Abstract - Web-based multimedia tutorials are being developed for use in several undergraduate courses in Electrical Engineering and Computer and Systems Engineering at Rensselaer. These interactive learning modules (ILMs) are created with the Director authoring environment and can be deployed using a standard Web browser with Macromedia's Shockwave plug-in as the interface. The ILMs can be used by faculty for in-class presentations and demonstrations, by students for in-class, structured exercises (particularly in the Studio format of course delivery) and by students anytime, anywhere via the Internet to explore concepts in more detail and gain practical experience in design and application. The ILMs are developed to provide application-based motivation for learning, present fundamental concepts using animation and visualization, and provide interactive practice on problem-solving and open-ended design experience. ILMs are now available on the 555 Timer IC, an Electrical Engineering Fundamentals Handbook (EE handbook), an Electronics Circuit Card Manufacturing Handbook, Common-Emitter Amplifier Design, Analog Filters, Operational Amplifiers, Fourier Analysis, and Convolution. They are currently being used in our introductory courses in circuits, electronics, instrumentation, and signals and systems, all of which are moving to the Studio format. Initial experiences by both faculty and students have been very positive. The combination of interactive learning modules and the Studio format of course delivery present a fundamentally new model for delivery of engineering education.

I. Motivation

Engineering programs are faced with the triple challenges of: 1) declining percentages of high school students choosing engineering as a collegiate major, 2) increasing diversity of those students who do choose to major in engineering, both in cultural background and high school preparation levels, and 3) continually increasing costs while revenues remain essentially flat. These challenges are exacerbated by the traditional pedagogy used for engineering education, which has remained relatively unchanged for several decades, and by the state of engineering educational facilities, particularly those used to develop professional practice skills, which are woefully out-of-date at most schools, despite the rapid changes in technology.

There is hope on the horizon! New models for delivery of education are being explored which offer the promise of attracting increasing numbers of gifted students to science and engineering, improving the levels of student learning, retention, and satisfaction, and reducing overall delivery costs. Most of these new models rely heavily on the increasing capability (and decreasing costs) of computing and information technologies, particularly those that use the rapidly evolving Internet. Examples include new on-campus ways to use asynchronous learning [1],[2] and new models for combining on-campus and distributed classrooms via distance learning [3],[4].

The model being developed in the Electrical, Computer and Systems Engineering (ECSE) department at Rensselaer involves the use of Web-based, interactive multimedia materials [5] in conjunction with a Studio [6] format of course delivery. Interactive learning modules (ILMs) are used in Studio classes by faculty to help explain concepts and demonstrate applications, and by students for specific learning exercises. Outside of class, the ILMs are available from anywhere at anytime over the Internet, using either public or private computing resources. They are used by students for more in-depth exploration of concepts and interactive practice with design and problem-solving activities.

The basic goal is to develop easy to use, highly interactive materials which simultaneously stimulate multiple senses. The student (or adult learner since the materials can be used for multiple purposes, including technical training) is first presented with the context of the material and hopefully attracted to peel off successive layers of the onion to gain a full understanding of the basic theory, principles and concepts. Additionally, the student is encouraged to play in a highly interactive, highly functional design space where he/she can get immediate answers to what if questions and develop the problem-solving and design skills that are such a valuable component of an engineering education.

We have begun using this model of combining ILMs and the Studio format in both a Circuit Analysis and an Analog Electronics course during the 1996/97 academic year and are extremely pleased with the initial results. We believe this approach can provide a fundamentally different model for engineering education.
II. ILM Development and Content

Our development objective is to create interactive materials that combine graphics, animations, audio/video, modeling and simulation in an enticing environment that allows the user to understand how electronic circuits operate and can be utilized in real-life situations. The ILMs pick up where most textbooks leave off -- via the use of multimedia -- to additionally allow the user to explore and understand the dynamic nature of how electronic circuits are designed, manufactured and applied. For example, the capability to see and hear the result of how an amplifier increases the amplitude and volume on an input signal provides the user with a much more powerful understanding of the circuit operation. The hope is that this integrated presentation approach will ultimately generate a much greater impact than that which single-dimensional books or static web pages can accomplish.

The ILM development is done using a Director authoring environment. The learning curve for this environment is a bit steep, but the advantages of enhanced functionality far outweigh the extra learning time required. In addition, Rensselaer has created an Academy of Electronic Media which will serve as a resource for faculty, staff and students to provide the guidance needed to facilitate their utilization of multimedia.

Each ILM is organized into three sections:

1) **An introduction** - which includes (nominally three) interactive examples of applications, introductory text, graphics, etc., and background tutorial material of real life configurations;

2) **A design, experimentation and analysis “playspace”** - which allows the user to design and test circuits in a series of highly interactive models via an analytical engine that can process chosen input(s) and generate output (in the form of graphic plots, audible signals, etc.);

3) **Problem sessions** - consisting of specifically tailored problems provided in a manner that allows the user to utilize the analytical engines from the prior section to explore their understanding of the material and providing on-line guidance and aid (when progress deems it necessary).

Many of the functions used in the design and analysis sections have been developed with a common interface to enable use in any of the modules. For example, a component chooser tool has been developed to select a resistor, capacitor or inductor using criteria that allows the user to select any value (without boundaries) or only from a list of those which are commercially available. In addition, specific capabilities (e.g. plotting and sound generation routines - utilizing higher level language routine development) have been developed and incorporated into the authoring environment to enhance the user experience wherever possible. This focus on standard functional units and common interfaces significantly reduces the time (and cost) of developing new ILMs. Admittedly, the cost of the first few ILMs is quite high, but the cost rapidly decreases as we develop additional modules. Some examples of these ILMs are:

1. **Manufacturing Handbook:** An electronics manufacturing handbook has been developed that offers animated presentations of current printed wiring board assembly processes. A prototype presentation of the equipment and processes used in NorTel’s RTP facility has been developed to give the user a sense of actual electronics production. Video footage is organized in a manner that shows the flow of production at the facility and the correspondences with the training oriented animated presentations. The user can select a process from a graphical interface that depicts the flow of the production and further choose to view an animation, video or ultimately virtual reality interactive presentations (using QTVR to “fly through the manufacturing floor” and view the design at various stages of the manufacturing process). The manufacturing handbook material is already available on the Internet, and can be accessed via: http://www.cieem.rpi.edu/mfghand.html.

2. **EE Handbook:** An EE handbook has been developed to offer descriptive presentations of a number of electrical engineering related topics, again in various levels of depth. For example, the electronic filters section presents the user with both a high level view of what a filter does and a lower level description of the corresponding circuit elements that filter electronic signals. These materials are intended to be used both as a stand-alone handbook and in conjunction with a particular circuit module as introductory and tutorial background materials (e.g. as a contextual precursor to the more comprehensive “Electronic Filters” module).

3. **Electronic Filters:** This module provides the user with an understanding of how circuits can be designed to tailor the frequency response of electrical signals. The capability for designing and testing a variety of single and higher order filters is available along with a means to allow the user to watch and listen to the output resulting from their circuit’s effect on a chosen input signal(s). The current implementation includes low-pass, high-pass, and band-pass passive circuits. The frequency and overall time domain responses can be viewed simultaneously, thus providing the user with relationship between the frequency and time domains.
4. **Operational Amplifiers**: The operational amplifier module allows the user to design and analyze various op-amp circuits via a combination of visual and audible input/output signals. Over 15 configurations are available for analysis, thus providing a rich suite of circuits for students to use in the challenges provided in the section’s corresponding problem session. In addition, the concept of device saturation (due to inappropriate DC supply choices) -- along with the resulting distorted output -- can be explored by the user examining the trade-off between the amplifier's gain and Vcc.

5. **Transistor Amplifiers**: An NPN bipolar junction transistor amplifier has been used as the foundation for this module, in which the user can investigate the basics associated with the characteristics, DC biasing, and configuration as a small signal amplifier. A highly interactive screen allows the user to investigate DC biasing via pointing and clicking. The module gives the user the ability to immediately observe the shifts in the amplifier gain induced by altering either the quiescent (Q) operating point or the amplifier resistances and then view the resulting effect (visually and audibly) on amplification of an AC input signal.

6. **555 Integrated Circuit**: This module presents the operation and application of the popular and versatile “555” timer integrated circuit. Astable and monostable configurations of the circuit are available to exhibit the timing circuits associated with oscillators and single pulse generation. The user can, in effect, peel the top off the chip to look inside and see what is going on (as seen in the screen from the 555 module). A series of double-clicking takes the user down sequentially through all the functional levels of the IC to gain a very basic understanding of how the circuit’s output signal evolves over time. This material is already available for deployment using the internet, and can be accessed via: http://www.cieem.rpi.edu/555.html.

**III. ILM/Studio Deployment**

The Studio format for educational delivery involves combining what is traditionally done separately in lectures, recitations/problem sessions and laboratories into a single facility, on a scale which provides overall cost effectiveness, and in an environment which promotes interactive learning. Rensselaer has successfully pioneered this approach in introductory science courses [6], while the current work represents the first Studio implementation in a discipline-specific engineering program and a first direct educational use of the Web-based ILMs.

Our approach is to create highly interactive classroom facilities that have state-of-the art information technology for display, simulation and network access, and appropriate disciplinary-specific technology to provide meaningful hands-on experimentation. Our first venture has been a Circuits/Electronics Studio which has been in operation since September, 1996. Two additional facilities are currently under development and will be in operation for the start of the 1997/98 academic year. Images of the Circuits/Electronics Studio are available at http://www.cieem.rpi.edu/ilm.html.

This facility is designed to hold 44 students working in teams of two, with each team using an interactive learning station consisting of a networked PC with a GPIB interface to electrical test and measurement equipment (oscilloscope, function generator, multimeter and power supplies), plus prototyping materials with which to create actual circuits. There are four display screens in the front of the room, each capable of overhead, video or computer display for mini-lectures and demonstrations. Special lighting controls are used to direct lighting to where the students are working, while providing good visibility for the displays. The PC’s are connected with a local ATM network, and a large video server is used to stream video directly to the students’ desktops at 10 Mbps. Generous equipment donations for this facility were obtained from Hewlett Packard, IBM, AT&T/Lucent, National Instruments and Lutron.

When students face the front of the facility, they are seated at a broad, flat surface on which to take notes, consult reference materials or perform design exercises. Students turn to face the rear of the facility for hands-on activities, where another flat surface contains the PC, test and measurement equipment, and the prototyping materials. Software tools include discipline-specific applications such as PSpice, plus campus-wide applications such as Maple, Matlab, Netscape, Word, Excel, etc..

Studio classes meet for 2 hours at a time, 3 days per week, for a 4 credit course. This is the same as the total contact time of the traditional versions of these courses which were separated into lecture, problem solving and laboratory components. The concept is to use a pedagogical approach that encourages students to discover and apply concepts, rather than simply remember them from a lecture. The overall time spent lecturing to students has been reduced by almost 50% from the traditional version, with a corresponding increase in hands-on activities.

We typically break a Studio class into 5 or 6 separate activities, so that the students are switching gears every 20-30 minutes to maintain interest and motivation. Activities typically include mini-lectures (no more than 15-20 minutes), pencil and paper exercises, interaction with Web-based ILMs (or other Web-based materials available from other schools), design, simulation, circuit construction and experimental measurements.

The ILMs clearly provide an exciting, interactive alternative to traditional classroom exercises. After introducing a new topic, the class may be directed to work their way through a portion of an ILM exercise, for a
specified period of time, before proceeding to simulate and/or build and test an actual circuit. Students can work at their own pace with the ILMs, with the more capable students able to go much further into the materials in the same amount of time, and the less capable students receiving assistance from the faculty member and two student assistants that are in the room for the full class period. Students are also encouraged to use the ILMs outside of class for further understanding and practice, although we have not yet introduced required outside use of the ILMs. Outside of class use is high, as measured by the levels of activity on our servers, but the affect of this on learning has yet to be specifically documented.

Students clearly see the use of ILMs as more fun than traditional paper and pencil problems, and enjoy being able to explore concepts in the context of real-life applications. Overall student satisfaction levels with the ILMs, as measured by surveys, are quite high. We believe the students will learn more and retain more, although it is still too early to have definitive data on the specific learning effects of the ILMs. To date, we have offered two separate courses using parallel groups of Studio and traditional formats. Attendance and student satisfaction levels are significantly higher in the Studio classes. Performance on traditional exams remains essentially the same. The traditional exams, however, do not seek to measure the increased experience with simulation, application and experimentation.

The early results of the combined ILM/Studio approach has been so encouraging that the ECSE faculty have voted to move all 8 of our introductory courses (typical enrollment = 80-150 per term) in Electrical Engineering and Computer and Systems Engineering to this format, and eliminating several required laboratory courses from the curricula.

IV. Impact and Future Plans

Students who have been involved in the development of the ILM materials have provided us with a unique perspective. These students first learn the material and then are part of a team that decides how to best present the information to others in an engaging and exciting manner. It is often the inputs from these student developers that lead to the tools which most actively involve the user in the learning experience. As a result of their participation, the students’ own cognitive process is enhanced in a manner that fundamentally changes the way they approach the development of new materials. It is interesting to watch the students who have been involved with the ILM development process, since they are now providing others with their newfound capabilities, knowledge sets and appreciation for growing up and living in a 30 Hz society. They are passing this on in a rather unique way that uses their enthusiasm and experience to produce a set of materials that the next generation can relate to, beyond that of what would be provided in a standard lecture modality.

Our future activities are intended to include ILMs on topics that dig deeper into the elements of design that are associated with cutting-edge products (e.g., greater than 250 MHz timing signals on a computer motherboard) along with an embellishment of the current ILMs. Design for manufacturing oriented considerations should be added to the EE Handbook to give the user a better sense of the limitations that production considerations place upon pushing the edge of electronics circuitry. These augmentations are intended to further serve as potential training materials for the industrial electronics manufacturing community and will challenge us to better integrate electronics design and manufacturing learning/training materials and functions.

This is just the beginning of the interactive multimedia era at Rensselaer. Experience with both success and failure garnered from developing ILM structures and strategies, and implementing the Studio format, will be utilized to further aid others in their pursuits of interactive learning. This is an area in which Rensselaer is making a major contribution to the way future students are educated and trained. Future progress in this arena is not dependent on vast resources, but on a commitment among faculty and staff to developing the most effective materials and methods possible, and to maximize their utilization in every appropriate avenue. Rensselaer has made that commitment.

Sample screen from the Manufacturing Handbook module
References

1. Oakley II, B., "Helping Faculty Teach in the Virtual Classroom", presentation at the National Electrical Engineering Department Heads Association annual meeting, San Diego, CA, March 1996.


