently modulated with a high-speed digital bitstream. Typical data rates are 2.5 Gb/s to 10 Gb/s per wavelength, though some systems use up to 40 Gb/s per wavelength. These systems operate in the 1.55 μm region, so that erbium-doped fiber amplifiers (EDFAs) can be used to compensate for fiber losses. For these systems, dispersion is more critical than loss, because EDFAs cannot compensate for dispersion. Narrow source linewidth is needed to reduce dispersion and to allow close spacing of carriers, which are typically separated by 100 GHz or about 0.7 nm at a wavelength of
Back
Launch simulation
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Virtual Experiment
Lesson
System Requirements
Prerequisites
Assessments
Related Topics
Fiber Cables
Grad MMF 50/125
Grad MMF 62.5/125
Step SMF 8.3/125
NZDSF, DSF 10/125
Dispersion Limited Length
0.8 km
Light Sources
Data Rate
515
MHz
x10 x100 x1000
LED
Δλ=35 nm
DHL
Δλ=2 nm
SM DHL
Δλ=0.1 nm
Wavelength, μm
0.85 1.31 1.55
Transmission length is 0.8 km, and is determined by dispersion limited length
Last mile connection
Attenuation Limited Length
Mode Dispersion
973 ps/km
Chrom. Dispersion
-4.2 ps/(nm*km)
Band Width
450 MHz*km
Cable Losses
0.52 dB/km
Reset
Start
Step 7. Experiment with the data rate until you find a rate at which the distance is limited by loss and dispersion simultaneously. You will have to reset the system each time you make a change. Record the maximum distance and optimal Data Rate on the worksheet.
Prev.
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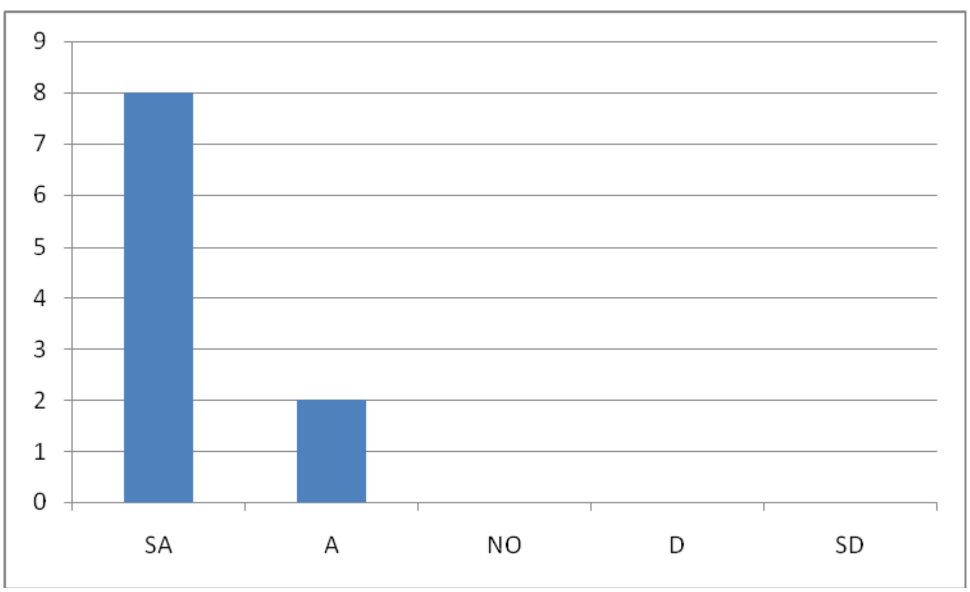
Appendix B

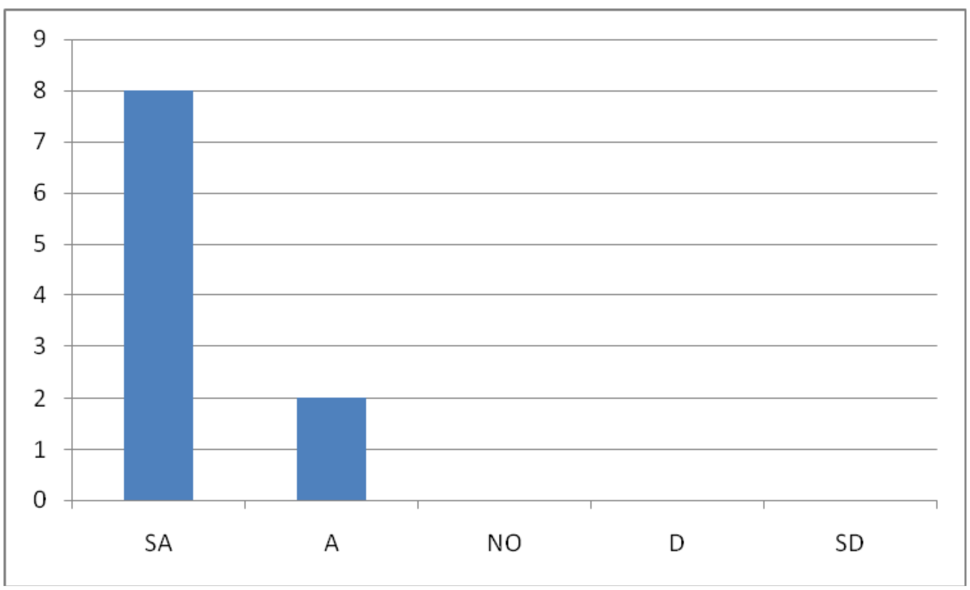
Assessment Results for the Hybrid Experiment (Fiber Optic Attenuation Mechanisms)

ECET-425 Broadband Communications

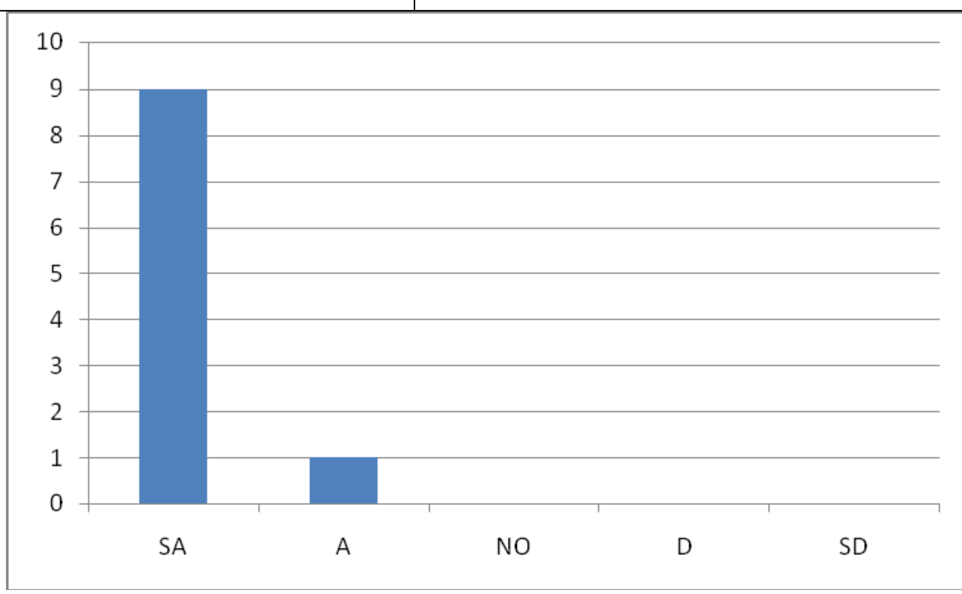
Part-1 Hands-On Experience	
1. Instructions for this part of experiment were clear and easy to understand.	5. Strongly Agree ________ 4. Agree ________ 3. No Opinion ________ 2. Disagree ________ 1. Strongly disagree _______ If answered 2 or 1, what improvement would you recommend: ____ ____ ____ ____



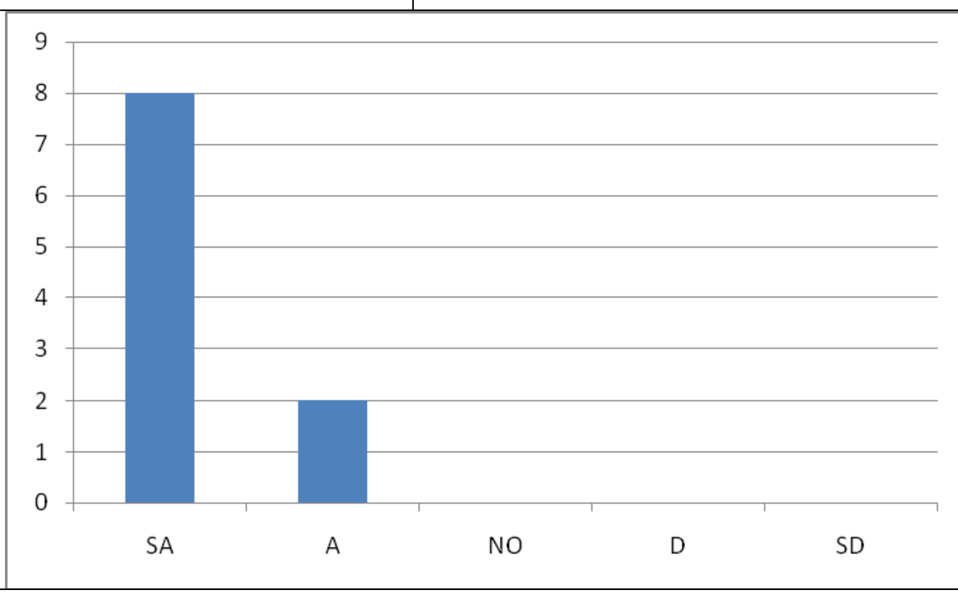
2. Did this experiment help you better understand the concepts of attenuation mechanism and loss measurement techniques in the optical fiber?	5. Strongly Agree ________ 4. Agree ________ 3. No Opinion ________ 2. Disagree ________ 1. Strongly disagree _______ If answered 2 or 1, what improvement would you recommend: ____ ____ ____ ____



3. Did you accomplish your learning objectives (learn how to measure cable and bending loss in fiber)?	5. Strongly Agree _______ 4. Agree _______ 3. No Opinion _______ 2. Disagree _______ 1. Strongly disagree ______ If answered 2 or 1, what improvement would you recommend: __________________________________ __________________________________ __________________________________ __________________________________



Part-2 Simulation Experience	
4. Instructions for this part of experiment were clear and easy to understand.	5. Strongly Agree _______ 4. Agree _______ 3. No Opinion _______ 2. Disagree _______ 1. Strongly disagree _______ If answered 2 or 1, what improvement would you recommend: ____________________________________ ____________________________________ ____________________________________ ____________________________________



<table>
<tr>
<td>5. Did this experiment improve your understanding of the theoretical concepts about attenuation mechanism in optical fibers?</td>
<td>5. Strongly Agree ________
4. Agree ________
3. No Opinion ________
2. Disagree ________
1. Strongly disagree _______

If answered 2 or 1, what improvement would you recommend:

____
____
____
____</td>
</tr>
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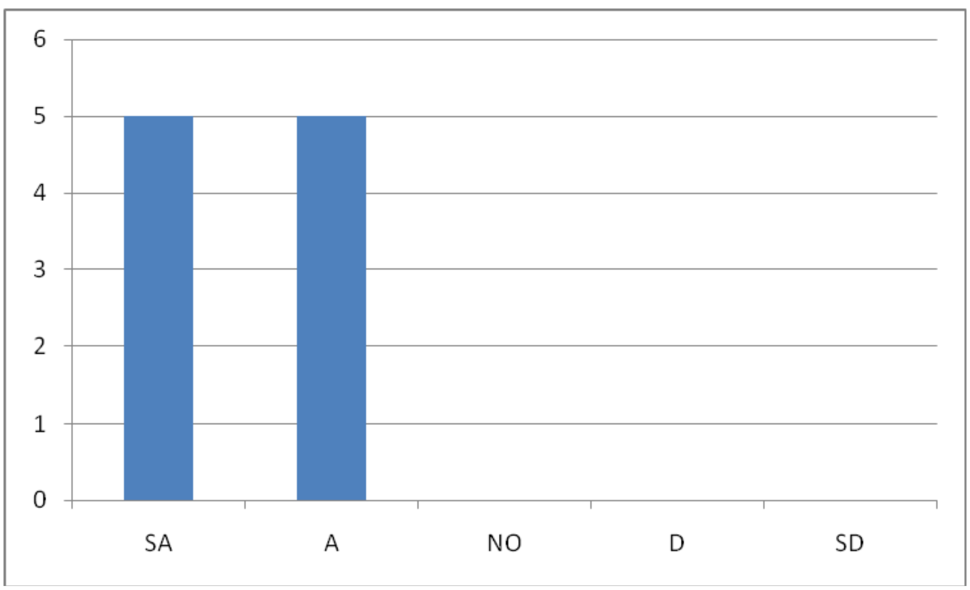
<td colspan="2">
</td>
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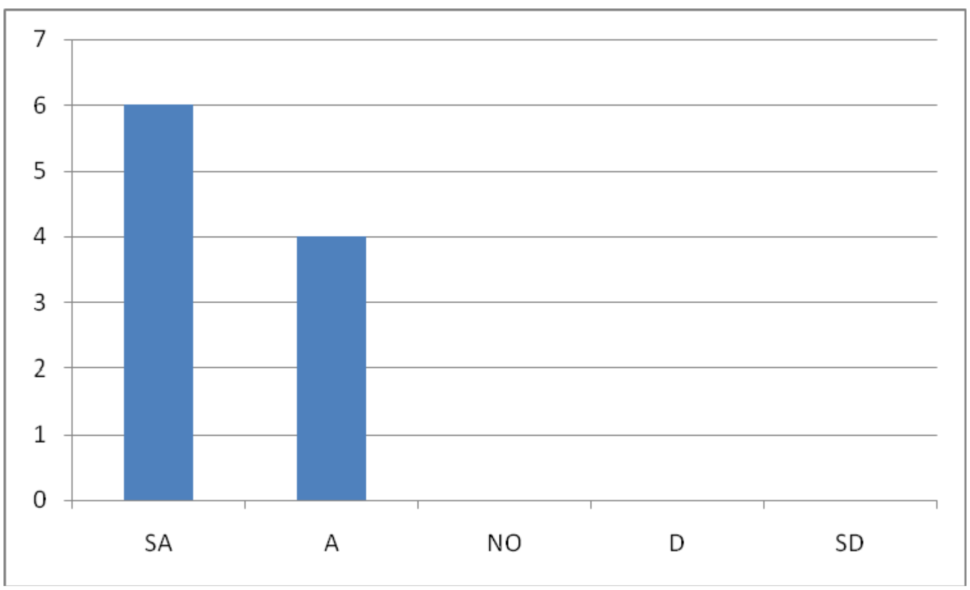
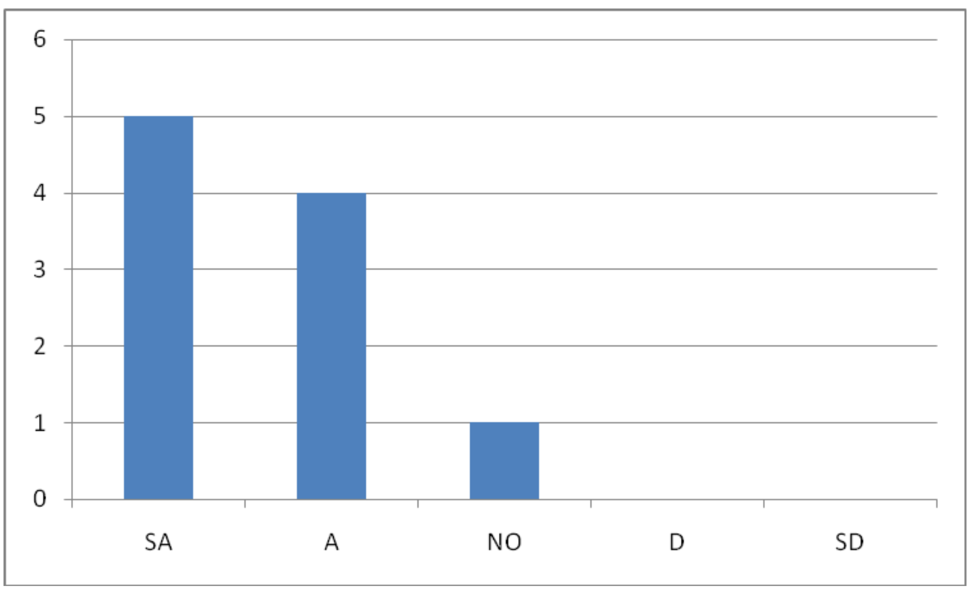
</table>

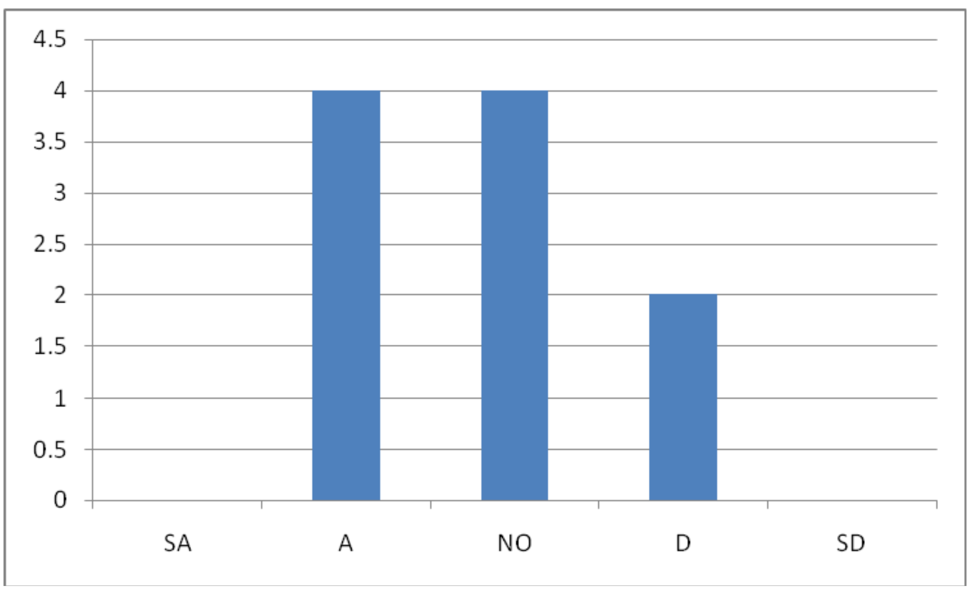
6. Combination of Hands-on experiment and simulation & virtual experiment enhanced my understanding of the theoretical concepts.	5. Strongly Agree _______ 4. Agree _______ 3. No Opinion _______ 2. Disagree _______ 1. Strongly disagree ______ If answered 2 or 1, what improvement would you recommend: ____ ____ ____ ____



Overall learning Experience	
7. I learn more with hand-on approach.	5. Strongly Agree ________ 4. Agree ________ 3. No Opinion ________ 2. Disagree ________ 1. Strongly disagree _______ If answered 2 or 1, what improvement would you recommend: ____ ____ ____ ____



<table>
<tr>
<td>8. I learn more with simulation approach.</td>
<td>5. Strongly Agree _______
4. Agree _______
3. No Opinion _______
2. Disagree _______
1. Strongly disagree _______

If answered 2 or 1, what improvement would you recommend:
____
____
____
____</td>
</tr>
<tr>
<td colspan="2">

• Add more explanation of various steps and processes
• Add more cause and effect information
• Add more mathematical formulas</td>
</tr>
</table>

9. I learn more with the combination of hands-on and simulation approaches.	5. Strongly Agree _______ 4. Agree _______ 3. No Opinion _______ 2. Disagree _______ 1. Strongly disagree ______ If answered 2 or 1, what improvement would you recommend: ______________________________________ ______________________________________ ______________________________________ ______________________________________