

Interactive Learning Modules for Electrical Engineering Education and Training

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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. The ILMs can be used by faculty for in-class demonstrations, by students for structured exercises (particularly in the Studio format of course delivery) and by students anytime, anywhere via the Internet. The ILMs allow the students to explore concepts in more detail and gain practical experience in design and application. They are developed to provide application-based motivation for learning, present fundamental concepts using animation and visualization, provide interactive practice on problem-solving, and open-ended design experience. This paper discusses the development, utilization and assessment of ILMs involving the 555 Timer IC, an Electrical Engineering Fundamentals Handbook (EE handbook), an Electronics Circuit Card Manufacturing Handbook, Common-Emitter Amplifier Design, Electronic Filters, Operational Amplifiers, and Convolution. Such modules are currently being used in our introductory courses in circuits, electronics, instrumentation, and signals and systems, all of which are taught using Rensselaer's Studio mode of delivery. The initial experiences by both faculty and students have been very positive, indicating that a combination of using interactive learning modules along with the Studio format of course delivery offers a new model for engineering education.

I. Introduction

Computers are such an integral part of our day-to-day lives that they control the microwave that heats our morning coffee, the publication of the newspaper we read with our breakfast, the car that carries us to work, and almost every aspect of the job once we get there. We gather information on the World Wide Web, and exchange information with colleagues via e-mail. But with all this available technology, we have only begun to scratch the surface of how we may harness the influence and power of the microprocessor to improve higher education.

Let us examine the students we are trying to reach. Those entering college today have become accustomed to television remote controls, computer games, and Web browsers that allow them to switch content at will - rather than stay engaged. Their shortened attention span, lowered tolerance for boredom, and aversion to static media challenge us to provide information in more dynamic, compelling, and interactive ways. Even the older students, who make up a growing off-campus

population, face greater demands on their time and are looking for institutions of higher learning that can be flexible in both course delivery methods and scheduling. Increased use of multimedia helps instructors meet these needs and, at the same time, integrate modeling, visualization, and decision-making processes associated with real-world applications. Using some combination of learning technologies, virtual simulations, web-based environments, and interactive materials, educators now have the potential to deliver needed information in shorter and more intense cycles to aid those competing in an increasingly technical and global market.

In 1994, Rensselaer Polytechnic Institute received approval from NSF for a three-year project to develop **Interactive Learning Modules (ILMs)** for education and training in manufacturing engineering. The project was part of the Technology Reinvestment Project Manufacturing Education and Training Program (TRP/MET) which was funded by the NSF, the Defense Advanced Research Projects Agency, and Rensselaer's corporate sponsors. The project generated materials that pick up where most textbooks leave off – to additionally allow the user to explore and understand the dynamic nature of how electronics are designed, manufactured and utilized. These materials provide application-based motivation for learning, present fundamental concepts using advanced visualization and animation techniques, and allow for interactive practice on problem-solving and open-ended design – some in a game oriented environment.¹ Building on what was learned from that successful effort, Rensselaer established the Academy of Electronic Media (the Academy) two years ago to serve as a university-wide resource for the development and utilization of multimedia teaching materials. In addition to the federal grant, funding for the Academy has come from Rensselaer, from industry contracts, and from New York State.

The trend toward Web-based learning has a long way to go, say Alfred Bork and David R. Britton Jr. of the University of California, Irvine.² What is the problem? Relying on HTML or even Java, the Web predominantly offers only point-and-click interactivity, yet full interactivity is an essential characteristic of effective learning systems. Bork and Britton have further commented that "for students to learn most effectively, they need a high degree of interaction. Effective learning materials continually diagnose student learning problems and provide immediate assistance to address those problems." Most of the courses they've seen on the Web "resemble poorly designed books with some hypertext capabilities. The kind of interaction that is needed can be provided only through systems that can understand natural-language responses from students to analyze the students' difficulties and to take appropriate action. Does this kind of system require artificial intelligence? No, it depends only on "careful design by excellent teachers who anticipate typical student responses." (IEEE Computer Jun 98)

While the original electronics oriented ILMs created under the 1994 grant were focussed mainly on retraining those who fell prey to military cutbacks, our group had begun to see a whole world of academic possibilities that could additionally address the interactivity shortfall discussed above. We established the Academy to embark upon an integrated interdisciplinary effort to develop electronic media, deploy educational products, and impact learning far beyond that which single-dimensional books or static Web pages can accomplish. The Academy has created dozens of multimedia products, containing hundreds of learning modules. They range from interactive tutorials to wholly immersive games. They can be distributed on the Web or CD-ROM. Most are aimed at a college-age audience, although many can be appropriate for technical classes in high school. We are currently creating special modules to teach and augment high school mathematics courses, particularly those using

distance learning elements. Working with the Center for Initiatives in Pre-College Education at Rensselaer, we will eventually address the whole range of kindergarten through life-long learners.

The modules can be used by faculty for in-class presentations and demonstrations, by students for in-class and out-of-class exercises, by trainers in corporate settings, and by lifelong learners - over the Internet - to explore concepts in more detail and gain practical experience in design and application.³ They are in use in engineering courses at Rensselaer and have been used in industry workshops given by Rensselaer faculty members and by faculty at a variety of other schools. The ILMs have also served as a model for those at other entities (e.g. AT&T, Boeing, Hudson Valley Community College, Stanford, UT-Dallas, etc.) to leverage the expertise garnered from developing multimedia. Examples of the ILMs can be accessed at <http://www.academy.rpi.edu>.

II. Interactive Learning Modules (ILMs)

The basic goal of the ILMs is to simultaneously stimulate multiple senses of the user to further engage them in the learning process. The user is first presented with the context of the material and then attracted to *peel off successive layers of the onion* to gain a full understanding of the basic principles and concepts. Additionally, the student is encouraged to *play* in an interactive, functional design space where he/she can get immediate answers to *what if* questions. The ILMs are intended to help the student develop the problem-solving and design skills that are such a valuable component of an engineering education.⁴ The modules encourage students to investigate dynamic principles that a textbook or formal lectures cannot address and are generally organized into three sections:

- 1) An introduction - which includes (nominally three) interactive examples of applications, introductory text, graphics, animated simulations, etc., and background tutorial materials that provide a sense of real life configurations available;
- 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 and games - consisting of specifically tailored, closed and open-ended problems that are configured in a manner that allows the user to utilize the analytical engines from the prior section (to explore their understanding of the material) and can provide on-line guidance (when progress deems it necessary).

The ILMs can be used in a variety of ways, as:

- supplementary material enriching a lecture with compelling illustration;
- introductory or supplementary material in a homework assignment, presenting the material in a multimedia format, using different sensory modalities to reinforce retention;
- collaborative problem-solving and/or design tools for teams of students, enhancing creativity through live dialogue and the ability to experiment;
- simulation game environments for individual or team participation; and
- play/tinkering environments, enabling exploratory, student-centered learning.

The ILM content has been developed using a modular structure so as to maximize the potential for multiple use of the same content. For example, each section of the EE Handbook can be used

individually in a specific tutorial module (e.g. "Filters" entries also provide introductory material for the "EE Filters" design module) or together in a group, such as in the handbook. This modular approach allows instructors with varying curricula and syllabi to pick and choose, adapting the materials to their own particular implementations. The individual instructor can mix and match ILMs and teaching styles adapting to their own educational needs. The following sections briefly describe a few of the electrical engineering education and training Interactive Learning Modules (ILMs).

555 Timer 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 figure 1 below). 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.

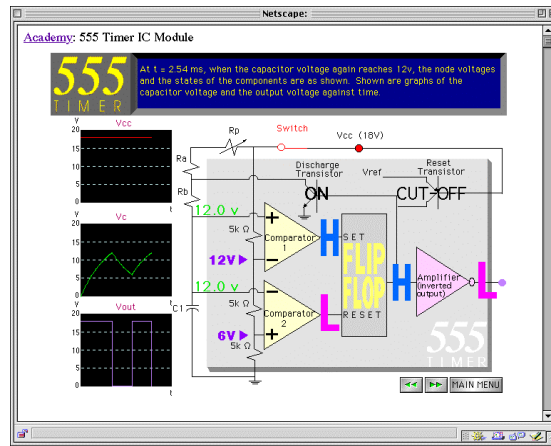


Figure 1. Sample 555 Timer Screen

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, an electronic filters section (an example screen from the high pass filter section is shown in figure 2 below) 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 for use as a stand-alone handbook and in conjunction with a particular circuit module to provide an introduction and tutorial background (e.g. as a contextual precursor to the more comprehensive “EE Filters” module).



Figure 2. Sample HPF Screen from the EE Handbook

Manufacturing Handbook: The electronics manufacturing handbook includes animated presentations of current printed wiring board assembly that are intended to provide students and industrial workers with an overview of the processes involved. A prototype presentation of the equipment and processes used in NorTel's Research Triangle Park (in Raleigh, NC) 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 electronics board manufacturing handbook material is already available on the Internet, and can be accessed via the academy website (an example is found in figure 3 below).

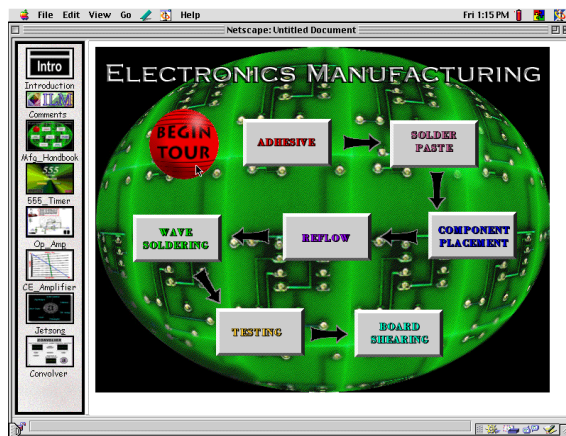


Figure 3. Sample Manufacturing Handbook Screen

Common-Emitter Amplifier Design: 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, 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 on amplification of an AC input signal (depicted in figure 4 below).

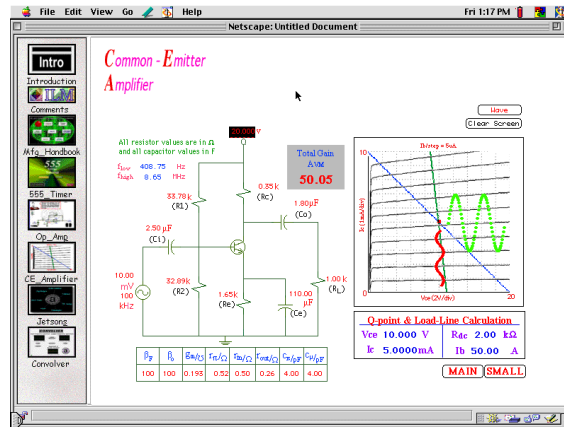


Figure 4. Sample Common Emitter Amplifier Screen

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 (as seen in figure 5 below), thus providing the user with relationship between the frequency and time domains.

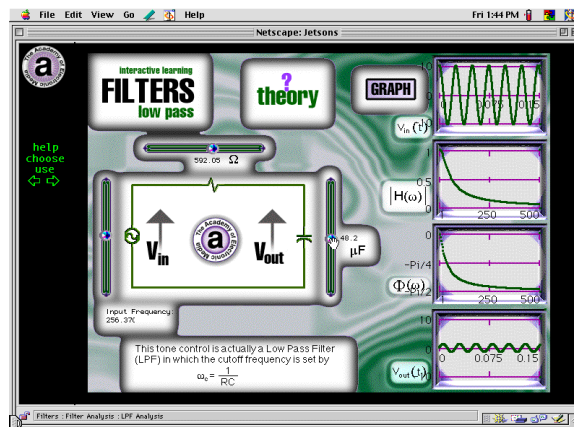


Figure 5. Sample Filters Playspace Screen

Operational Amplifiers: The operational amplifier (Op Amp) module allows the user to design and analyze various op-amp circuits (a screen from which is shown in figure 6 below) 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 their challenges provided in the section's corresponding problem session. In addition, the user examining the trade-off between the amplifier's gain and power supply (V_{cc}) can explore the concept of device saturation (due to inappropriate DC supply choices) -- along with the resulting distorted output.

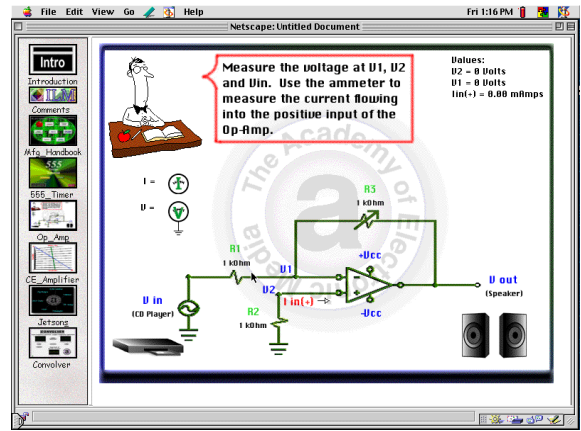


Figure 6. Sample Op Amp Screen

Convolution: The convolution module allows the user to pick two choices from a variety of common signals that they would like to convolve. In addition, the user can modify the signals' amplitudes and duration to further understand the impact on the resulting signal waveform. The subsequent screens provide an animation of the convolution process, using the values chosen in the introductory playspace screen (depicted in figures 7 and 8 below). The user can further choose to step through the graphical depiction of the convolution process or run the animation in its entirety. This module is an excellent example of how dynamic media can vastly improve a student's opportunity to grasp the basic concepts.

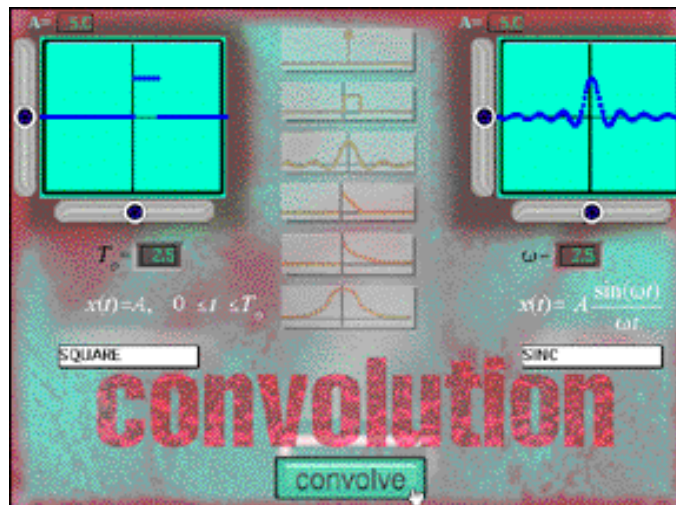


Figure 7. Sample Convolution Introduction Screen

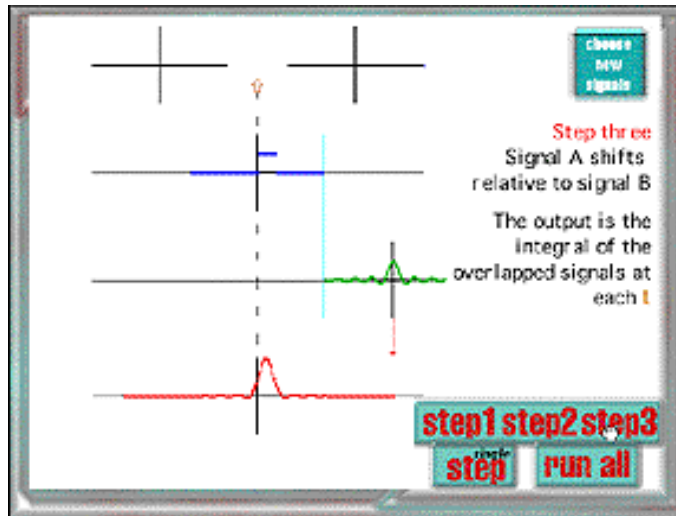


Figure 8. Sample Convolution Module Output Screen

III. ILM Development

Compelling multimedia typically involves four zones of creation: cognitive research; development; deployment; and assessment. These benefit most from multidisciplinary collaborations at every level and through the consideration and completion of tightly woven cycles of feedback as depicted in figure 9 below. These collaborations benefit most from involving cognitive scientists, content experts, graphic artists, programmers, production managers, deployment personnel and prospective users at the start of the creative process. This team approach to multimedia creation allows insight into how learning occurs to potentially improve the retention of the concepts presented. For example: the choice of where interactive elements are placed on the "Filters CAD" screen (shown in figure 10), in conjunction with the resulting graphical changes generated by the movement of an element (such as the choice and use of sliders that control the component values), can dramatically affect the overall user experience.

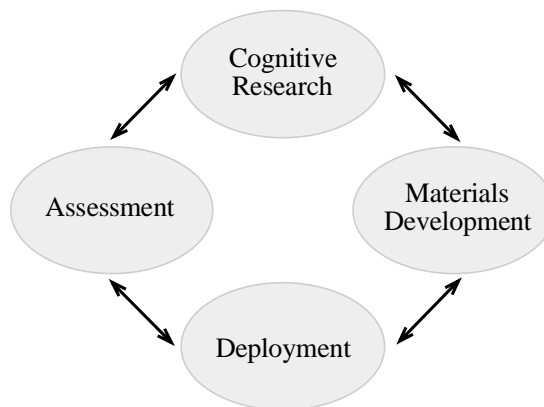


Figure 9. Cycle of Multimedia Modular Materials Creation

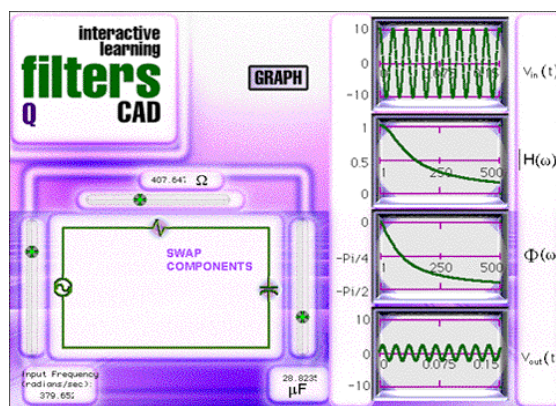


Figure 10. A Sample Interactive Multimedia Learning Module Screen

Even the best intentions to develop highly stimulating, highly interactive and educational applications must overcome significant human resource impediments. The development of multimedia requires creative personnel who are capable of: helping content experts to "storyboard" their materials; rapidly acquiring and manipulating media; keeping up with the multimedia authoring tool(s) learning curve(s); and serving as multimedia catalysts for the organization. They further guide the organization through the design of starting "templates" and the development of re-usable libraries that contain the source code for programming the interactive elements. The genesis of such a core competence typically involves a group of somewhat unique individuals who have typically spent many sleepless nights exploring the potential of the latest and greatest software applications. They are passionate about multimedia creation, just as any artists would be about their work. The Academy involves a staff of such experts to facilitate and manage the ILM development processes.

Thorough ILM storyboards, developed by the team from the onset, have drastically reduced the number of cycles of feedback necessary to bring a module to completion. Acquisition and production of the media proceeds in parallel with the programming effort, thus resulting in shorter deployment organization and testing. Furthermore, the content is typically best sub-divided into basic modules that can be developed in parallel and then ultimately be linked together to create the final product (via a website or compiled application). The deployment modality, along with the target audience, is identified and understood prior to the authoring process in order to optimize the user experience in graphics development and programming phases. Platform dependencies, network connections, web server access times, input/output limitations and overall CPU performance were considered in the initial development phase and addressed in the deployment testing phase of the product's evolution.

The ILM developers now have a proliferation of user-friendly multimedia authoring tools to choose from. Adobe's "Photoshop" (for image and graphics manipulation) and "Premiere" (for video capture, editing and compilation) utilize intuitive graphical user interfaces that allow novices to develop and modify media in dramatically reduced production cycles. Even software programs once viewed as primarily office tools (e.g. Microsoft's "Word" and "PowerPoint") are now focused on rapid web-oriented media development and utilization. Today's tools allow developers to push current technologies to their edge and beyond, to augment existing multimedia authoring programs and

discover unique applications. For example, Macromedia's "Director" (for multimedia authoring) and "Dreamweaver" (for website development and organization) products provide extensible architectures (via the use of "Xtras") for developers to program additional "cool" functionality into their products using higher level languages (such as C++ and Java). The ILMs have been created using "Director" because of its ease of use, time-oriented operational metaphor, cross-platform development and distribution opportunities, pre-programmed interactivity (via "Lingo", Director's programming language) and extensible architecture.

We have found that students need to be involved in the development of the ILM materials to best provide us with a fresh perspective. The students often serve as part of the team that decides how to best present the information to others in an engaging and exciting manner. Many of them had recently been exposed to such material in lectures and can offer what was either missing or not very clear in the delivery. This input is then combined with the storyboards generated by the content experts to clarify and provide interactive visualizations where possible in the multimedia modules. It is often the input from our student programmers that results in modules that most actively engage the user. These students additionally perform a "check-and-balance" step prior to full deployment in a classroom by testing the modules and offering commentary on the education garnered from the 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 new-found capabilities, knowledge sets and appreciation for living in a media driven society. They harness their enthusiasm and experience to produce materials that the next generation can relate to, way beyond that which is typically provided in a standard lecture modality.

IV. ILM Deployment

The multimedia materials have been organized in a way that encourages students to successively dig deeper into the theory and gain a full understanding of the basic principles and concepts. The 555 Timer Tutorial, for example, allows the user to take the top off the chip and play with the circuitry inside. With further clicks of the mouse, the user can continue to move down through the layers of the 555 integrated circuit. The historical process of beginning with theory and later offering applications can be switched around by providing "play spaces" where one can assemble, test, and assess virtual experiments to uncover and better grasp the underlying theory. In our simulated operational amplifier, users make adjustments and take measurements in a module designed to help them discover Ohm's Law. Students should be encouraged to play in highly interactive functional design space where they can get immediate answers to "what if" types of questions. In the amplifier module, they can make adjustments to improve the performance of the equipment and then hear the differences in the sound. Such exercises help them develop problem solving and design skills that are such a valuable component of an engineering education.

The ILMs are designed to allow professors to use them in different ways, depending on the level of the course and the abilities of the students. We have found that the more modular the material, the easier it is for others to adopt as a part of their courses. The content is typically broken down into the smallest kernel possible, in order to best serve a large community of educators who will pick and choose nuggets for what they constitute as a course. For example, the ILMs are being used in basic engineering classes at Rensselaer, in distance learning classes, and in adult training classes. We also are developing modules that can be used in K-12 environments to feed the pipelines and further allow community colleges to offer technical degrees and certificate programs in direct response to rapid

surges in industry sectors. The 555 module described earlier can be used in a high school physics class to illustrate the concept of a capacitor storing charge and in a community college class to understand the fundamentals of timing circuits.

The ILMs are made available at anytime, from anywhere so that the student is no longer restricted by the walls of a classroom, the bindings of a book, or the capabilities of a single lecturer. Our modules are made available to the students via the internet in an organizational presentation format called "Jetsons" (which is depicted in figure 11 and can be accessed via <http://academy.rpi.edu>) and can be additionally discovered by entering "555 timer" into a search engine such as Yahoo.

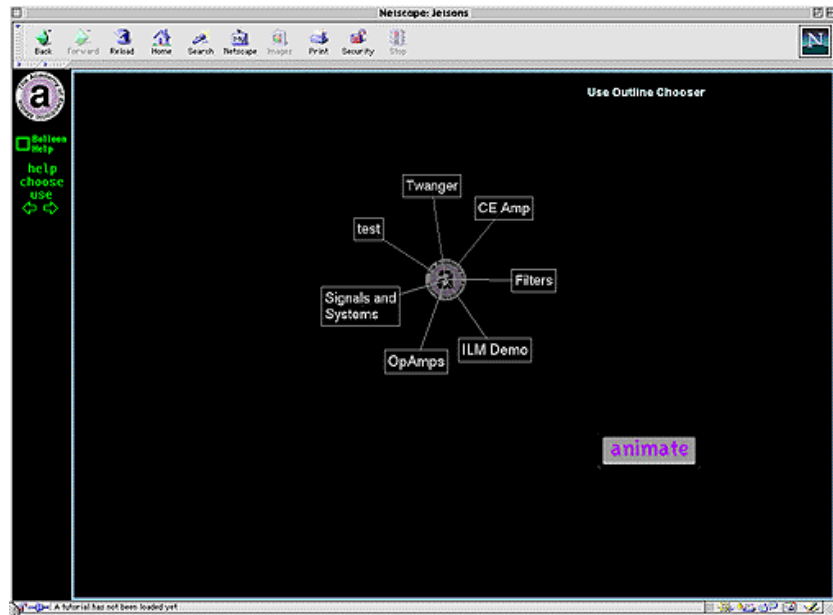


Figure 11. Sample "Jetsons" Screen

V. ILM Utilization

The prospect of using the ILMs in the classroom required us to rethink basic pedagogy. At Rensselaer, we have turned to the studio classroom for educational delivery.⁵ In this format, we eliminate large lecture classes. Instead, 40 to 60 students participate in sessions that integrate lecture, laboratory, and recitation sessions. Classes focus on student problem solving, not on presentation of materials. The instructor acts as mentor and adviser in a classroom designed for hands-on cooperative learning. Rensselaer has successfully pioneered this approach in introductory science courses.⁶ We are revising the electrical engineering curriculum, which is the first studio implementation in a discipline-specific engineering program. In these classes, we have introduced the use of our Web-based ILMs. We began using this model in Circuit Analysis, Analog Electronics and Electronics and Instrumentation courses during the 1996, '97, and '98 academic years, and we are extremely pleased with the initial results.

We usually break a Studio class into five or six separate activities, so that the students are switching gears every 20-30 minutes to maintain interest and motivation. Activities could include mini-lectures (no more than 15-20 minutes), pencil and paper exercises, interaction with Web-based materials, design, simulation, circuit construction, and experimental measurements. In a typical class, a professor

briefly explains a concept -- perhaps the operation of the 555 timer. The professor then asks the students to run through one of the simulation modules. They swivel their chairs to face tables behind them that contain multimedia-capable personal computers and an array of electronic equipment. The ILM shows them how the circuit operates, giving them step-by-step picture of its operation. When the students have had a chance to explore the module, the professor then asks them to assemble a real circuit, perhaps an oscillator that uses a 555 Timer.

The ILMs clearly provide an exciting, interactive alternative to traditional classroom exercises - allowing students work at their own pace. The more capable students progress further in the same amount of time, while less capable students receive assistance from the faculty member and student assistants. Although students are not yet required to use the ILMs outside of class, faculty members encourage them to do so to further their understanding and practice. Outside-of-class use is high, as measured by the levels of activity on our servers, but the affect of this on their 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 appears is quite high. Many of our preliminary conclusions are based on the impressions of professors who have taught in both formats, but there have been some surveys. In one comparison of two sections of circuit analysis taught in spring 1997, students in the studio/ILM version performed slightly better and reported greater satisfaction. The median exam score for studio students was 79.68, compared to 74.29 for a similar group of students in the lecture version. On a scale of 1 to 4, students rated the lecture version of the course at 3.0 and the studio/ILM version at 3.6. When asked if the course increased knowledge and skills in the subject, the students rated the studio version at 3.8 and the lecture version at 3.4

The early results of the combined ILM/Studio approach has been so encouraging that the faculty have voted to move all the introductory electrical engineering courses to this format, eliminating several required laboratory courses. We are completely renovating the classrooms needed to teach the needed sections of eight one-semester courses -- with typical enrollment of 80 to 150 each -- in this format.

VI. Conclusion

Our challenge, as educators, is to entice and maintain interest by providing content that fuels a desire to "stay tuned", similar to that which the long running TV show "MASH" once generated. We can meet this challenge by producing contextual, dynamic, multidimensional media that weaves theory, principles, and problem-solving techniques into stories that first captivate the user and entice them back again and again. Our vision should be to unleash the potential for the individual to feed at the information smorgasbord of the web by engaging the user via interactivity. By posing a scenario in which the student is asked to develop a circuit that electronically mixes the signals from the various instruments in a rock band, a relevant context is provided along with a compelling challenge that grabs the attention of the student. The Op-Amps module can then be used to offer a basic understanding and an interactive design "playspace" in which the user can then prototype and test their mixer circuit by listening to the resulting output. The next time the user accesses this site a totally new contextual design challenge appears for them to solve. In this way, the future should offer a time in which the only limit to what can be learned and utilized by an individual using these interactive materials is exhaustion!

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