Modified Studio Lab-Classroom Used to Teach Electrical and Computer Engineering to Non-Engineers

Robert J. Voigt, Robert Ives, Jesko M. Hagee
U.S. Naval Academy

Abstract

This paper addresses a solution to the challenge of teaching Electrical and Computer Engineering to non-engineering majors. All non-engineering students at the Naval Academy are enrolled in a two course Electrical Engineering sequence as a core requirement. There are many challenges in teaching this type of course. For example, the students have various mathematical abilities, most being humanities majors while others may major in Math or Physics. There is a diversity of learning styles in this mixed student population and, as a result, we have chosen to implement an interactive learning environment which we have found to be very suitable. The approach is a hands-on, learn by doing, integrated laboratory/classroom approach. To accomplish this, we constructed several studio classrooms, modified versions of those in use at Rensselaer Polytechnic Institute (RPI). One major difference is the number of students per section; ours are much smaller than RPI. Another difference is the need to teach a variety of subjects in the same classroom/lab. The two-course sequence covers everything from basic circuits and motors/generators to digital communications and networks. Our class sizes are small and there is a great deal of interaction between the students, working in teams and individually. In this paper we shall address the preparations required to offer this course including the equipment set-up, the room layout, the syllabus, lesson objectives and scheduling of the rooms. The assessment of the success of this model will be addressed, although it may be years before we gather enough data to have any statistical significance. We illustrate the importance of cooperative and collaborative learning in this environment and show how we have integrated these concepts into the courses. Finally, we present an overall assessment of this course from both the students' and instructors' points of view.

I. Background

The United States Naval Academy is unique in many ways. For one, we hire all of our own graduates. While they may choose different areas of the service to serve upon graduation, they are all Navy or Marine Corps officers in a military that is as technically complex as it has ever been. Thus, all of our graduates, no matter which major they choose, take a rigorous technical core. This core includes three semesters of Calculus, two semesters each of Physics and Chemistry and among other engineering courses, two semesters of Electrical Engineering. This two semester course sequence is designed to prepare the students to be able to understand, at a most basic level, the equipment they will be responsible for operating and maintaining in the fleet. A secondary goal of these courses is to instill in the student an ability to solve complex problems through the use of critical thinking skills. Up until recently, the humanities majors took only a single semester course in Electrical Engineering. Fleet input from a 1997 survey, however, indicated that our graduates were not fully prepared to deal with the high level of information technology integration in today's military systems.[1] This survey, part of a curriculum review, entitled "Curriculum 21," was the primary reason for instituting a second course and was an input into the process that defined the make-up of that course. The results of that study are reported in more detail along with the initial response to that study in the form of a new course.[2] The Academic Dean's desire was to look at how we could get this material into one of the required courses in the technical core that all non-engineering students must take.

II. Technical Core Improvement Group

In the year 2000, the Academic Dean formed a committee, the Technical Core Improvement Group (TCIG), to examine the entire technical core. This group looked at not only the course developed by the Electrical Engineering Department in response to Curriculum 21 but also all of the present and potential needs in the area of information technology for the fleet. The result was an outline for a two course sequence; EE301: Electrical Fundamentals & Applications and EE302: Electric Machines and Information Technology Systems. The first semester course was not much different from the previous one semester course that all students already took. It was basically a circuits course for non-engineers. The second semester course was very different and included a wide variety of topics from motors and generators to computer networks. Many problems were evident when these two courses were put together as a two-course sequence. One problem was in course content and sequencing. If motors and generators was to be taught in the second semester, it had to be done in the first few weeks while three phase power from the first semester was still relatively fresh in the students' minds. Another problem, and one potentially more difficult to solve, was how to configure the facilities to teach such a variety of topics. Third, the size of the course was a problem that manifested itself in many places. It was to be taught to approximately 700 students with less than a year of course preparation time. It was also made clear that there would not be any new laboratory space given to the department to allow for separate and unique laboratories for the two courses. It was about this time when we were first exposed to the studio laboratories being used at Rensselaer Polytechnic Institute (RPI).

III. The Studio Classroom Concept

The Studio classroom concept, as developed by RPI, consisted of a combination lecture/laboratory space. In the words of their college president, Dr. Jackson, "In these classrooms, knowledge and application are intertwined seamlessly."[3] In their Laboratory for Introduction to Embedded Controls, the studio classroom implementation was in a tiered room where the students could face the front of the room and have an instructor present material on a blackboard or overhead and then turn around to have a laboratory bench available to do the laboratory interactive portion of the course. They also believed, at the time, that the proper size for such a room would accommodate 60-70 students. We did not have the funds or the room to be able to set up our version of the studio classroom in this manner. We had already planned to purchase new benches to replace our aging benches from the circuits course which had been in use since the 1960s. We also have always had class sizes of around twenty and were not willing to sacrifice our low student-to-teacher ratio. The teaching concept of the studio classroom was what we really wanted for our students. The students in this course were not engineers so we felt that this format for learning was an obvious choice. The students would get more hands-on applications-oriented learning than we could offer in a separate classroom and laboratory experience. It was also clear that we would be able to maximize this effect for a wider variety of topics in a single studio classroom better than with application specific labs and generic classrooms. We had one other goal: we wanted this to be fun and interesting to students who really had no desire to be in the class for its content, but were there simply because it was required. This goal is not as altruistic as it sounds: recruiting technical majors is challenging, but if the students can enjoy the material, it makes attracting freshmen that much easier.

IV. The USNA Prototype Studio Lab/Classroom

Our prototype room was approximately 1500 square feet. We divided the room into two areas, one with lab benches and one with movable tables for lecture and group work. Each room was equipped with a ceiling mounted projector, plenty of chalk board space and an instructor station. The instructor station consisted of a computer, wireless keyboard and mouse, a document camera, a VHS tape player and a DVD player all wired into the overhead projector and ceiling mounted speakers. In order to support the variety of topics, the benches are powered by 208V three phase power. The benches are all wired together with six common signal connections to a master workstation driven by a LabView virtual instrument. There are 21 of these benches in a room with the goal of one student per bench for certain exercises and the ability to team for others. The room also contains a cart with 24 laptop computers with wireless network cards, a base station and printer on top of the cart. This setup allowed for the topics listed in the syllabus, discussed in a later section, to be covered. The tables were movable for cooperative/collaborative group work and power was supplied from the floor for the laptops.

V. The Schedule

The Naval Academy has six 50 minute periods in a normal scheduled day. Our traditional format for teaching a laboratory course consisted of 3 one hour lectures (MWF) and a two hour laboratory period (Tu or Th). One of the changes that RPI had to make to accommodate the studio classroom was to use three 2 hour lessons per week. This made it possible to spend some time lecturing, some time problem solving and provide adequate time on the applications portion in a single class meeting. We did not have the luxury of adding a contact hour to the students' schedule, yet we knew we needed more than a single hour class to make this work. Room scheduling is always an issue but we could schedule these rooms 100% of the time using the old format. We needed to maintain that efficiency while allowing for longer class times but, at the same time, not increase the contact hours or do something so radical that the students would not be able to schedule their other classes. Our solution is described in Figure 1. In this figure, blocks of common shading represent a single section's schedule. We have only one 1 hour lecture period and two 2 hour periods which allow for the interaction that we were looking for. Of course, the ability to schedule and use a room 100% of every available hour was appealing.

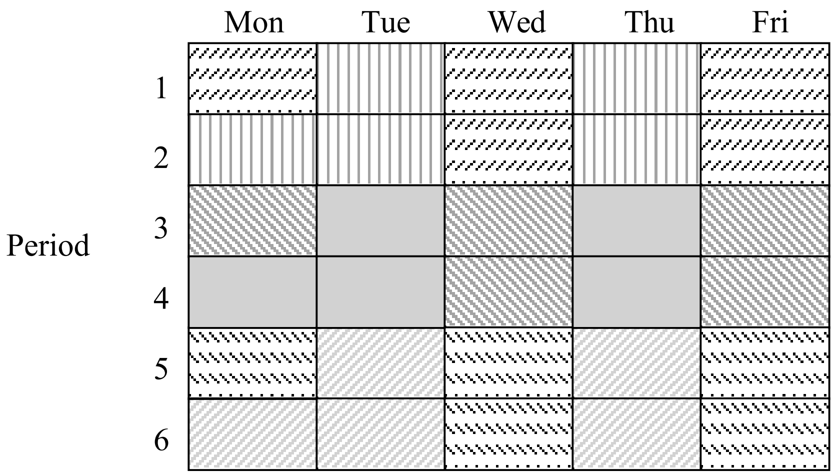

Figure 1: Room scheduling

VI. The Syllabus

The TCIG recommendation for a two course sequence was awkward primarily due to the splitting of logical topics across semesters. Motors and Generators was put in the second semester simply because there was no room in the first semester. Once we started to rearrange the topics according to the new schedule and integrate our applications-oriented exercises, which we dubbed the "Practical Exercise" (PE), we found we had more time in the schedule and were able to move that topic back into the first semester. The TCIG recommended topics listed for each course is listed in Table 1 below. The final content agreed upon for the first attempt will be discussed in a later section.

TCIG Recommendations for Technical Core Improvement	
EE301 Topic List	EE302 Topic List
Introduction to the EE Toolbox	DC Motors and Generators
Simple DC Circuits	AC Motors and Generators
DC Circuit Analysis Techniques	Digital Theory
Transients with Differential Equations	Computer Architecture
Math Review	Analog and Digital Communications
Simple AC Circuits	Satellite Communications
AC Circuit Analysis Techniques	Computer Networks
Ideal Transformers	
Three-Phase Power	

Table 1: Original recommended course content

VII. Staffing

USNA does not have Teaching Assistants and very little post doctoral help. Professors who teach laboratory courses also run the laboratories. We use our laboratory technicians to supplement the professor in the lab environment for safety reasons and to aid the students in accomplishing the exercise, essentially acting as teaching assistants. We had a problem with only a handful of technicians to assist us; they could not spend every hour of every day in the classroom and still maintain and repair equipment. Our lab manger devised a scheme which would allow the technicians to be present for those exercises where safety was a concern (i.e. motors and generators) but still be able to do their maintenance jobs. We assigned a priority to each PE based on our perception of required support and we gave him a fairly detailed schedule of when they would take place to the hour. Based on this, he assigned laboratory technicians to move around and cover the course.

VIII. Weekly Lesson Guide

In light of the number of professors teaching in the new studio classroom format, we decided that a course management tool was necessary. By integrating the laboratory exercises with lecture into a common time slot, there was less flexibility in the timing of the lectures. Since our old method of having a separate 2-hour lab time no longer existed, we had to ensure that ample time was available whenever a lab was scheduled. Additionally, the two course sequence was being taught to nearly 700 students with a section size of about 20. The first semester it was taught, there were 35 sections and 19 instructors. In order to spread the administrative tasks of homework and exams, the students had common homework assignments and exams. We thought it prudent to give guidance to the instructors to ensure that all the students would cover material in a similar manner and more importantly, at a similar pace. One tool we used was the Weekly Lesson Guide.

A sample Weekly Lesson Guide, shown in Figure 2, broke down each lesson for the week. The intent was to give the instructor guidance on how long they should spend on lecture and still have time for students to complete the other activities planned for that lesson. Due to the rotational nature of the military faculty at the Naval Academy, this also gave new instructors some structure to their lessons before they walked into the classroom for the first time. Our primary goal, however, was making sure we had adequately accounted for time to lecture, perform demonstrations for the students, do group work, work at the benches, etc.

Lesson 4	Lesson 5	Lesson 6	Minutes
Series Circuits and KVL Lecture	PE Calculations	Parallel Circuits and KCL Lecture	10
	PE #3 – KVL		20
			30
Homework Problem Solving		Demo #3 – Grounds	40
	Voltage Division Lecture		50
		PE Calculations	60
	PE Calculations	PE #5 – KCL	70
	PE #4 – Voltage Division		80
			90
	Homework Problem Solving	Quiz	100
			110

Figure 2: Weekly lesson guide sample

When we began putting the Lesson Guide together, it became apparent that, unlike in the traditional lecture format, the lecture became secondary to the other exercises. Practical Exercises (PEs) drove the schedule. We worked the lecture time around the applied work we wanted the students to accomplish. The end result was often achieved by determining the topic of emphasis for each day and designing PE and lecture simultaneously to fit into a two-hour block. This also achieved our goal of utilizing the practical work on the lab benches immediately to reinforce the theoretical material presented only minutes earlier.

In addition to the PEs, we wanted to incorporate other new ideas into the course. Previously, all demonstrations were created by the individual instructor and conducted at their discretion. Since we now had unprecedented access to lab equipment in the lecture classroom, many more options for demonstrating concepts were available to us. Demonstrations will be discussed in greater detail below, but we started to see that planning them in the Lesson Guide would help ensure instructors did not run out of time to perform relevant demonstrations as they presented them in class.

In order to use collaborative learning, we planned time into the class day for problem solving. The instructor either assigned problems to do or allowed students to begin their homework in class. This jumpstart on work, especially when the students worked in groups, proved to be very productive. Questions which had previously not come up until the next lesson after the students had worked on homework were asked and answered for the entire class. Their classmates answered many of the students' questions as they worked together. The end result was fewer questions and less confusion after they left the classroom and more productive work on the completed homework. The students left the class with a better understanding of the material.

IX. Practical Exercises

In lieu of traditional labs, we used Practical Exercises (PEs) which consisted of applied work and experiments. With PEs, we tried to emphasize to the students, who were not engineers, that the theory and equations on the chalkboard were tied directly to the applications they used everyday. PEs in general provided excellent hands-on training for the students. Although this was done to reinforce that fact to non-engineers, the same would be just as true for engineering majors. In order to accomplish this seamless transition, the PEs were different in two significant ways from the two hour labs.

The biggest change was the complexity and emphasis of the PE. Because lab and lecture occurred during the same time period, there was no choice but to shorten the time at the bench. In order to reduce the time spent on each PE, we had to reduce the complexity. We did this by keeping the PE specifically focused on the topic being taught. Long experiments involving multiple concepts all tied together were extremely limited. As this was the first EE course taken by non-engineering students, this also helped focus the student's attention on understanding the basic concept behind the PE rather then trying to decipher the multiple concepts. Since we were not restricted to a dedicated laboratory to conduct lab exercises, we could conduct PEs everyday. In some cases, we even conducted two PEs during the course of one lesson.

The second big difference was in the preliminary calculations required for the students. Since the PE was now conducted minutes after they were taught the material, it was impractical to assign lengthy pre-labs for them to accomplish outside of class prior to the lab. We turned this into an advantage by planning for PE calculation time in the Lesson Guide. In this way, the students would see the theory on the board, perform their own calculations for the circuit, and apply the concept at the lab bench all in the same day – the biggest advantage of the studio classroom.

The time allotted for pre-calculations was 10 minutes for basic PEs and 20 minutes for the more difficult ones. These were necessary to ensure that as the students were working through the PE, they knew the approximate values they should be measuring and could seek assistance if the values weren't within a certain tolerance. The instructors checked each student's calculations before allowing him or her to move to the rear of the classroom to begin the exercise. In some cases, the instructor was required to give some guidance on the calculations in order for the students to complete the practical exercise in one class period: some examples are the first practical exercises where real inductors or real transformers were used in a circuit (ideal inductors and transformers were emphasized in class).

There were occasions when more time should have been allotted to a particular practical exercise. Case in point PE #1, Introduction to the Workstation: the vast majority had never seen or operated this type of equipment before, and needed more time to gain an acceptable familiarity. If students were unable to complete the PE in the specified time, or missed a class period when one was assigned, it was up to the student to find the time to make it up. There were several opportunities provided for them to make up or finish PEs. Primarily this occurred 1-2 nights a week when extra instruction was offered in the studio classrooms. An instructor was present and kits were available for the components for each practical exercise.

Since there was wide diversity in the time for all students to complete PEs, the instructors were sometimes left with a few students completing it after most had finished. To keep those who finished occupied until the end of the class period, most instructors had them work on the homework assignments or assist other students who were having difficulty.

X. Demonstrations

As mentioned earlier, we wanted to more fully utilize the lab equipment now at our disposal during the lecture period. Since there were so many instructors teaching, we standardized our demonstrations. These Demonstrations were designed to show the students applications which were either too lengthy or too complex for our expectations of them at the lab bench. It also allowed the instructor a time to introduce new equipment before the students put hands on it.

A one page instructor guide was written for each Demonstration. It delineated both the setup of the Demonstration as well as bulleted major speaking points to cover. The guide was also provided to the lab technicians. This allowed them to have the Demonstration fully setup prior to class. The guides purposefully did not walk the instructor through by hand, only covering the highlights of what should be covered. This allowed the instructor to tailor the presentation based on their own style. Additionally, the Demonstration could be taken in different directions depending on the questions asked by the students. It was often found that the students' probing revealed possibilities in the Demo that the instructor had not considered. This type of immediate feedback for the entire group is not as easily available in the individual PEs.

XI. The Final Syllabi

One of the unexpected results of putting together a detailed weekly lesson guide and the elimination of the separate laboratory was that we found there was more time to cover topics in the semester than before with the same contact hours. So while we may actually be spending more time, overall, with students at the benches, we are highly efficient in the classroom leading to more time to teach. This fact, in hindsight, seems obvious. Two hour laboratories were designed for the average student to complete the laboratory in the allotted time. Many students finished early and had extra time. With more concise scheduling and more focused laboratories, there is not as much slack time built into the schedule so we gained hours over the course of a one semester course to cover new material. The resulting syllabi for the two semesters are shown below in Table 2. One of the more challenging tasks was selecting a text for this course. EE301 was fairly simple, it is very close to a standard circuits course, however, EE302 required a custom text comprised of 4 different textbooks. The second semester course was also renamed since it no longer contained electric machines and became "Digital Communications and Computer Technology."

EE301: Electrical Fundamentals & Applications	EE302: Digital Communications & Computer Technology
Resistors, Current and Voltage	Analog vs. Digital Information
Ohm's Law, Power & Energy	Analog to Digital Conversion
Series Circuits, KVL	Binary Numbers
Voltage Dividers, Grounds	Multibit Analog to Digital Conversion
Parallel Circuits, KCL, Current Divider	Digital to Analog Conversion
Loading Effects, Series-Parallel Circuits	Logic Gates & Boolean Algebra
Nodal Analysis	Karnaugh Maps
Thevenin's Theorem	Logic Design
Max Power Transfer Theorem	Multiplexing, DeMux, & Latches
Capacitors	Sequential Logic, Flip-Flops
Principles of Magnetism, Inductors	Combining Flip-Flops, Timing, States
Sinusoids, RMS Values	Flip-Flop State Machines
AC Response, Ave Power	Computer Architecture
Complex Numbers, Phasors	Intro to Networking Terms & Definitions
AC Series, Voltage Divider, AC Parallel	TCP/IP, OSI model
Current Divider, AC Thevenin	Network Addresses & Services
Max Power, AC Power, Power Triangle	Data Transmissions, Transmission Media
Power Factor, Power Factor Correction	Data Communications
RLC Circuits, Resonance	Networking Approaches
Low Pass/High Pass Filters	Wide Area Networks
Band Pass/Band Stop Filters	LAN Technologies
Transformers	Network Security
Linear Machines, DC Motors	Communications Model
AC Generator, 3-Phase, Y-Y, Y-Delta	Amplitude Modulation
AC Motors, 3-Phase Power	Other Modulation Techniques
	AM Communication Applications
	AM Superheterodyne Receiver
	Digital Communications
	Satellite Communications, Link Budget
	Military Requirements, Security

Table 2: Condensed syllabi for the two semester courses

XII. Cooperative/Collaborative Learning

Collaborative learning did play a part in this course. Students were encouraged to collaborate on homework problems together, although duplication of work was not allowed. In general, since there are several ways to attack complex electrical problems, this fostered an exchange of ideas and methods on the best way to reach a solution.

Since there were enough lab benches for each student, most PEs were done individually. There were, however, some PEs that supported working in teams. In particular, the PE that measured the DC transients in a capacitive circuit which involved recording varying voltage levels, and the Motors and Generators PE due to its complex wiring and level of hazard. In addition, the pre-calculations for most PEs were performed in groups.

XIII. Lessons Learned

The schedule worked extremely well but great attention to detail was needed in the planning phase in order to accommodate it. Since the amount of time spent on a PE varies and this is incorporated into the classroom time, it is necessary to have all PEs smoothed before the semester begins so that the appropriate amount of time is scheduled. Due to the large number of students and instructors, it is extremely difficult to make any significant changes during the course of the semester.

There must be a PE, a Demo, or cooperative/collaborative problem solving session during every two-hour class period. While this was a goal of ours when we began, we did not make it an imperative and we discovered that it needs to be. Two hours of straight lecture is bad for both student and instructor. Some of the PEs need to be broken down into more basic elements, so we can both ensure there is applied work in every class period and emphasize a single concept in each PE. Also, the more focused the PE is, there is less variance in the time it takes to complete.

With the lab resources available in the classroom and the renewed emphasis on applications, a Quiz Practical or Exam Practical could be easily accommodated. We did not test their hands-on skills outside of the PEs. In the old method of teaching this subject, the laboratories were a separate room and sometimes in a separate building from the classroom. This made a practical exam very impractical, but the studio classroom lends itself to this possibility very readily. This would continue to emphasize the importance of the applied nature of the course.

Not all of these ideas can be incorporated by the next offering. We will have to pick what is achievable short term and work each year towards the final vision for the course. The first iteration of the studio-lab was a huge success and a big step forward from the traditional manner in which we have always taught EE, but more can be done to continue to make the course relevant, practical, and enjoyable without losing the rigor needed in an engineering course.

XIV. Assessment

We do not feel that we have enough data to accurately assess the success of the new courses compared to the old way of doing business. In addition, after reviewing the course content and the differences in the courses, there may not be a meaningful way to do a comparison. One of the tasks by the Dean in developing the new course was to add rigor, and require the use of differential equations in the course. This was incorporated into the transient analysis portion of capacitors and inductors. We have compiled an average of grades given for the old course (EE300) over the past 4 years, offered in both semesters, and compare them to the single semester (2003) of grades we have so far for EE301. Those results are in the Figure 3 below. There appears to be no significant differences in performance by the students.

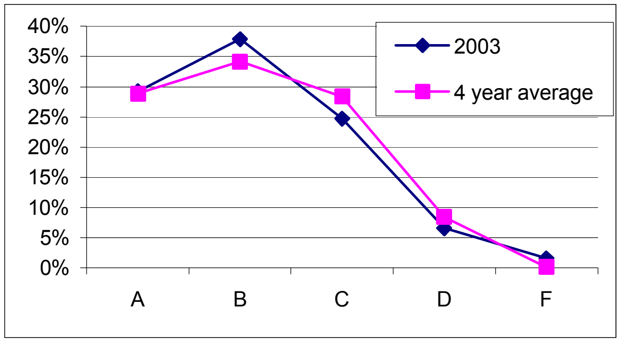

Figure 3 Comparison of grade distributions

XV. Conclusion

The amount of time and effort in the planning stages for these courses was significant. We were much better prepared for the first semester course than we were for the second. The evidence is clearly in support of greater planning and attention to detail, especially with the PEs. We are in the midst of teaching the second semester course and, because this course material is new, the format is new and the facilities are new, we have considerably more rough spots that need to be worked out.

Feedback from the students has been mostly positive, however, some rather pointed comments on how all of these many and varied topics fit together has been a consistent theme. To help prevent this in EE302, which is even more topically diverse, we created a reference model to use as a method to illustrate the big picture. Much of the feedback with respect to the PEs from EE301 was very positive. Students commented on how in traditional laboratory courses they had taken, the theory might have been covered up to a week's time away. They really appreciated being able to reinforce the lecture material so soon after hearing it. This is yet another endorsement for the studio classroom/laboratory concept. It works as advertised and, for this audience, much better than the traditional methods.

Instructor feedback has also been very positive. If the instructor was used to bringing hardware demonstrations to their classroom, they were delighted to have the facilities close at hand. For those who did not, when demonstrations were provided, they became more inclined to use them. Instructors' overwhelming dislike for a 2 hour lecture should help to ensure we don't have to do that the next time the course is taught. Already the revisions are in place to expand and add practical exercises so that no lesson is without one. Most instructors felt that the students got more out of the PEs than they had in laboratories. This was evident in the quality of graded work.

The textbook selection for the second course will continue to present problems. It took a good deal of time to sort through many texts on these topics and find those that had the material at the appropriate level and with the right amount of detail. There is no single text that teaches these topics and, as disjoint as they may seem, they are very related and are all areas which are becoming pervasive in our daily lives. We feel as more schools attempt to integrate technology into their non-technology curricula, textbooks in this general area of computers and communications will emerge.

Our initial impression of this style of teaching is very positive. We have begun to implement this type of teaching in the Electrical Engineering major introductory courses. Our primary goal was one of pedagogy, a better way to present and teach the material that would increase understanding and retention. Side benefits that we had not planned for are the efficiency of room scheduling and the time gained by incorporating the laboratories into the class periods. Both instructors and students are more engaged. We do not see this as the only way to teach a laboratory course. Single use laboratories that are also used for research are not well suited for this approach. We do, however, see it as a better way for much of the core courses as we continue to improve and refine our program.

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ROBERT J. VOIGT
Captain Robert J. Voigt USN is the chair of Electrical Engineering Department at the U. S. Naval Academy in Annapolis Maryland. His research interests include real time, fault tolerant computer architecture and networking, particularly hierarchical multicast. He graduated from the Naval Academy in 1979 and received his MSEE in 1986 and his Ph.D. in 1996 both from the Naval Postgraduate School in Monterey, California.

ROBERT W. IVES
Robert W. Ives received the B.S. degree (mathematics) from the US Naval Academy, Annapolis, MD in 1982, the M.S. degree in electrical engineering from the US Naval Postgraduate School, Monterey, CA in 1990, and the Ph.D. degree in electrical engineering from the University of New Mexico, Albuquerque, in 1998. He is currently an Assistant Professor in the Electrical Engineering Department at the US Naval Academy. His research interests include signal and image compression, information theory, adaptive signal processing and communication systems.

JESKO M. HAGEE
Lieutenant Jesko Hagee USN received his B.S. degree in Systems Engineering from the United States Naval Academy in 1995. He received his M.S. in Electrical Engineering from the Massachusetts Institute of Technology in 1997. His research was in power systems simulation. Lieutenant Hagee is currently an active duty officer in the US Navy and a Master Instructor in Electrical Engineering at the Naval Academy in Annapolis, Maryland.