# New electronic courseware modules for selected upper-level electrical engineering courses.

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**Abstract**

A recent award from the National Science Foundation (DUE-III program) was used to establish a computer-integrated classroom to support instruction in selected undergraduate electrical engineering courses. The new classroom is being used to address three pedagogically fundamental problems:

(1) insufficient mastery of engineering mathematics by many students,
(2) student passivity within the traditional lecture format,
(3) insufficient use of computation and visualization in the learning process,

New electronic courseware is being developed, using state-of-the-art software for mathematical computing, to facilitate and foster an active learning environment. Through increased use of computation and scientific visualization, we expect to see improvements in students' level of interest, increased classroom participation and finally, improved learning outcomes.

## Introduction

Many students in engineering and the sciences have difficulty learning fundamental concepts in their field of study because of their limited command of mathematics. A student's lack of adequate mathematical skills is one of the primary barriers to effective learning. To compound the problem, many courses in a typical electrical engineering curriculum remain taught by means of a more or less traditional lecture. For many students, the combination of difficulties with the level of mathematics and passivity within the traditional lecture style has an overwhelmingly negative impact on their ability to learn and understand the subject matter. In recent years, scientific visualization has emerged as an important tool in helping us understand many complex physical phenomena. However, the problem of translating standard mathematical notation into the traditional high-level computer languages has made it difficult to use programming and computers in the undergraduate classroom.

To overcome these problems, state-of-the-art software for mathematical computing is being integrated into the teaching process to facilitate and foster an active learning environment. The plan is to replace many of the typical "chalkboard" lectures with closely supervised interactive, "hands-on" sessions in a computer equipped classroom. The essential feature in this new approach is the systematic use of a powerful mathematical computing environment that simultaneously forces and empowers the student to be an active participant in the lecture. Ultimately, the goal is to enhance understanding of fundamental theoretical concepts within the discipline by significantly increasing the use of computation and visualization in the learning process.

However, to fully realize the potential of active learning strategies in the engineering classroom, students must be given not only the software tools but courseware materials that-make it possible for them to experiment with mathematics and more generally, computing. Recently, advances in mathematical software and the computational power of a desktop computer have finally made it possible to put a sophisticated learning tool in the hands of every student. For the first time, this enabling technology truly allows the average user to explore complex phenomena using mathematics, by experimenting interactively and intuitively with the defining equations and computational algorithms. The most recent version of *Mathematica,* a leading computer algebra (CA) system, has made it possible to do technical computing using fully functional and properly typeset traditional mathematical notation. This dramatically decreases the need to explain language syntax, thus simplifying the development of online courseware materials and their integration into a classroom environment.

**The Mathematica Classroom**

The Mathematica classroom is organized to maximize interaction between student, course material, instructor and computers. The workstations are positioned along the periphery of the room, facing inward, with standard seminar tables in the center. Such an arrangement allows easy mixing of classroom activities to suit the specific computational needs of any particular lecture session. A networked printer, an instructor's station and a projection unit complete the equipment list. *Mathematica* (Wolfram Research) was chosen as the computational tool for this project, since within one program it successfully integrates visualization, computation and presentation features. It excels in symbolic and graphical computation and has a very powerful suite of numerical functions. Combined with an extremely powerful and rich programming language that supports a variety of programming styles, it has all the necessary features for easy, natural prototyping of computational tasks, from simple to complex. Indeed, a significant portion of *Mathematica* is written using the *Mathematica* programming language[1]. Unlike traditional high-level programming languages, it is well suited for in-class use. The *Mathematica* language combines in a completely consistent and uniform way both traditional mathematical formulas and computer code[1], thus making it a superior technical documentation medium. The decision for adopting *Mathematica* was also influenced by the well-publicized calculus reform effort* and the use of the software in selected sections of the Calculus sequence at USM. Thus, a majority of engineering students gains some exposure to the software in their first year at USM.

A typical course is organized as an alternating sequence of traditional and *Mathematica*-based lectures and exercises. Frequently, a single class session mixes the two types of classroom activities. Traditional lectures are used to lay the theoretical foundations, while the laboratory sessions reveal implementation details and provide opportunities for experimentation, visualization and testing. The two forms of instruction complement each other well. Theory and implementation reinforce each other building a deeper understanding of the subject matter. To achieve this end, *Mathematica* is used in a variety of ways. As a productivity tool, it helps students solve many of the problems found in standard undergraduate textbooks. The student benefits by spending more time formulating and understanding the problem than on algebraic manipulation. Standard examples of algebraic evaluation common to many introductory undergraduate courses include partial fraction expansion of rational polynomials, solutions to constant coefficient difference and differential equations, solutions of systems of linear equations and evaluation of Fourier, Laplace and convolution integrals. These are examples of "calculator-like" problems easily solved by *Mathematica* with typically a single, simple command.

(1) Inverse DTFT of ideal halfband differentiator

In[2]:= $\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} \mathrm{I}\,\omega\ \mathrm{Exp}[\mathrm{I}\,\omega\, \mathrm{n}]\, d\omega$ // ExpToTrig

Out[2]= $\frac{\pi \,\mathrm{Cos}[\frac{n\pi}{2}]}{n} - \frac{2\,\mathrm{Sin}[\frac{n\pi}{2}]}{n^2}$

(2) DTFT of exponential sequence

In[3]:= $\sum_{n=0}^{\infty} r^n\, \mathrm{Exp}[-\mathrm{I}\,\omega\, n]$

Out[3]= $\frac{E^{I\omega}}{E^{I\omega} - r}$

(3) Symbolic partial fraction expansion of a transfer function

In[14]:= Factor$\left[\frac{z^2 - 1}{z^2 - 0.9\, z^1 + 0.81}\right.$, GaussianIntegers -> True$\left.\right]$

Out[14]= $\frac{1.\ (-1 + z)\ (1 + z)}{((-0.45 - 0.779423\, I) + z)\ ((-0.45 + 0.779423\, I) + z)}$

In[15]:= Apart[%]

Out[15]= $1. + \frac{0.45 + 0.901308\, I}{(-0.45 - 0.779423\, I) + 1.\, z} + \frac{0.45 - 0.901308\, I}{(-0.45 + 0.779423\, I) + 1.\, z}$

**Figure 1.** Examples of basic calculations with *Mathematica.*

To deepen understanding and further promote active learning, "take-home" assignments and computer projects complement such simple exercises. It has been our experience that projects are an important learning instrument. Given a capable computational tool that makes mathematics more accessible and programming easier, projects help to motivate the student, they reward initiative and creativity, and prepare for independent, unassisted learning. Systematic use of writing and revision is also an important cognition tool, so an essential component of these projects is the requirement that results be presented in clear, coherent prose.

In summary, the use of *Mathematica* allows many students to overcome their typical algebraic manipulation difficulties. More importantly, it serves as a powerful exploratory tool that leads to a deeper understanding of the subject matter. Finally, thanks to the development of course materials that make use of powerful computation and visualization features, a significantly richer curriculum is indeed possible.

**Courseware Development**

To date, *Mathematica* has been integrated into three upper-level electrical engineering courses in the signal processing area, including junior-level Signals and Systems, and two senior-level elective courses: Digital Signal Processing and Digital Image Processing. The developed courseware materials accompany and extend the excellent traditional textbooks selected for each of the courses[3,4,5]. The available materials consist of topical lectures covering selected important topics in each course. Each notebook is used in one or more $1^{1}/_{4}$-hour class meetings. At the present moment there are approximately 10-15 electronic lectures, at various stages of development, for each of the three courses. A few simple principles govern the organization of a notebook. Each notebook typically deals with a single important course topic. It includes moderate levels of introductory and explanatory text to allow some degree of independent study. The notebooks have examples of typical calculations that demonstrate solutions to standard problems. Additionally, each notebook includes “discussion problems” that students answer during the lecture session. This activity promotes self-discovery, and allows the student to actively participate during the lecture. Finally, a set of basic and extended computer-based homework problems are attached to each notebook. The role of the latter is to extend the students knowledge and interests beyond the necessarily limited confines of the lecture material. An important component of the learning environment in these courses is the extended computer project. This is a way of tapping the tremendous learning potential of engaging students in solving relevant computational problems in the context of their discipline. In a recent Digital Image Processing course students wrote *Mathematica* implementations of two-dimensional unitary transforms and compared three different image compression algorithms[6]. This past semester, students in Signals and Systems explored the concepts of the short-time Fourier transform and time-domain windows in the process of coding a spectrogram. A spectrogram is a pictorial representation of the spectral content of an audio signal as a function of time.

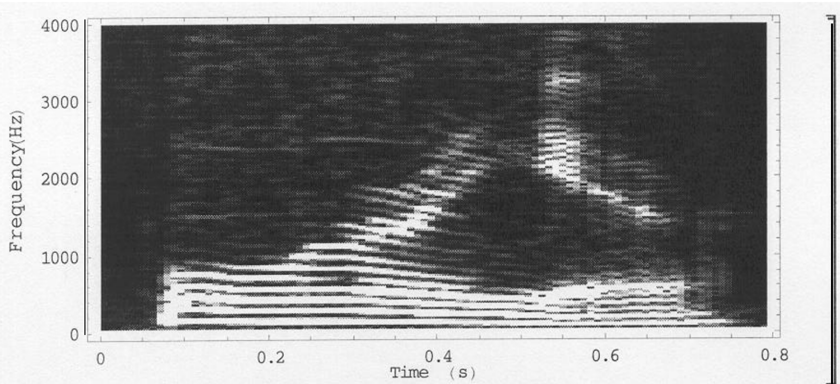


**Figure** 2. Spectrogram of the word “Fourier”.

Other projects have included the design of an adaptive differential pulse code modulation system (ADPCM), a half-band discrete differentiator, and an implementation of the Schűr-Cohn stability test.

**Summary**

*Mathematica,* a leading computer algebra system is being integrated into selected undergraduate electrical engineering courses. The goal is to improve how students perceive the courses and how they learn the fundamental concepts. A large number of supporting lecture notes, in the form of *Mathematica* notebooks, have been developed and are presently being used in a dedicated computer equipped classroom. Student evaluations of the new courses, based on questionnaires and informal discussions, indicate guarded acceptance of the new format. There are clear indications of satisfaction on the part of some students, but also strong concern about the many difficulties encountered in learning and using *Mathematica.*

**Acknowledgment**

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Biography

MARIUSZ JANKOWSKl received the Ph.D. in Electrical Engineering from the City University of New York in 1989. He was Visiting Assistant Professor of Electrical Engineering at City College from 1989 to 1990. He is currently an Associate Professor of Electrical Engineering at the University of Southern Maine. His research interests are in the area of signal/image processing with emphasis on signal enhancement, restoration and measurement in biomedical applications.