2006-927: EXPERIENCES IN UPDATING THE ECE CURRICULUM WITH SIGNAL PROCESSING FIRST AND KOLB/4MAT PEDAGOGY

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Experiences in Updating the ECE Curriculum with Signal Processing First and Kolb/4MAT Pedagogy

Introduction

In the Electrical and Computer Engineering (ECE) Department at the University of Colorado at Colorado Springs (UCCS) we have successfully implemented key features of the Kolb/4MAT learning paradigm in a freshman-level course *Introduction to Robotics*[1] and have recently propagated these features to a new sophomore-level course *Introduction to Signals and Systems*, taught for the first time in the fall of 2005, and the sophomore-level *Circuits and Systems I*, taught for the first time in the spring of 2006. We are planning to implement features of this learning paradigm into one additional newly designed course: junior-level *Circuits and Systems II*, to be taught for the first time in the fall of 2006. We expect to completely redesign the systems core classes within the next several years.

Our goals for this updated curriculum and pedagogy are to enhance the appeal of electrical and computer engineering to a wider spectrum of potential students, instill skills to encourage life-long learning, develop improved communication abilities, better prepare our graduates for a variety of job opportunities, enhance their creative aptitudes, and promote the meaning and importance of research to a wider segment of our graduates.

This paper discusses in more detail our rationale for changing a traditional approach to the early systems-area courses (*Circuits I & II* followed by *Linear Systems Theory*) to the new format using the Georgia-Tech approach that introduces signal processing as the first course, followed by additional circuits and systems course(s). We also give preliminary results from adopting this approach, including anecdotal evidence, data from student survey responses, and from student achievement in the courses.

We further discuss the instructional balance achieved via the Kolb/4MAT learning paradigm, and describe some additional features we set forth to implement in these courses, including emphasis on the interdisciplinary nature of modern engineering, more hands-on learning experiences, integrated labs, more opportunities to develop communication skills, and earlier exposure to the importance and necessity of research.

We conclude the paper with our vision for continued curriculum change comprising "weaving" unifying content "threads" through courses comprising a cross-section of the EE program. These threads will include robotics, software/wireless defined radio, and core electronics. Theoretical, hands-on and open-ended team-based project elements of each thread will appear in multiple courses, tying the curriculum together, thereby adding coherence. From the freshman to senior years, they will expand in both breadth and depth, culminating in an enhanced two-semester capstone senior design course.

Rationale for a Change

Based on our positive experiences with a new-to-us freshman-level course *Introduction to Robotics*[1] we set out to perform a comprehensive curriculum review of core courses in our ECE programs. We felt that the robotics course had been successful in part because the concept of robots was not foreign to the students, because there was a high degree of hands-on content in the course, and because we had been careful to use modern pedagogy in different learning environments. We have made several decisions that are designed to propagate these successes further: (1) to put a signal processing course first in the systems sequence, followed by two updated courses in circuits and systems (previously, we had two circuits courses first, followed by a linear systems course); (2) to combine the lecture and laboratory portions of each of these three courses into a single entity; and (3) to update the pedagogy of each course to reach, reinforce, and challenge students of all learning types.

The "signal processing first" approach has been introduced in recent years by several electrical engineering departments throughout the United States for a variety of reasons. Most important, perhaps, is that the exposure that today's students have had to technology is different than in the past. Typically, beginning students in electrical engineering now are very familiar with devices based on digital technology – devices that have come into common usage in the past ten to thirty years such as computers, iPods, CD players, and cell phones. So, we have changed our beginning course sequence in ECE to capitalize on this shift in the experiences of our students. A second feature of this new course sequence is that the accompanying laboratories have been integrated with the main part of the courses, traditionally called "lectures". The thing that we hope to capitalize on here is that all students do not learn in the same manner. By offering a variety of learning experiences we hope to address the learning styles of more individuals in our foundation ECE courses, and to stretch the preferred learning style of each student to more readily learn in more than one dimension.

This last point is one that we wish to focus on at the moment: Individual students perceive and assimilate academic content differently. A variety of theories have been developed to try to understand this phenomenon better so that instructional methods may be developed to reach all students. One well-known instrument used to assess learning styles is the Myers-Briggs Type Indicator (MBTI)[2]. Students are required to complete a survey that categorizes them as either introverts or extroverts, sensors or intuitors, thinkers or feelers, and judgers or perceivers. The exact definitions of these terms are not critical here besides noting the following: extroverts like working in settings that provide activity and group work; introverts prefer internal processing; sensors like concrete learning experiences; intuitors prefer instruction that emphasizes conceptual understanding; thinkers like logically organized presentations; feelers prefer a personal rapport with their instructors; judgers like well-structured instruction; and perceivers like choice and flexibility in their assignments[3]. *The engineering profession requires that its practitioners function in all types of circumstances, so the goal of the educational process should then be to provide a* balance *between all of these modalities to reach, reinforce, and challenge all students.*

We are using Kolb's elements of learning combined with the 4MAT system[3, 4, 5] to formulate our balanced engineering pedagogy. A condensed summary of the approach is presented in graphical form in Figure 1. In Kolb's framework, students' learning styles are projected onto two dimensions: ***perception*** (how a student takes things in), and ***processing*** (how a student makes things part of him/herself). Perception may be either concrete or abstract, and processing may be either reflective or active. Based on these two continuums, Kolb enumerated four different types of learner, as identified by the four quadrants in Figure 1. Each quadrant is characterized by a question: quadrant 1 asks the question "***Why***?"; quadrant 2 asks the question "***What***?"; quadrant 3 asks "***How***?"; and quadrant 4 asks "***What if***?". These four questions guide an instruction paradigm, the 4MAT system, which cycles through all four quadrants of the perception/processing domain, as shown in Figure 1. Instruction that adheres to the 4MAT system is expected to (1) reach students of all learning types, and (2) teach students how to traverse the learning cycle for themselves, preparing them for life-long learning. Representative teaching/learning activities that stimulate students of each learning style are listed in the appropriate quadrant. In the first three quadrants, the instructor plays the roles of motivator, expert, and coach, respectively. In the fourth quadrant, the instructor plays a mentoring role, as the student is fully in charge of learning in this mode.

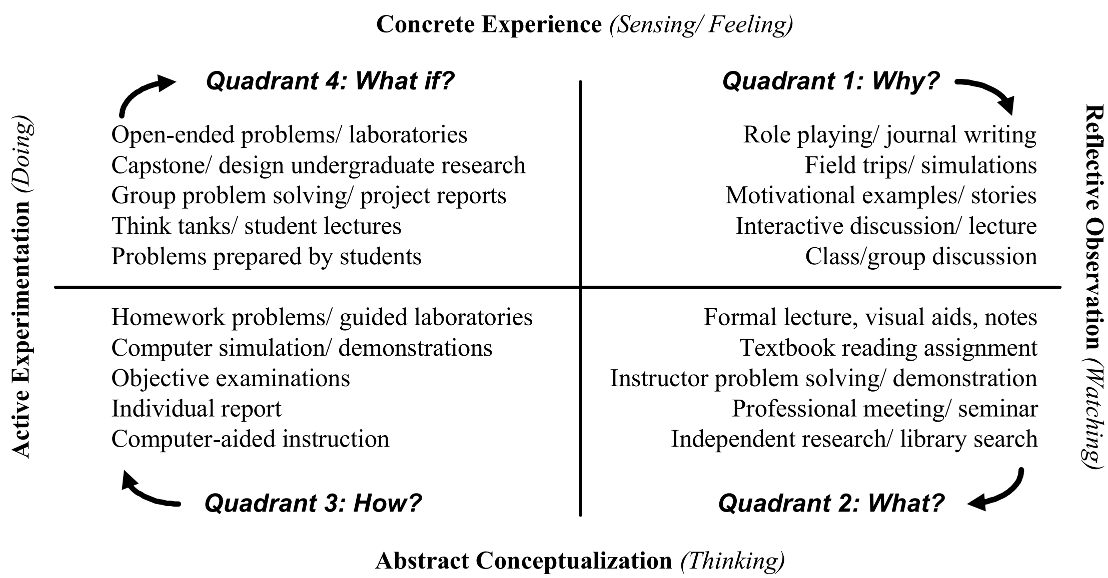

Figure 1: Kolb elements of learning and learning styles with overlaid learning activities and 4MAT learning cycle (arrows); adapted from[3].

Vision for Curriculum Enhancement

Based on ideas generated by the Kolb/4MAT system, and funded by an NSF curriculum planning grant[8], we have redesigned our systems area curriculum. Overall, we have identified 38 credit hours of courses that will be affected: a two semester sequence in circuit theory, a two semester sequence in electronic circuit analysis and design; a linear systems theory course, their companion non-integrated laboratories, senior technical electives and their companion non-integrated laboratories, and the senior seminar/senior design courses. The old core and its proposed replacement are depicted in Figure 2.

The redesign of our systems core courses from the top down has the goal of introducing proper (*i.e.,* Kolb/4MAT-based) balance, with the long-range intent of this redesign propagating throughout the entire curriculum. We are adding hands-on aspects, group-learning aspects, and undergraduate research aspects from the very first course to the capstone design project. By redesigning the entire systems-area sequence of courses at once, we have flexibility with respect to when and how material is presented, and can avoid unintentional duplication of coverage.

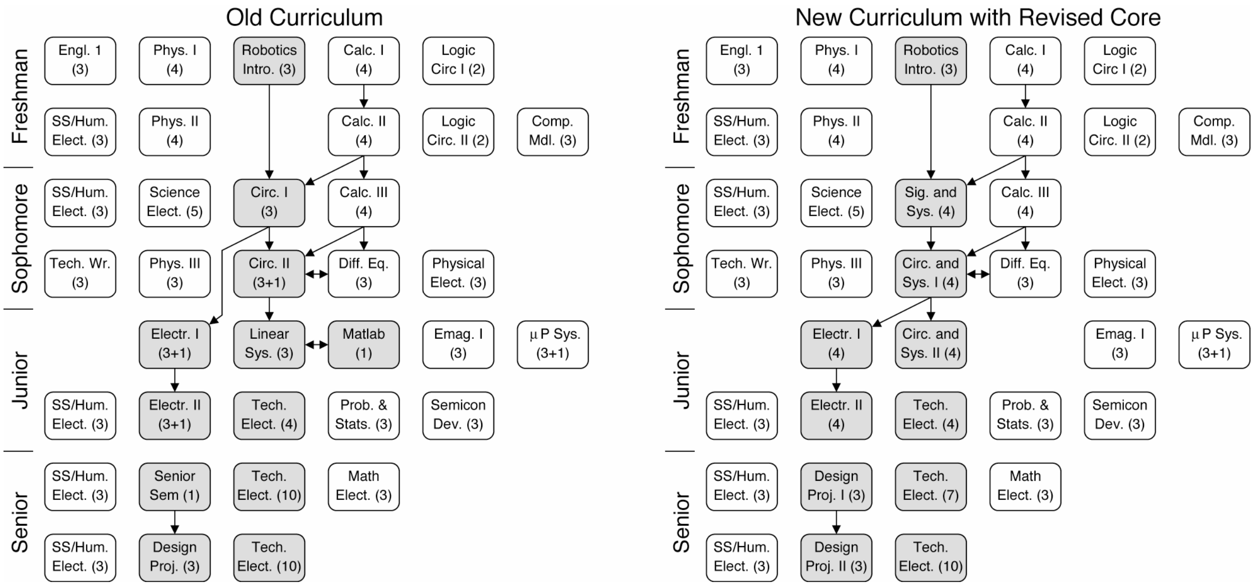

Figure 2: Old and proposed new curricula for the UCCS Electrical Engineering program.

Using *Introduction to Robotics* as an example[1], we believe that one reason for its success is that it is more balanced among learning styles than our traditional classes. We motivate our lectures with real-world examples to stimulate quadrant-one learners; we cover theoretical content in lecture to stimulate quadrant-two learners; we have eight pre-packaged laboratory exercises to stimulate quadrant-three learners; and, we have a seven-week long group-based open-ended final design project to stimulate quadrant-four learners. All students encounter all four learning modalities. Weekly laboratory reports, weekly project progress reports, and a final design report stimulate writing skills. None of the students is comfortable in all learning quadrants, so all students are stretched—their "comfort zones" are expanded—while all students are reached and reinforced, as each has a preferred learning style.

In the sequel, we will focus on how we have introduced these concepts to our new courses *Introduction to Signals and Systems*, *Circuits and Systems I*, and *Circuits and Systems II*. We conclude by giving our vision for future work.

Introduction to Signals and Systems

Introduction to Signals and Systems is a 4-credit course that leverages the students' familiarity with iPods, CD players, and the like receive and process signals. In this course, the student learns about basic signals and their characterization in terms of their frequency content and representation in terms of samples taken periodically, how filters process such sample-data signals, and how to use the *z*-transform for modeling, analyzing, and designing devices that process sample-data signals, whether from music, voice, or some other source. Finally, the student learns about the Fourier transform for characterizing signals in terms of their frequency content. All of this is set in the context of storing and processing of signals such as music and voice by devices familiar to the student like iPods, CD players, and cell phones.

We offered *Introduction to Signals and Systems* for the first time in the fall 2005 semester. The course is based on a textbook by the same name, and accompanying supplementary materials.[6] The class met for three 75-minute sessions per week, with a 15-week semester. The Monday and Wednesday meetings were conducted in a lecture format, and the Friday meeting was conducted in a laboratory format, using selected laboratory exercises from the textbook. There are weekly homework assignments, one quiz per book chapter, a midterm a final exam, and a final project. The schedule followed for the fall 2005 semester is shown in the table below.

Monday	Wednesday	Friday
Ch1: Intro, Course Overview	Ch2: Sinusoids	Lab 1: Introduction to Matlab
Ch2: Sinusoids	Ch3: Spectrum Representation	Lab 2b: Complex exponentials
(Labor day)	Ch3: Spectrum Representation	Lab 3: AM and FM sinusoidal signals
Ch3: Spectrum Representation	Ch4: Sampling and Aliasing	Lab 4: Synthesis of sinusoidal signals
Ch4: Sampling and Aliasing	Ch5: FIR filters	Lab 4: Synthesis of sinusoidal signals
Ch5: FIR filters	Ch5: FIR filters	Lab 6: Digital images; A/D and D/A
Ch6: Freq. Resp. FIR	Ch6: Freq. Resp. FIR	Lab 6: Digital images; A/D and D/A
Ch6: Freq. Resp. FIR	--: Review for midterm	Lab 7: Sampling, convolution and FIR filtering
(Midterm Exam)	Ch7: z transform	Lab 7: Sampling, convolution and FIR filtering
Ch7: z transform	Ch8: IIR Filter	Lab 8: Frequency response: bandpass/nulling
Ch8: IIR Filter	Ch8: IIR Filter	Lab 8: Frequency response: bandpass/nulling
Ch8: IIR Filter	Ch9: Continuous-time	Lab 9: Encoding and decoding touch-tone signals
Ch9: Continuous-time	Ch9: Continuous-time	Lab 9: Encoding and decoding touch-tone signals
Ch10: Cts frequency response	*(Thanksgiving)*	*(Thanksgiving)*
Ch11: Fourier Transform	Ch11: Fourier Transform	Lab 11: PeZ, z,n, omega domains
Ch11: Fourier Transform	Ch12: Applications	*Final Project Due*

Outcomes of *Introduction to Signals and Systems*

Our approach to *Introduction to Signals and Systems* addresses all four quadrants of the 4MAT method illustrated by Figure 1. Motivational examples, stories, and interactive discussions (Quadrant 1) serve to stimulate interest; our formal lectures, reading assignments, and demonstrations (Quadrant 2) provide a base of knowledge to support the laboratory work in Quadrant 3, where a guided series of progressively more difficult projects unfold over the semester. Chapter quizzes, a midterm examination, and a final examination are administered to encourage study and evaluate progress. The first three quadrants of the 4MAT cycle set the stage for the last, a multi-week self-guided experience in which our students engage in an open-ended design project using Matlab to create their own audio CD of tracks that they have processed in specified ways. Thus, this course takes our students through a complete cycle of the 4MAT experience.

For the first offering of *Introduction to Signals and Systems*, we offered voluntary pre- and post-semester surveys to each student with a bribe consisting of $20 worth of “munch money” to be added to their student ID card at the end of the semester should they complete both parts of the survey. In addition, an “Index of Learning Styles (ILS)” survey[7] was taken and scored by the individual student. To ensure confidentiality, the pre- and post-semester survey tools were given out and collected by two faculty members not teaching the course. About one-third of the class chose to participate in the survey.

The survey tool used led the student to classify her/himself along four learning continua: (1) Active versus reflective; (2) Sensing versus intuitive; (3) Visual versus verbal; (4) Sequential versus global. Of those students taking the survey, the following was true:

1. Both fall 2005 and spring 2006, a majority were reflective learners (75%) (57%);
2. In fall 2005 a majority were sensing learners (75%); they were in the minority in spring 2006 (43%);
3. Both fall 2005 and spring 2006, a clear majority were visual learners (75%) (71%);
4. In fall 2005 a majority were global learners (63%); they were in the minority in spring 2006 (30%).

Most found the course interesting (according to their final questionnaire) although taxing in terms of homework and lab reports. (The content is challenging to students at this level.) The most often reported favorite aspect of the course was "applications of the material" or "labs and final project". Some ended up with a lower grade than they anticipated getting at the beginning of the course, although others met their expectations in terms of a grade.

Some anecdotal results from teaching the course are: (1) While incoming students understand trigonometric functions, they have a very difficult time embracing trigonometric signals (*i.e.*, sinusoids). Despite repeated warnings, many students underestimated the importance of the complex-exponential sinusoidal signal. More emphasis will be placed on this in the future. (2) The workload for this class, especially the laboratory work, can be crushing (both for faculty and students). This is one reason that we moved to allowing two weeks per laboratory assignment (see how the schedule in the table above changes as the course progresses). (3) We were initially concerned how the students at the sophomore level would fare with discrete-time signals and the z-transform. As it turns out, this was the part of the course where students did the best. (4) We found that (as is likely typical) students' work rose to the level of expectations. These students were first-semester sophomores, and had not had a challenging engineering course before. When it became clear that we expected an order of magnitude greater professionalism than they had put in before, their output rose to that level. A corollary is that if we had not had this expectation, the quality of their work would likely have been very poor.

Circuits and Systems I

The second course in our revised sequence is the 4-credit *Circuits and Systems I.* In this course the student learns about common basic circuit elements – resistors, capacitors, inductors, and operational amplifiers – and how they interact with voltages and currents. The student learns systematic procedures for analyzing circuits made up of these elements when they are powered by voltage and current sources. The analysis techniques first taught are based on representation of the voltages and currents in the time domain. After doing this, it is shown how much easier analysis becomes if the Laplace transform is used to transform to the *s*-domain. Here the student hopefully sees that mastering the mathematics of complex numbers pays off.

We offered this course for the first time in the spring 2006 semester. The course is based on the follow-on text[9] and our own supplementary laboratory materials. Again, the class met for three 75-minute sessions per week, with a 15-week semester. The Monday and Wednesday meetings were conducted in a lecture format, and the Friday meeting was conducted in a laboratory format. There are weekly homework assignments, one quiz per book chapter, a midterm a final exam, and a final project (the final project is to build a robot that follows a black line on a white surface until the robot hits a wall—then to reverse and follow the line until it hits another wall, and so on. The robot uses only analog electronics—no computing devices (except op-amps and comparators) are allowed). The schedule followed for the spring 2006 semester is shown in the table below. Note that a major component to the laboratory exercise is to introduce basic instrumentation.

Monday	Wednesday	Friday
	Ch1: Circuit Elements and Models	Lab 1: Digital Multimeter
Ch1: Circuit Elements and Models	Catch-up day in Lab	Lab 1: Digital Multimeter
Ch1: Circuit Elements and Models	Ch1: Circ. Elem. & Ch2: Circ. Eqns	Lab 2: Kirchoff's Laws
Ch2: Writing Circuit Equations	Ch2: Writing Circuit Equations	Lab 2: Kirchoff's Laws
Ch2: Writing Circuit Equations	Ch3: Subnetworks	Lab 3: Oscilloscope
Ch3: Subnetworks	Ch4: Operational Amplifiers	Lab 3: Oscilloscope
Ch4: Op Amps, --: Capacitors/Inductors	Catch-up day in Lab	Lab 4: Simple Op-Amp Circuits
--: Capacitors and Inductors	--: Time-domain 1st/2nd order solns	Lab 4: Simple Op-Amp Circuits
Catch-up day in Lab	--: Time-domain 1st/2nd order solns	Lab 5: Complex Op-Amp Circuits
--: Time-domain solutions 1st/2nd order	*(Midterm Exam)*	Lab 5: Complex Op-Amp Circuits
(Spring Break)	*(Spring Break)*	*(Spring Break)*
Ch5: Laplace Transform	Ch5: Laplace Transform	Project in lab
Ch6: Circuits in Laplace Domain	Ch6: Circuits in Laplace Domain	Project in lab
Ch6: Circuits in Laplace Domain	--: Series-Parallel RLC	Project in lab
--: Series-Parallel RLC	Ch7: System Functions	Project in lab
Ch7: System Functions	Ch7: System Functions	Demonstrate project in lab
Ch7: System Functions		

As this paper is being written, this course is still in progress. Initial observations are (1) Students find this course far easier, especially after the rigor of *Introduction to Signals and Systems*, (2) Many of the students have no prior experience to basic EE laboratory equipment, so even deciphering something like a breadboard takes time. Due to instructor illnesses and conferences, we scheduled some lab "catch-up" days on Monday and Wednesdays, and these were greatly appreciated. (3) The students who "made it" through *Introduction to Signals and Systems* on their first attempt (a "C" grade is required to pass to the next course) were far better prepared to continue than those who did not. We continue to monitor this course.

Circuits and Systems II

Circuits and Systems II is a 4-credit course that will be offered for the first time in fall 2006. Our plan is to build on the concepts learned in the previous courses so that practical applications may be considered such as alternating current and power distribution. The student also learns about Bode plots and the Routh array for analyzing control circuits. The student learns more about continuous-time filter circuits, first introduced as sample-data devices in *Introduction to Signals and Systems*. The student then learns how to design, as contrasted with analyzing, digital filter circuits. Finally, the analysis and design of systems involving a combination of continuous-time and sample-data signals are considered. A sample schedule is shown below.

Monday	Wednesday	Friday
Ch8: Sinusoidal Input Signals	Ch8: Sinusoidal Input Signals	Lab 1 (warmup):
Ch8: Sinusoidal Input Signals	Ch8: Sinusoidal Input Signals	Lab 1 (lab):
(Labor day)	--: AC Power/ Transformer Circuits	Lab 2 (warmup):
--: AC Power/ Transformer Circuits	--: AC Power/ Transformer Circuits	Lab 2 (lab):
--: Fourier Transform Review	Ch9: Frequency Response (Bode)	Lab 3 (warmup):
Ch9: Frequency Response (Bode)	Ch9: Frequency Response (Bode)	Lab 3 (lab):
Ch9: Frequency Response (Bode)	--: Active Feedback ex.; Routh	Lab 4 (warmup):
--: Active Feedback ex.; Routh	Ch10: (Analog) Filter Circuits	Lab 4 (lab):
(Midterm Exam)	Ch10: (Analog) Filter Circuits	Lab 5 (warmup):
Ch10: (Analog) Filter Circuits	Ch10: (Analog) Filter Circuits	Lab 5 (lab):
Ch10: (Analog) Filter Circuits	Ch10: (Analog) Filter Circuits	Lab 6 (warmup):
--: SP1 Review (sampling etc.)	--: Digital Filter Design	Lab 6 (lab):
--: Digital Filter Design	--: Digital Filter Design	Lab 7 (warmup):
--: Digital Filter Design	*(Thanksgiving)*	*(Thanksgiving)*
--: Hybrid System Integration	--: Hybrid System Integration	Lab 7 (lab):
--: Hybrid System Integration	--: Engineering Circuit Examples	*(no lab)*

Note that we plan to re-use the text from the initial circuits course, but add significant content from other sources. The final result of the three-semester sequence is to start with signal processing, show how computers (DSP) can implement discrete-time signal processing, show how circuits can implement continuous-time signal processing, and then as a capstone project build a hybrid system having both continuous- and discrete-time components. We understand that this is a challenging goal for an undergraduate sequence, but believe that it is entirely feasible.

The Future—Unifying Curricular Threads

Quite frankly, the implementation of these three courses in a very short time has left us worn out. However, we still have plans for future improvement, once we catch our breath! One of these we have started to implement as we have designed these three courses is to "weave" several "threads" throughout a longitudinal cross-section of the overall curriculum, to tie together various courses, and to bring coherence to the bachelors programs (electrical engineering and computer engineering). These threads will unify a curriculum that, at present, often appears to lack coherence. Our vision is to deliver academic content in the subject areas of these threads in multiple courses, from the freshman year through the senior year. The first visitation of a thread will, by necessity, require a high level of simplification. In subsequent visitations, detail may be added to develop full understanding that is both broad and deep.

Coherent threads of topics and lab experiences will lend purpose to the process: Instead of having loosely coupled or unrelated scatterings of laboratory assignments, these hands-on experiences will be closely integrated with lecture materials to reinforce and emphasize theory, and will also culminate in a complete project at the end of each course. For brevity we will discuss only a robotic thread here, although we have additional plans for a software/wireless radio thread, and a core electronics thread.

Implementation of the Robotics Application Thread

Freshman-level *Introduction to Robotics* was a trial course introduced in 2003. By our incorporating all quadrants of the Kolb/4MAT cycle, we sought to determine whether any improvements in student learning, retention, and so forth were made. In our estimation, this course has been very successful, and led to the proposal that resulted in NSF awarding a curriculum planning grant. This course is the foundation of the robotics thread, introducing a wide variety of engineering topics through the medium of robotics. Students learn aspects of hardware, software, mechanical design, electronics, control, and microprocessor-based systems. Eight lab assignments teach valuable construction and programming skills, resulting in robots of increasing complexity. These experiences are integrated by students in an open-ended final design project that culminates in a robot competition.

We are working to integrate concepts from *Introduction to Robotics* with follow-on courses. In particular, we delve more deeply by considering aspects of sensor/actuator design, control and implementation of mobile robotic systems. In *Circuits and Systems I,* the robotics thread manifests itself in the integrated hands-on lab experiences within the course. There are exercises to demonstrate that simple voltage-divider circuits may be used to construct sensors for robots (*e.g.*, light and temperature sensors). There are exercises to demonstrate an op-amp dc motor driver, and a servo-motor driver. The op-amp comparator is introduced as a decision-making device, a simple RC circuit is used to implement switch de-bounce, and an op-amp is used as a speaker driver. While these labs individually reinforce fundamental concepts, together they provide the practical experience to be integrated into an open-ended final project where the students will be required to construct a robot that will follow a line until it ends, turn around, follow the line to the other end, and repeat, optionally playing a note on the speaker when the line ends. The robotics thread continues the theme of robotics throughout the systems-area curriculum, but also ties together a single course in an interesting and challenging final project.

The robotics thread will again manifest itself in integrated hands-on lab experiences in the junior-level *Circuits and Systems II* course. Students will build pulse-width-modulated dc- and servo-motor controllers, a D2A converter (from an op-amp and discrete components), an A2D converter (from the previously built D2A converter, a comparator, clock signal and FPGA-implemented logic), and a rotation sensor. They will integrate all of these into a proportional-integral-derivative (PID) controller for motor drive. The final project will be a robot that balances an inverted pendulum. Students will implement this with both an analog PID controller and a digital PID controller using the sub-assemblies built in the previous labs and they will be required to evaluate engineering tradeoffs between the methodologies.

As a capstone to the entire robotics thread, we plan to introduce an elective junior/senior-level course *Embedded Mobile Robotics*. In keeping with the theme of this proposed work, this course will again embrace the Kolb/4MAT system. Theoretical issues in robotic control, image processing, wireless communication, means of locomotion (including wheeled, legged, and treaded robots), and so forth will be covered. The hands-on portion will involve design tradeoffs between traditional embedded system approaches using micro-controllers and other possibilities using FPGAs. We expect students to leverage this course and the robotic mechanisms that will be made available through it to enable much more sophisticated senior design projects than we have seen in the past, since students will be better prepared and will have a better mechanical basis to start from.

Conclusion

A curriculum change in the systems core that began with the desire to address a wider range of learning styles has been discussed. It is built around the Kolb/4MAT learning paradigm. So far, it has been implemented in three courses (as of January 2006), and will be propagated course-by-course throughout 38 credits of the systems core of the curriculum. Goals for this updated curriculum and pedagogy include enhancing the appeal of electrical and computer engineering to a wider spectrum of potential students, instilling skills to encourage life-long learning, developing improved communication abilities, better preparation of graduates for a variety of job opportunities, enhancing students' creative aptitudes, sparking entrepreneurial spirit, and promoting the meaning and importance of research to a wider segment of graduates.

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