AC 2011-2684: USE OF ADAPTABLE SIMULATION-BASED VIRTUAL LABORATORIES FOR TEACHING ALTERNATIVE ENERGY AND ENERGY CONSERVATION IN ENGINEERING & TECHNOLOGY PROGRAMS

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Use of Adaptable Simulation-based Virtual Laboratories for Teaching Alternative Energy and Energy Conservation in Engineering & Technology Programs

Abstract

The paper presents multilayered highly interactive simulation-based integrated and adjustable virtual laboratories for engineering and technology education focusing on alternative energy and energy conservation courses. 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 in an online environment. The simulations and labs also help students explore the economic aspects of using alternative energy devices. The virtual labs can be used in conjunction with the related hands-on labs to form the hybrid laboratories.

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 of Flash simulations, specific learning objectives, experiment descriptions, step-by step instruction for students, worksheet, built-in lessons and technical manuals to facilitate "just-in-time" learning, embedded assessment 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 a solar water heating system is shown in Figure 1

Realistic simulations visualize processes occurring in the devices and enable students to observe the physical processes at different levels (from macroscopic to subatomic), analyze constraints between physical parameters, compare actual and virtual data, and much more. The simulation and virtual experiment materials presented in this paper have been developed with the partial support from the NSF.

I. Introduction

Today, with many colleges offering distance education programs in engineering and technology, the demand for truly interactive simulation-based online labs is on the rise. An interactive lab is capable of partially substituting or extending conventional hands-on laboratories. Virtual labs have great potential for facilitating the active learning mode and transforming "e-learning by reading and watching" into a more efficient "learning by doing". They also provide 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 interest in the renewable energy and energy conservation technologies has led to an increased demand for engineering and engineering technology graduates who are not only skilled in installation, maintenance of equipment used in theintelligent infrastructure systems required to generate and supply electricity in commercial and residential applications, but who also understand the fundamental principles underlying the design and operation of alternative systems. However, incorporation of such learning processes and the state-of-the-art technological tools and equipment requires 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:

- 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.

Highly interactive and complex Java and Adobe Flash simulations, with associated HTML/XML parts and scripts, are the core components of educational tools discussed in this paper. State-of-the-art graphical interfaces and realistic models of the simulations provide an "insight" view of the processes and help users become familiar with the internal structure and operation of complex engineering systems and devices.

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

(1) Observe the physical processes insightfully at different levels of detail (micro and macro)
(2) Analyze the constraints between relevant parameters (relationships)
(3) Push these parameters beyond normally allowed values to simulate infrequent operating conditions or casualty situations (cause and effect)
(4) Run “what IF” scenarios (minimizing risk)
(5) Acquire data from virtual experiments for detailed analysis and comparison to actual operating conditions in a theory-to-practice approach. (This narrows the understanding gap between theory and practice.)

Realistic-looking simulations can help students conceptualize the physical principles underlying the operation of an actual device.

Figure 1. Screenshots of a solar powered house simulation.

The first screen of the simulation (shown in the left) enables students to vary the geographical location of the house, seasons, time of day and weather conditions and to observe how these factors affect the system power output. The second screen (on the right) helps students to explore major components of the solar power system. The controls and meters allow them to collect and analyze such data as current power generated by solar panels, total electrical energy produced by the system through out the day and monthly savings due to the solar power system. Virtual experimentation helps students develop their understanding of all the pros and cons of a solar photovoltaic system.

After introduction to the solar power system and technical and economical aspects of supplying electricity using such systems the students can use the set of simulations that model and visualize the basic processes occurring in semiconductors. Screenshots of two of these simulations are shown in Figure 2 below.

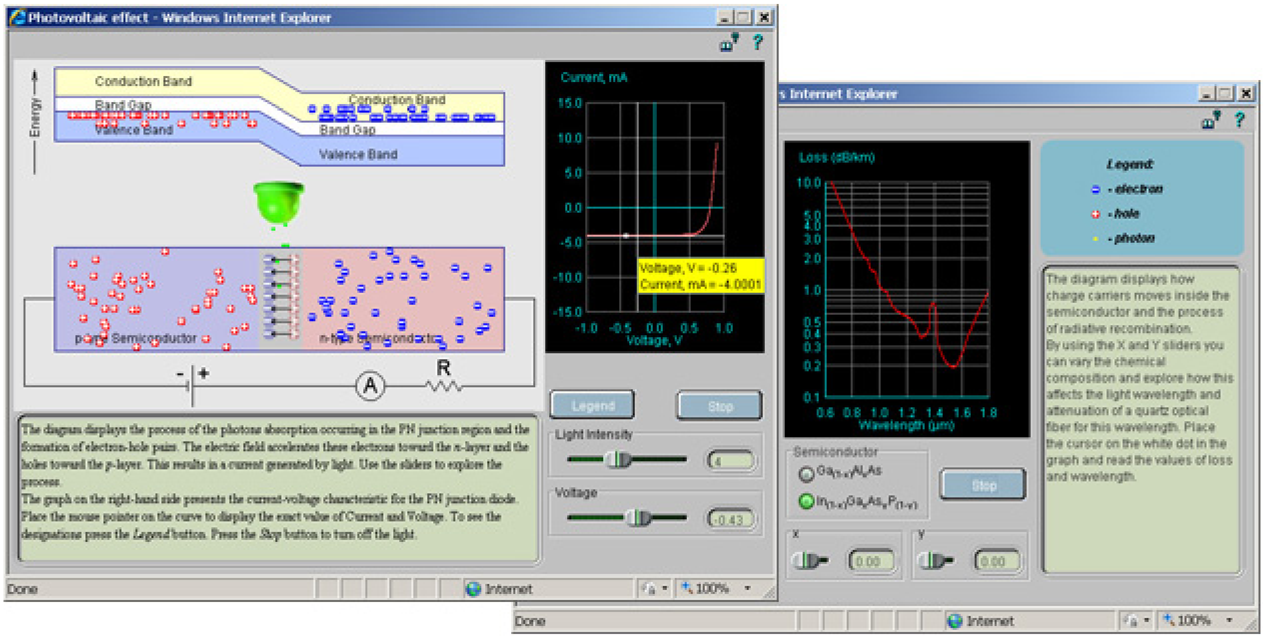

Figure 2. These simulations enable students to study photovoltaic effect in semiconductors and explore how various radiative loss mechanisms in a semiconductor depend on the composition of the material. Students are able to vary light intensity and applied voltage (Figure 2 left) and to study how these parameters affect the current-voltage characteristic of a photovoltaic device. This helps students better understand fundamental laws underlying the operation of photovoltaic panels.

There are distinct differences between a simulation, a virtual experiment, and a virtual laboratory. A simulation is task and learner neutral, i.e., it models a process, an object/system 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 a guided activity which focuses on a particular task. In addition to a simulation, a virtual experiment includes specific learning objectives, scenario/assignment, worksheets, assessments, 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 thorough a set of step-by-step instructions to accomplish a particular educational assignment. Whereas the Virtual labs incorporates several virtual experiments that can share simulations and supplementary e-learning resources

Figure 3 below shows the virtual experiment designed to study heat transfer and thermal conductivity of building materials. In this particular experiment students should determine the impact of wall insulation materials on the cost of maintaining comfortable temperature in a house. First, students are presented with the specific learning objectives and experiment description. Then a simulation is launched.

Figure 3. An example of a virtual experiment "*Influence of Thermal Wall Insulation on Energy Expenses*".

The simulation, which is the foundation of the virtual experiment, enables students to vary the thickness and type of materials used for the wall and insulation, inside and outside temperatures. By selecting different materials the students can instantly see how these changes impact energy consumption and the monthly utility bill. An instructional panel beneath the simulation displays step-by-step instructions for the student. An Excel spreadsheet (or simple worksheet) can be opened within the experiment. It can also be printed out for a traditional "paper and pencil" mode. The spreadsheet helps students to conduct the experiment and to collect and analyze the data. From within the main simulation an auxiliary simulation (shown in the middle left) can be called up for additional exploration.

Each virtual experiment includes an associated control quizzes (shown in the top right) that can be answered either online or in a "pen and paper" mode. An embedded lesson (in the middle) provides "just-in-time" learning opportunity. An optional Instructor Agent keeps track of student actions and provides feedback and tips to the learner. The Agent's programming can be modified by the instructor. In most other simulations a student can toggle between the American (British) system of units and the Metric system (SI).

Like a traditional hands-on lab, where several experiments can use the same set of labware; an unlimited number of different virtual experiments can be based on the same simulation. Several virtual experiments can form a virtual laboratory and share auxiliary resources.

An easy-to-use authoring tool that enables instructors with no programming or scripting experience to produce appealing and pedagogically sound interactive virtual activities is available as well.

In an energy efficient house, LEDs replace inefficient incandescent lamps and less efficient fluorescent lamps. Screenshots illustrated in Figure 4 enable students to understand the design and operation of a Light Emitting Diode (LED).

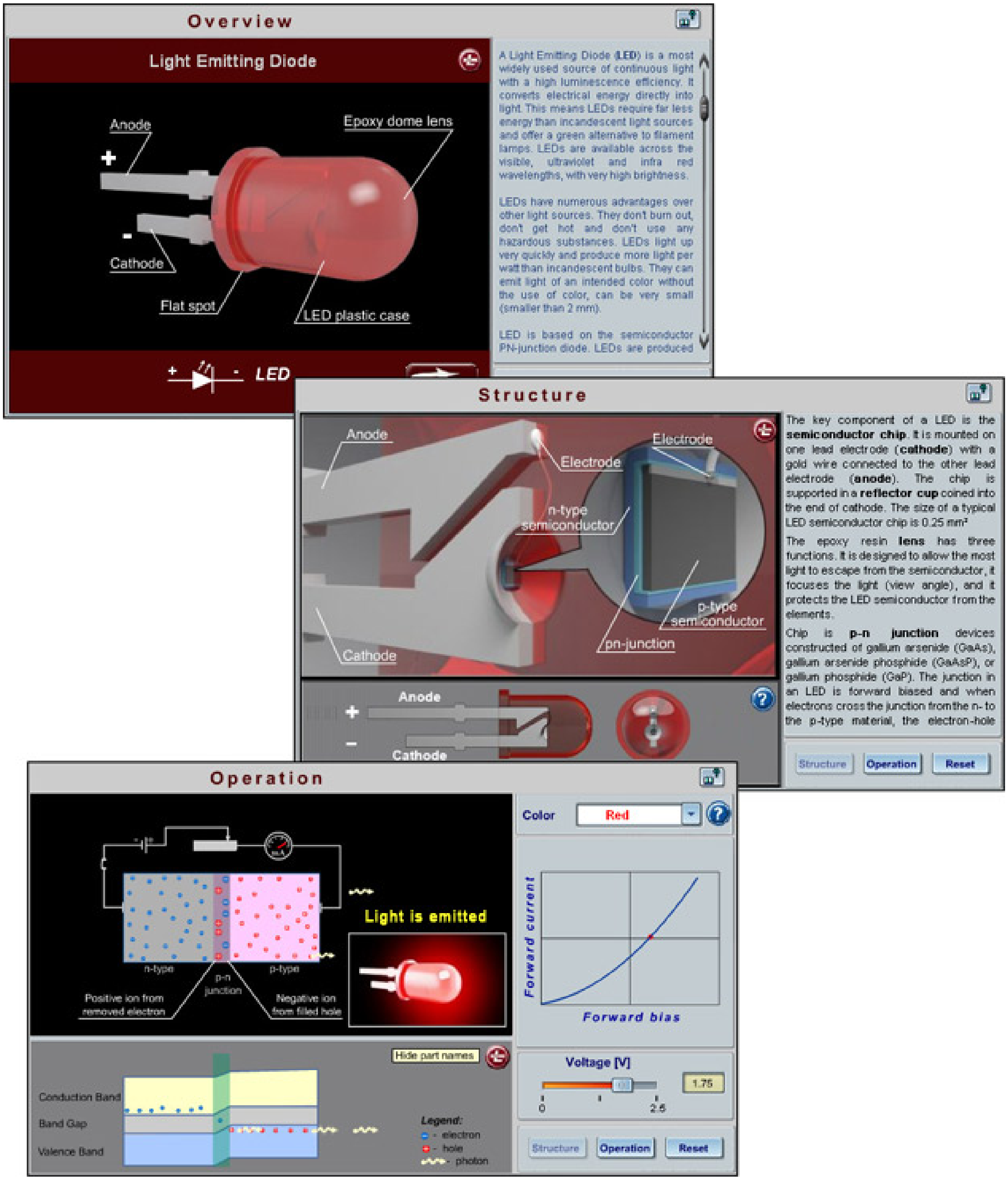

Figure 4. Screenshots of the simulation about Light Emitting Diode (LED) depict the inner and outer construction of a LED and a cross section of a PN junction illustrating the recombination of electrons and holes in the depletion region leading to the spontaneous emission of radiation.

II. Incorporation of Simulations and Virtual Experiments to support DeVry University's Academic Programs:

For the past several years, DeVry University has been using ATeL's software with measurable success to support laboratory objectives in our Wireless and Broadband courses, as well as one general education course titled, "Technology, Society and Culture" (HUMN-432). Figure 5 below shows two screenshots of a simulation that enables students to visualize and measure air pollution in one of the case studies of HUMN-432 course, wherein students explore the social and ethical implications and influences of technologies on society, and the relationships between societies and technologies.

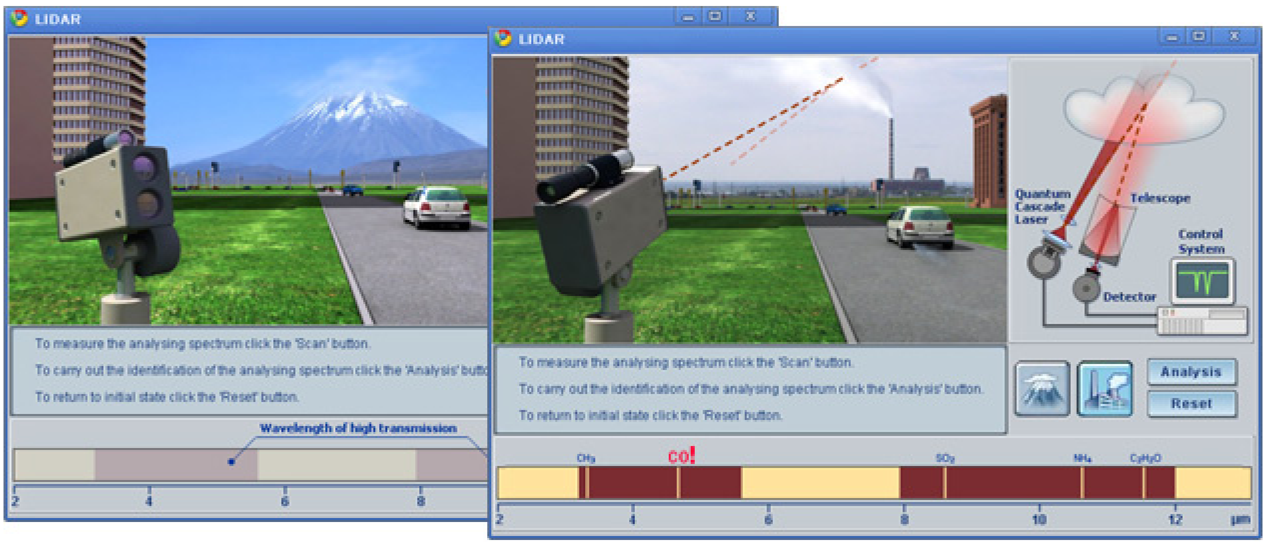

Figure 5. Screenshots of the simulation **LIDAR** *(Light Detection And Ranging*) depict the operation of a device that measures the properties of scattered light to determine the composition of pollutants in the atmosphere near a natural (volcano, *left*) or industrial (*right*) source of air pollution. The diagram in far right illustrates a LIDAR operational scheme. The LIDAR simulation enables students to first choose either a natural pollution source (volcano) or industrial one (factory chimney), and then to use the LIDAR scan for determining the chemical composition of the air and clouds near the chosen object. Next the simulation can be triggered into the analysis mode to analyze the chemical spectrum. If any components exceed the allowed limits (e.g. CO in Fig. 5) the program marks them and generates a warning message.

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

A number of simulations and virtual experiments based on ATeL software have been incorporated into the Wireless Communications Engineering course (EET-380) and Broadband Communications course (ECET-425) at DeVry University, Addison, IL. The students' assessments of ATeL software-based experiments as shown in Appendix A 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. 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.[5]

Because of reasons cited above, a number of simulations and virtual experiments based on ATeL's alternative energy software are being evaluated for adoption into our new Renewable Energy Engineering Track of our Electronics Engineering Technology (EET) program. Data on effectiveness of the ATEL software in successfully conducting renewable energy experiments will be gathered and analyzed during the 2011 summer and fall semesters using similar assessment methodology as for the wireless courses. We expect that experience with such virtual labs along with limited number of real-world alternative energy platforms will help students in learning conceptual and practical skills and lead to a successful career in "renewable energy industry".

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

Appendix A

Simulation Software Assessment Matrix used for Wireless and Broadband Communication Courses

Evaluation Topics:

1. **Instructional**

Topic	What Was Done	Who Were Involved	Tools Used
Technology Orientation	The software was used to conduct lab experiments in a Wireless Communications course (ECET-380)* and a Broadband Communications course (ECET-425)*	Approximately 80 students over a period of four 8-week session based course used the software	Lab computers connected to the Internet via a T-1 line; experiments and projects developed by ATEL
Instructor's role	Guidance and consultation	Students	Handouts/worksheets
Learner's control	Conducted experiments and projects	Students	Pre-developed labs in the software
Interaction and feedback	A questionnaire was used to collect feedback after each experiment	Students	Questionnaire
Treatment of errors	Errors within the experiments could not be introduced	Students	Pre-developed labs in the software
Motivation (speed of Java Applets)	Software and experiments were accessed from the ATEL central server	Students	Internet connected via a T-1 line

2. Curriculum

Topic	What Was Done	Who Were Involved	Tools Used
Cognitive level	Experiments performed by students via simulation and hands-on activity with hardware equipment.	Students and faculty	ATEL Labs plus labs in the course textbook
Cognitive Apprentice ship	All ditto	Students	All ditto
Learner's control	All ditto	All ditto	All ditto
Sequencing	All ditto	All ditto	All ditto
Ability to create new models/expe riments	Not Applicable		
Understandi ng/ Intuitiveness	All ditto	All ditto	All ditto

3. Technical

Topic	What Was Done	Who Were Involved	Tools Used
Installation	Not needed. SW accessed via ATEL's central server	Faculty and students	Lab workstation connected to the Internet via a T-1 line
Speed of execution (Java applets)	Experiments conducted	Faculty and students	Workstations and laptops used both Internet Explorer and Firefox browsers
Operating system compatibility	Labs performed on workstations using Windows XP, Vista,	Faculty and students	Lab workstation connected to the Internet via a T-1 line

	and Ubantu operating systems		
Assessment of student learning and record keeping	Students submitted individual reports for each experiment, and faculty graded and maintained these records.	Faculty and students	

***Course Descriptions:**

ECET-380 Wireless Communications Engineering
This course introduces principles and techniques used to analyze and design wireless communication systems. Topics include electromagnetic waves, antennas, propagation and digital modulation. Mobile and cellular systems are emphasized; other selected applications such as wireless local area network (Wi-Fi), broadband wireless (WiMAX) and Bluetooth (Wireless PAN) are also covered. Students use computer software to simulate, analyze and solve problems.

ECET-425 Broadband Communications
This course introduces systems concepts in communications. Topics include microwaves, antennas, transmission lines, propagation, fiber optic systems and satellite systems. System performance measurements and applications are also addressed. Students use computer software to simulate, analyze and solve problems.