Technology-Based Electromagnetic Education

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Invited Paper

***Abstract*—In this paper, we will briefly review the various roles of technology in stimulating interest and deepening understanding of abstract and highly mathematical subjects such as electromagnetics (EM). The general advantages of using technology in offering web-based courses and professional training will be described and examples of the ongoing activities in this area will be summarized. Focus, however, will be placed on the development and effective use of multimedia assets in the modern teaching of fundamental EM and more advanced microwave courses. Development and use of interactive components such as virtual laboratories, virtual instruments, simulation software, animation, and virtual participation in practical applications will be described. The new "Conceptual Learning of Engineering" project will also be described, and examples demonstrating the various ongoing activities will be presented.**

***Index Terms*—Degrees, education, electromagnetic, Internet, microwave, multimedia, simulation, training, virtual laboratory, web-based courses.**

I. INTRODUCTION

NEW technology advances and the ability to prepare educational material in a variety of media—including video, audio, and interactive multimedia modules—present a unique opportunity to boost the quality of education, increase student interest, deepen understanding, and offer avenues for providing cost-effective outreach and distance learning activities. It is possible to group the basic roles of technology in education into the following modalities:

1) provide web-based courses, Internet degrees, and distance learning;
2) develop multimedia assets and interactive course ware;
3) use technology to implement the new program of "Conceptual Learning of Engineering" (CoLoE).

In Sections II–V, each of these components will be described in more detail and examples of the developed educational aids will be presented.

II. WEB-BASED COURSES IN EM AND MICROWAVE EDUCATION

Regarding web-based courses, it is well known that there are ongoing activities to provide these courses in a typical university environment for professional and distance learning. Besides their significant outreach and distance-learning benefits, these courses provide continuous and on-demand support for students through references, access to databases, online help, near-instantaneous feedback, and access to available multimedia assets. Improved quality of education through active learning, team work, communication through video conferencing, message boards, e-mails, etc. are also among the benefits of using technology and web-based courses. Besides these benefits, however, web-based courses might be the only available cost-effective option for providing professional training and for implementing outreach educational activities in rural and remote areas.

It is because of these advantages that there has been significant growth in the development and implementation of web-based courses and educational aids for continuing education. The Educational Activities Board of the IEEE, for example, is teaming up with universities to develop web-based courses that capitalize on unique IEEE capabilities such as linking these courses with IEEE Xplore [1]. Challenges in designing these courses and in meeting varying educational experiences, backgrounds, and learning environments are significant and are currently being addressed. The development cost and the desire to incorporate high-end multimedia components, as well as the implementation procedures that would standardize the delivery system, make the process of creating, managing, and distributing these envisioned web-based courses highly challenging and certainly much more than just adding technology to the instruction process. This process of course development and distribution on the Internet should not be confused with the tremendous benefits from web resources including online journals, countless web sites for news and entertainment, access to digital libraries, e-commerce, etc. As a matter of fact, we believe that it is useful to reference web sites such as Engineering Outreach at the University of Idaho.[1] The Indiana Higher Education Telecommunication System,[2] and a commercial site that provides access to international resources in higher education.[3] It may be worth mentioning that the Engineering Outreach at the University of Idaho Web site provides links to 13 modules on distance learning that range from an overview and strategies for teaching at a distance to interactive video conferencing and copyright issues. Links to prime sites on information technology, and to topics on the subject of web-based and distance education are also among the available information on the Indiana Higher Education Telecommunication System web site cited above.

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[1][Online]. Available: http://www.uidaho.edu/evo/distglan.html
[2][Online]. Available: http://www.ihets.org
[3][Online]. Available: http://www.iberry.com

Of particular interest in this paper is the development of basic electromagnetics (EM) and microwave courses and managing their distribution and technical support on the web. To this end, examples of the ongoing activities to address this need will now be discussed. Prof. Gupta and his colleagues at the University of Colorado at Boulder are pioneering the use of the idea of "concept maps" for the development of RF and microwave courses and modules [2]. The idea is to organize concepts in a logical sequence so as to facilitate building modules effectively and to graphically illustrate the relationship between modules, as well as the sequential development of ideas [2], [3]. Examples of some of the developed microwave modules are given in [2]. In another effort to develop web-based educational aids, Prof. L. Dunleavy, Prof. T. Weller, and their colleagues at the University of South Florida, Tampa, are developing multimedia virtual laboratories for teaching wireless and microwave basics [4]. This effort is a follow-up to the currently available physical laboratory and associated courses in the Wireless and Microwave Instructional (WAMI) laboratory and present an attempt to share and disseminate the developed materials using Internet technology. Efforts are also underway to enhance the contents and the web-delivered version of these courses by incorporating multimedia components, video clips, animation, and easy-to-use navigation tools.

In another related effort that is being supported by the IEEE Microwave Theory and Techniques Society (IEEE MTT-S), the group at Drexel University, Philadelphia, PA, is developing an electronic book for teaching microwaves [5]. The main feature of this effort is to incorporate simulation and microwave design software tools and results from design examples using even commercial tools such as the High-Frequency Structure Simulator (HFSS) and microwave circuit design tools such as ADS. In an aggressive and integrative approach, the group at Villanova University, Villanova, PA, is developing web-based microwave courses that provide real-time access to laboratories and measurements for distance education students [6]. The developed over-the-web distance learning environment also provides access to computer-aided design (CAD) software and audio and video recorded lectures that may be attended live or on a time-delay basis. Discussion of the challenges faced in developing these microwave courses and procedures for overcoming some of the technology and intellectual property issues are discussed elsewhere [1], [5]. Other ongoing efforts to develop web-based courses include the use of time-domain simulation software [7][4] and the enhanced teaching of microwave courses using visualization and simulation software [8]–[14]. In all, many of the challenges in developing web-based courses have been recognized, significant advances have been made, and ongoing efforts are expected to enable this technology of web-based education technology and realize its much-anticipated benefits.

III. Multimedia Assets and Their Effective Use in Education

The use of multimedia assets and the ability to provide educational material and course ware in a variety of modalities represent one of the most recognized, appreciated, and widely used form of technology in education, training, and entertainment. Multimedia assets such as virtual laboratories, guided use of

[4][Online]. Available: http://www.faustcorp.com

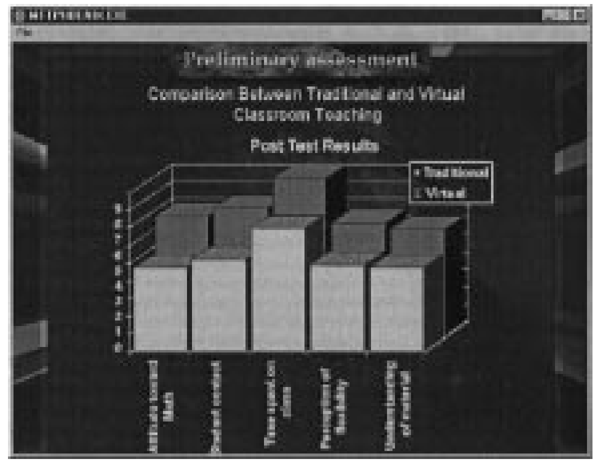


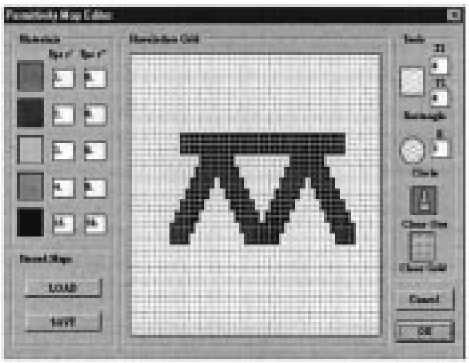
Fig. 1. Results of a comparative study between virtual and traditional learning in a statistics course at California State University, Northridge [21].

simulation software, virtual instruments, animation, and virtual participation in practical applications are becoming an integral part and provide an important component in effective teaching in general and in developing web-based courses in particular. Multimedia assets and their distribution either on CDs or over the Internet simply represent a much broader avenue for boosting the quality of education even in traditional classroom teaching and in typical university laboratory environments [15]–[20].

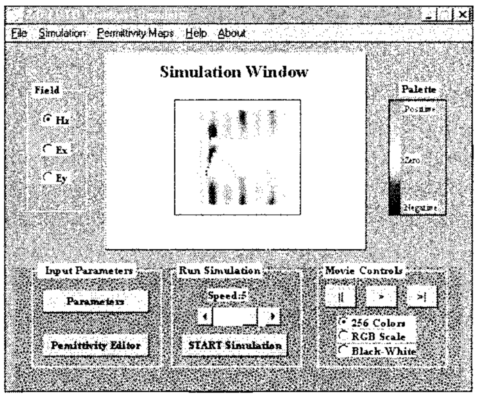
Studies on the benefits of technology-based education show that multimedia provides motivation, increases learning rate, contributes to retention, and even helps in managing large classes where the role of the teacher is expected to change from information provider to a coaching-type guide and facilitator. Fig. 1 shows a summary of results from one of these such studies where it is clear that benefits from technology implementation in education are many and certainly impact more than just improved learning of the course material [21]. Increased communication, improved attitude toward math, and spending more time studying are general benefits that are expected to impact and improve quality of education in general and beyond the course being taught.

It is generally known, however, that development of multimedia assets and technology-based aids is expensive and time consuming. Furthermore, simpler implementation of technology such as in the development of electronic texts and page turners has proven to be ineffective and unattractive to students. Therefore, focus should be placed on topics and products that benefit most from the advantages and capabilities of the computer technology and on courses and subjects that benefit most from animation, visualization, and simulation aids [16], [22].

The use of technology is best utilized when highly interactive environments such as virtual labs and virtual instruments are developed. Student understanding is deepened and retention rate is increased when providing information in more than one modality and by including video clips, animation, and audio description of the information. With the proliferation of simulation tools and the use of software in education, technology aids, and multimedia modules may be used to complement these products, provide guided use of this software, and to explain the physical phenomena and engineering concepts behind the graphical presentation of simulation results.



(a)



(b)

Fig. 2. Screen captures of the 2-D FDTD program in the EM CD [16]. (a) Parameters editor. (b) Simulation screen and results. It may be noticed that the user can visualize either one of the three field components in real time and while the simulation is in progress.

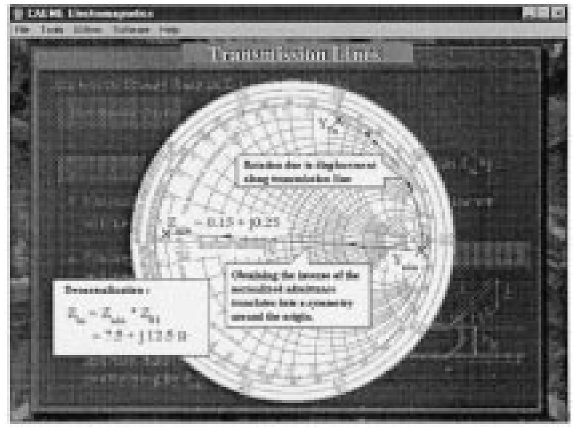


Fig. 3. Screen capture of the electronic Smith chart in the EM CD. Tandem connection of transmission lines, single- and double-stub simulations can be carried out using the software package [24].

Due to the page limitations on this paper and to satisfy a main objective of providing examples of technology-based aids and multimedia assets in teaching EM, focus will be placed on illustrative examples of the *Electromagnetics* CD recently developed by the CAEME Center for Multimedia Education. The reader is encouraged to review other available activities at universities and on the Internet.[5] [6] [7]

In the area of simulation software, the CAEME multimedia CD includes one-dimensional (1-D) and two-dimensional (2-D) finite-difference time-domain (FDTD) simulators [23], Smith chart implementation of steady-state analysis of transmission lines [24], wave interference and standing waves, and the transient analysis of transmission lines using reflection diagrams. Fig. 2 shows a screen capture from the 2-D FDTD code, while Fig. 3 shows an example of the electronic Smith chart solution of a tandem transmission-line system. Virtual laboratories and virtual instrumentation represent a significant component of multimedia assets and educational aids in EM [14], [15], [17], [25]. The EM CD includes a virtual antenna range, a time-domain reflectometer, and most-interesting visits and virtual participation in the laboratories of the pioneers who aided the development of Maxwell's equations.

Fig. 4 shows a screen capture of the antenna range virtual laboratory module. In a series of screens such as the one shown in Fig. 4(a), an interactive description of an anechoic chamber is provided, while Fig. 4(b) provides the various network analysis, scanning, and computer equipment required for making these measurements. In this module, students may select a specific antenna from a provided collection and then decide on the dimensions, operating frequency, the scan range, and the number of measurement points, as shown in Fig. 4(c). The output on the computer screen in the instrumentation room then shows the desired measured radiation pattern. The antenna range module is now available on the Internet for free access and can be downloaded by the interested reader [11].[8]

Besides software, virtual instruments, and virtual laboratories, the CD contains video clips, animation, and an extensive navigation bar. Examples of the video clips include demonstration of EM waves and their propagation characteristics, electric- and magnetic-field measurements, and video clips to support some of the discussed research projects and practical applications [23], [25]. Fig. 5 shows a video clip from the demonstration of the characteristics of plane waves, while Fig. 6 shows the generation and characterization of standing waves.

Fig. 7 shows the experimental setup that leads to virtual participation in one of the applications, i.e., Microwave Methods for Measuring Lung Water Content [23]. Extensive animation was included to graphically describe various coordinate systems and dynamically illustrate concepts such as the polarization of plane waves, standing waves, materials interaction with EM fields, and graphical transmission-line analysis using the Smith chart. In addition—and to help provide a user-friendly multimedia package—extensive navigation capabilities, text search, and hypertext links were provided throughout the CD. Fig. 8 shows the navigation bar implemented in the EM CD.

IV. Conceptual Learning of Engineering

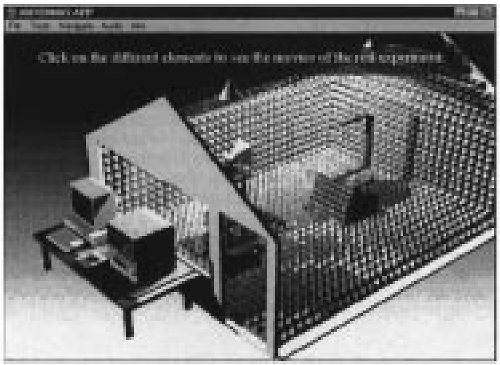
In traditional software packages and computer simulation aids, equations are programmed, computational techniques are implemented, and results of simulations are presented graphically. As mentioned earlier, multimedia applications may be used to guide these simulations and help in the interpretation

[5] [Online]. Available: http://www.ieee.org/eab/navigator

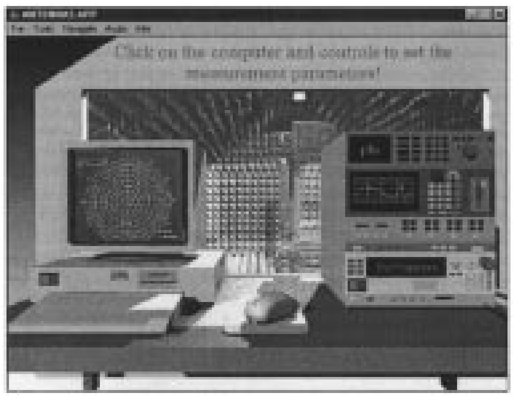
[6] [Online]. Available: http://www.ieee.org/pdi/

[7] [Online]. Available: http://www.Uwex,edu/disted/home.html

[8] [Online]. Available: http://128.110.18.180/caeme/em.zip



(a)



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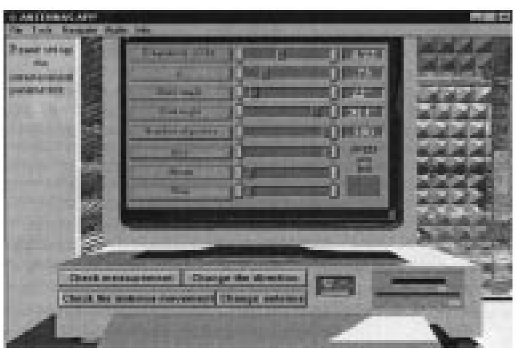


(c)

Fig. 4. Screen captures from the virtual antenna range laboratory. (a) Anechoic chamber. (b) Network analysis and computer control equipment. (c) Screen for the input data and measurement parameters.

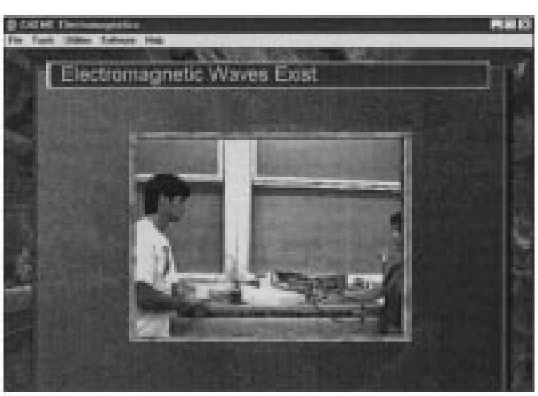
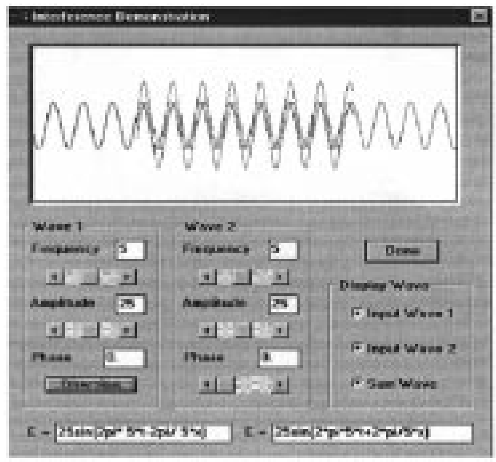


Fig. 5. Video clip of the plane-wave characteristics demonstration. Polarization, wavelength, power density, and interference characteristics were demonstrated using transmission between two X-band horn antennas.

(a)



(b)

Fig. 6. Video clip and screen capture of the demonstration and simulation of the characteristics of standing waves. (a) Wave reflection from a ground plane and the monitoring of the nodes and peaks in the standing-wave pattern using fluorescent light. (b) Interference characteristics of two waves traveling in opposite directions. Pure standing-wave pattern occurs when the two waves are of the same frequency and equal amplitude.

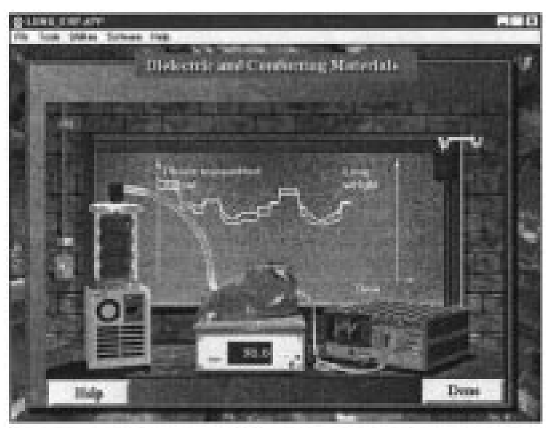


Fig. 7. Screen capture of the virtual experiment illustrating the use of microwave methods for measuring changes in lung water contents. This figure shows an isolated lung placed on a scale, a network analyzer to measure the phase of the transmitted microwave signal, and a respirator for ventilating the lung. Also shown are two traces of the experimental results that illustrate the accuracy of the procedure.

of the obtained graphic results. A new and emerging procedure for using computers in education is the conceptual learning of science (CoLoS) approach pioneered by colleagues from the

Fig. 8. Navigation bar in the multimedia EM CD. Forward, backward, go to beginning and end of each section, go to main manu, word search, and hyperlinks were all implemented in the navigation bar.

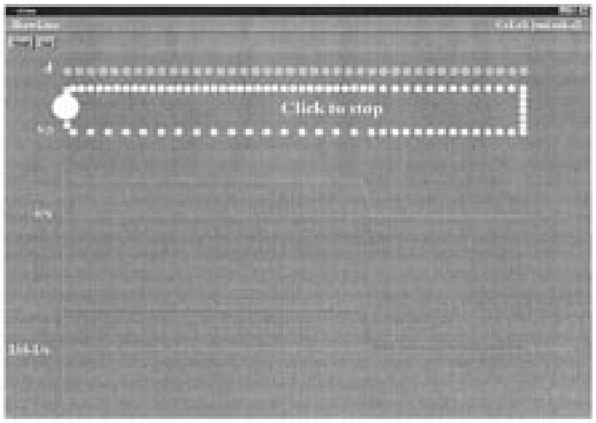


Fig. 9. Screen capture of the output from a CoLoS software package. Shown in this figure is the relationship between the charges bunching in the transmission-line conductors and the corresponding current (flux flow) and voltage (charge density) distribution along the line [29].

Hewlett-Packard Company and implemented by the European consortium CoLoS group [26]–[29]. The approach is unique; it is still under development, and the extent of its application in the development of engineering courses is being studied and evaluated under a National Science Foundation (NSF) grant [30].

The idea behind this effort is to use computers not to solve equations and make calculations, but to mimic nature and facilitate conceptual understanding based on basic and fundamental interatomic interactions subject to the application of the basic laws of nature [27]–[29]. For example, intuitive understanding may be developed based on interactions between a large number of atoms and subject to the most fundamental laws of nature such as conservation of energy, gravitational and electrostatic forces, conservation of momentum, etc. Observation of these interactions under a wide variety of conditions such as an applied voltage, changing temperature, and varying pressures would lead to conceptual understanding of the phenomenon on hand. Mathematical equations and behavior models may be obtained as a result of the developed conceptual understanding and not as the source of learning. For example, by observing the behavior of the interatomic interactions in time and space and under a variety of excitation and operating conditions, finite-difference equations may be developed; hence, the mathematical equations may be realized and derived from the conceptual understanding.

Colleagues at HP Laboratories and from the CoLoS consortium have been working on this approach for several years [26], [29], [31]. To date, several successful models have emerged, including a most fascinating module for transient transmission-line analysis based on the interatomic interactions and charge flow in the transmission-line conductors [29]. It is truly rewarding to use such an approach, and it helps answer interesting questions such as why EM waves travel in transmission lines with the velocity of light while the charges producing them travel with a much lower velocity. Fig. 9 shows some of the simulation results illustrating the relationship between bunching of charges in the transmission-line conductors and the propagation of the current and voltage signals along these lines. Interested readers should contact authors of the CoLoS concept for additional information and examples of available modules [26], [29], [32].

V. Concluding Remarks

Technology provides new and effective means for revitalizing, enhancing, and addressing growing needs of modern education. Besides web-based courses and distance learning, development of multimedia modules and the use of simulation tools provide an effective approach for increasing interest and deepening understanding of courses and mathematical subjects. In addition, technology provides a unique opportunity to mimic nature, develop conceptual understanding, and drive equations and mathematical models based on the developed intuitive learning. After all, the geniuses of the past developed our available mathematical models and equations based on simple experimentation and conceptual understanding of the phenomena in hand.

Much of our presentation was, however, focused on features of multimedia modules for teaching EM. Screen captures of virtual laboratories, virtual instruments, simulation software, animation, and virtual participation in practical applications have been presented. It has been emphasized, however, that development of multimedia assets and educational aids is expensive and time consuming; hence, efforts should be focused on topics and procedures that could benefit most from the technology. It was also noted that electronic textbooks, and page turners are ineffective and unattractive to students. It is simply difficult to read text on a computer screen and the development of highly interactive modules and educational aids represents the true benefit from the multimedia and computer technologies. Caution, however, need to be exercised when using these virtual assets in teaching, classroom demonstrations, and in computer laboratories. Virtual experiments and virtual participation in practical applications may not convey difficulties in the real world and in conducting actual physical experiments. Every effort should be made to complement virtual laboratories, experiments, and exercises with real and physical ones, just to emphasis practical aspects and real-world situations.

The CoLoS approach for using computers to mimic nature and drive equations based on conceptual understanding is a novel approach for using technology and computer tools that need much attention from interested educators. Even after several years since its inception, its full capabilities are yet to be realized and the possible limitations of such an approach are yet to be determined.

Regardless of modality and whether it consists of web-based courses, multimedia on CD-ROM, or a CoLoS applications, the advantages of using technology to aid in teaching engineering courses are many and educators are encouraged to reach deep and discover new, innovative, and promising means for using the technology in preparing the future workforce in the 21st Century.

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