Integrated System-Level Design in Electrical Engineering

I. Motivation: Why System-Level Design

Electrical Engineering students typically receive an excellent education in how transistors, diodes, capacitors, transmission lines, Fourier transforms, amplifiers, filters, lasers, digital circuits, and op amps work. They do a lot of homework that includes design of these individual components, and they experiment with each one individually in a laboratory or two, and compare the measured responses with theory. As each concept is “passed off” on the midterm or final, it can be summarily forgotten by many of our students. Only sporadically throughout the curriculum do students have the opportunity to put these disparate ideas together into a system-level design and experiment with how each part impacts the design of the others and the system as a whole. Yet, when they reach the engineering workforce, this is exactly what they are expected to do.

At the University of Utah, we have already noted the excellent value of system-level design to improve student understanding, motivation, and capability and have built on this with our planning grant this year. We have a few very popular courses where the students design a small system (Analog IC Design, for instance, where students design, fabricate, and test an ASIC of their choice.) We have a superb senior design sequence for the electrical engineering students where industries sponsor (for $25k) groups of five students with a faculty mentor to complete a significant senior capstone design project. We have slated this program for extension to the computer engineering students for the coming year. This year we received university funding to integrate two of our junior-level courses (Signals and Electromagnetics) through the lab where students will build and test a wireless communication system for a cardiac pacemaker. This real-world problem stemmed from NSF-sponsored research projects, and provided an excellent catalyst for student interest, learning, and involvement. We will continue this program in the coming year, and will be extending it to a pair of elective courses in these areas. Taking on the challenge of directly integrating research into the curriculum, the Numerical Electromagnetics students completed homework projects that provided simulation results that are being directly incorporated into two research publications.

In addition, as a result of curriculum evaluation by the faculty and industrial advisory boards that stemmed from our planning grant, we have established relationships with both the college of Business and the college of Fine Arts in order to broaden the project-based experiences of our students. We are both building on successful university programs for Service Learning, Interdisciplinary Study, and
Leadership and Communication as well as forging new opportunities for cross disciplinary application and experience. Hands-on business experiences lead by Professional MBA students are planned for integration in the junior level design sequence in the coming year. Design-based explorations of the engineering applications in art (music, theater, visual arts, dance, etc) are planned for a general education course to be taught for the first time next fall or spring. ECE is spearheading these projects, but is anticipated that several other engineering departments will join in when the courses have been perfected.

As a result of the NSF Planning grant, virtually all faculty in the department (those who are tenure-track as well as several who are instructors or adjunct/research professors) have become involved in curriculum evaluation and the development of project-based designs for their courses. The microwave engineering class included a project for the first time this fall, and the antennas class is working on a dual band antenna design project this spring. The microfabrication classes have exploded with students clamoring for the real-life experiences available through their projects. Each faculty has submitted a project proposal and will be using ½ month of the planning grant to support either themselves or a TA (2 months) to do the preliminary design of their projects. Virtually all tenure-track faculty are involved in this grant, and several of the research/adjunct/instructor professors as well. Several multiple course projects have already been implemented, and more are planned for the coming years. Novel methods of incorporating research into the classroom have been tested, and classroom students have contributed to two research publications already. Funding from a full implementation grant will be used to fully implement, write up, and disseminate the laboratories and associated course materials for these project-based designs across the curriculum. Also as a result of the planning grant, we have forged links with researchers (Center for Teaching & Learning Excellence) who specialize in novel assessment strategies that are clearly needed for assessing the projects that we have underway and planned. Links with the Colleges of Business and Fine Arts have already matured to the point that new/modified classes with active learning opportunities in these areas are planned for the coming year. We have integrated with the UU CLEAR and ELEAP programs to provide extensive opportunities for our students to improve written and oral communication skills, team management, etc. This planning grant provided more than just a bit of funding. It also provided impetus and reason to take a good look at all aspects of our curriculum. New relationships were formed between several faculty members who otherwise hadn’t had the time to pursue collaborative opportunities. Faculty mentoring has greatly expanded, as has the involvement of our graduate students in the curriculum development process. A plan for long-term sustainment of this program has been developed and includes significant resource commitment provided by the university in support of this concept, utilization of senior design projects in ongoing lab development, and integration of graduate teaching assistants in the curriculum development process.
We have been amazed at the systemic change already in full swing as a result of the planning grant, and the university support for our efforts. We are excited about the opportunity to apply for a full implementation grant to allow us to follow through and complete the fledgling efforts we have established. Faculty and TA efforts to think up, design, test, redesign, write up, and teach a class project for the first time is daunting without reasonable financial support. Once established, the program will be self-sustaining in part because of the generous agreement of the university to provide a permanent ECE technician for ongoing lab support and development in the event this grant is funded. At present, our ECE curriculum is very typical of the many state schools across the nation. Our projects will be freely disseminated on the web, so that other schools can implement them as well. We have successful experiences with this formula in the past on a small scale and are very excited to implement this broadly across the curriculum.

The few system-level design experiences that our students have are so positive that we would like to expand and emphasize this excellent learning opportunity throughout the entire curriculum. There is significant demand for this already. Our industrial advisory board, alumni surveys, senior exit interviews, and employer surveys all note the need for system-level design and ask for more experience in this area. Students particularly note the motivation and positive reinforcement that these projects provide (“They are FUN too.”).

II. Objective: System-Level Design Integrated Throughout the Curriculum

The overall goal of this project is to:

Incorporate system-level design and understanding at all levels of the curriculum.

A. Integration of individual topics into system-level design experiences will be implemented in several different ways:

- Integrate multiple courses via system-level design lab projects. (This year, it was observed that this model is highly effective for integrating research into the undergraduate

- Integrate multiple courses through teaming on projects

- Integrate individual labs within a course into a system-level design
• Enhance the junior-level design experience with formal training in project management, entrepreneurialism, and system integration. (This is an interdisciplinary initiative between the Colleges of Business and Engineering spearheaded by ECE as a result of our NSF Curriculum Planning Grant.)

• Encourage professors to emphasize system design throughout their normal teaching.

B. In addition, we will make a department-wide effort to enhance the quality of our teaching and the student learning environment through seminars, discussions, and shared experience for professors on:

• Assessment methods (improved use of traditional assessment methods, alternative and novel assessment methods, methods for assessing students, projects, and curriculum)

• Engineering team learning

• Learning by teaching

• Learning styles and how to teach for everyone

• Mentoring and encouraging minority and women students

• Enhancement of the hands-on laboratory experiences at all levels

C. This proposal is directly related to our long-term department-wide goal to enhance system design education. Significant efforts that are already underway include:

• Development of Advanced Teaching Laboratories (equipment and capability):

  o Wireless Communication Systems Lab

  § Received $100k in UofU funding, $176k in corporate funding and donations this year.

  o Digital Signal Processing Advanced Teaching Lab

  § Received $55k in equipment donations from Texas Instruments, Inc. and Analog Devices,
- Optical Systems Lab

§ Awarded funds (BEEF): $58,000
§ Direct donation: $40,000
§ Total acquisition value: ~ $150,000

- IC Systems Labs

§ Received $66k in UofU funding, and $100k in corporate funding this year

- Control Systems Lab
  - Integration of Junior-Level Signals and Electromagnetics classes

- Received $22k in UofU funding for TA support in 2003/2004.
  - Several Individual courses are using or preparing to integrate system design concepts
  - Cross-Disciplinary team experiences with the Colleges of Business and Fine Arts

III. U of U ECE Curriculum Today

The U of U ECE curriculum is a fairly typical four-year ECE curriculum, which means that successful changes we implement within our program are likely to be transferable to many others throughout the country.

Some of the particularly positive points of our present curriculum provide an excellent framework for the changes we would like to implement as we move towards a more integrated system-level education:

- EE Senior Thesis: This is a significant year-long capstone design project. Industry sponsors contribute $25k per project for groups of 5 students plus a faculty mentor to do an engineering design project for them. At the end of the year,
students present their work through a complete professional report and engineering presentation that are judged by industrial engineers. This program has been highly successful, and clearly contributes a huge amount to the learning process. It provides an excellent framework for integration with other areas (project management, entrepreneurialism, and writing). It also provides a good example for expansion into the junior year. As a result of our planning grant, one of the projects that will be implemented in the coming year is to expand this model to the CE degree, which is co-taught by CS and EE departments in UofU.

- Ethics and Diversity Classes: As part of our general education requirement, students are required to take a class in ethics, and another in diversity. These are taught by non-ECE departments but address a number of issues that we think are important. This provides an example for how the time that students spend in general education can be utilized for topics that are of critical interest to engineers.

As a result of our planning grant, we are now working with the Colleges of Business and Fine Arts to enhance the general education our students receive.

- In the freshmen year, starting fall 04, students will be encouraged and eventually required to take an Engineering LEAP series (2 courses), which serves as a humanities and social sciences general education. This course emphasizes team learning, written and oral communication, societal impacts and opportunities for engineering, creative design, and problem solving skills. The students in this course volunteer time as science teachers and mentors for K12 students in disadvantaged city schools, a positive service learning opportunity.

- In the junior year, we are adding a business team experience to our prethesis course. Groups of 5 ECE juniors will be teamed with a professional MBA student (commonly a working engineer returning for an MBA) to prepare a market, business, and project management plan for one of the senior design projects. Business and ECE professors will team teach this seminar course, and a related course for the PMBA students in the business school. PMBA students are professionals, commonly engineers, working on their MBA. It is anticipated that this course will provide direct hands-on experience in the business aspects of engineering and may result in engineering students becoming more involved in the entrepreneurial program and opportunities available on campus (a business incubator, a $40k student business grant, etc.), and that the PMBA students will serve as effective mentors both in and out of class for the juniors.

- Artistic Engineering, a Fine Arts general education class, is being planned for fall or spring 2004-5. This course will cover visual arts applying microprocessors (the professional specialty of the art history professor who is planning to teach the
course), mechatronic puppetry and theatre, music engineering, sensing and interaction in art (such as the “Interactive Moose” project done by ECE juniors and artists this year ... a life-sized moose on display in Park City, Utah, that responds to people nearby with discussions about moose habitat and life cycles, artistic flashing colored lights, etc.) These yearly projects will be incorporated into the Leonardo Center, a fledgling city science, art and humanities center. It is anticipated that minority and female students could find a connection to engineering through these art projects and associated hands-on engineering&art experiences. It is also anticipated that university students would learn by teaching high school and potentially middle school students in engineering&art experiences.

IV. Integrating System-Level Design in the UofU ECE Curriculum

There are several exciting opportunities for incorporating system-level design within the curriculum. Examples are described below, and where each aspect shows up in the curriculum is noted in color (and asterisks, for B/W printers) below the descriptions:

A. Multiple Course Integrated Design Project:

Two or more courses will be integrated (typically through the labs) to build a system requiring knowledge from both courses. Typically students would take both classes simultaneously.

Example: Junior-level Signals [Signals] and Electromagnetics [Furse EM] [ref: Farhang and Furse]

This year we received $22k in UofU internal funding in addition to $10k from the NSF planning grant to integrate the junior-level Signals and Electromagnetics courses. Professors Furse and Farhang along with two Phd-level TAs, combined the labs to enable students to build a wireless communication link for a cardiac pacemaker. In many cases, the components of the system were lab projects before the classes were combined (filters, matching networks, etc.), but were designed in the context of the system instead. This experiment was very successful and will be enhanced in the coming year. Students enjoyed the labs and reported that they did “most of their real learning in the labs.” The course evaluations rose in both classes,
and the students are getting very positive comments from recruiters when they show up for interviews with their projects in hand. This change to system-level design required faculty time to design the system and the labs around it and a very experienced TA the first time through the labs (hence the funding), some change in the order in which course material is taught (“just in time learning”), incorporation of system-design concepts into the class (material previously glossed over), and a reconsideration of material taught in the classes to determine if the traditional ways we have been teaching it are the best, or if some of the concepts could be better learned through design and experimentation (simulation and laboratory).

Two senior project students are now designing labs to be used in the follow-on senior-level Digital Communication (signals) and Wireless Communication (systems, EM) next spring. A parallel project (same concept implemented a different way) is being planned for the Microwave Engineering course. This work is being sponsored in part by Agilent Technologies, who has provided both equipment and cash funding support. This is an already-positive result of the NSF planning grant we received, and we are very excited about continued project development in this area. After having the bugs worked out in a few of our classes, we will disseminate the laboratory instructions freely through both the UU website and Agilent’s Educators’ Corner. In addition, a publication is being prepared (coauthored by the senior students) for the IEEE AP Magazine column on education.

Notably, this project is a significant integration of university research into the classroom. Professors Furse and Chung have design biocompatible antennas for implantation, partially funded by NSF. [Furse Pace] Professors Harrison, Stolzacher and Kalla build integrated transceivers for medical implant communication. Professors Chen and Farhang have collaborated on the communication protocols and methods. Professors Norman and others in bioengineering/UU Medical Center have designed the implantable neural probes that require this communication system, and have built a small local company to build and market them.

B. Multiple Course Component Design Project:**

Two or more courses will be integrated (typically through the labs) where the students in one course utilize the components built in the other, but the overall project requires only moderate understanding of the other course. Students would not typically take both courses simultaneously.
Electromagnetics

These four courses are the cornerstone of electromagnetic technical electives at
UofU and most other universities nation-wide, and they provide an ideal
opportunity, previously implemented by Dr. Furse at Utah State University
(Furse, 2003) and partially implemented at UU in fall 03, for students in EM to see
how what they learn in one course affects designs in the others.

Microwave Engineering I:

A power source based on combining power outputs of two solid-state amplifiers
each working at the WLAN frequency of 2500 MHz was designed during fall 03. The
students also designed and tested a quarter-wave monopole antenna capable of
serving as a radiator in the frequency band 2400 to 2600 MHz. They designed and
tested power combiners/dividers for use in such a system that operates in the
802.11 b/g band of 2415 to 2465 MHz. The initial design of this project is [Furse
WLAN]. During the next academic year they would also design, compare and test
low-pass and band-pass amplifiers to allow low loss transmission at the WLAN
frequencies of 2400 to 2600 MHz with a design goal of at least 40 dB suppression of
the second harmonic frequencies to meet the FCC requirements for such radiators.
This project is also an integration of research into the classroom. A modified
version of this circuit (built in discrete components) was used in a research project
on location of robotic vehicles from the FSK transmission power by professors Furse
and Chung and engineers at a local entrepreneurial company. This system design
project has been replicated at other universities, and was the 10th most popular
download from the Agilent Educator’s Corner website in 2001, when it was first
presented.

Microwave Engineering II: Students build the transmitter (oscillator and amplifier)
for the FSK WLAN. All students will previously have taken Microwave I, so can now
combine the hardware from both classes. Full implementation is planned for spring
’06 with NSF funding.

Antennas: Students build directional high-gain antenna arrays (patch or wire
arrays) to improve the performance of the FSK WLAN. This will include design and
testing of a dual band patch antenna for use at 802.11 b/g and 802.11a frequencies
of 2.45 and 5.25 to 5.8 GHz, based on Gandhi research. The students will design and
fabricate the dual band patch antennas and will test their design using the antenna
pattern measuring setup available in the Antenna Laboratory. This project
integrates the research of Gandhi [Gandhi 1 and 2], Chung and Griffiths (the PhD students supported to design the EM labs) into the curriculum along with numerical methods developed by Gandhi and Furse.

Wireless Communication: [Furse WC] This class does a link budget and loss analysis for the FSK WLAN and measures/characterizes the multipath communication environment in which it operates. Students utilize the loss, etc. that they measured in the previous classes, or the values measured from the demonstration system. Students will also build and test a PN code generator, DSSS and FHSS communication systems, and simulate network protocols associated with them. Labs are currently being designed by senior project students and are planned for implementation in spring 05. This course integrates research from several projects. The link budget analysis from the Nanosatellite project at Utah State University (for which Drs. Furse and Chung helped design the antennas) is used as a major design project, and the multipath measurements set up by students in the last class are currently being done in aircraft rather than buildings (results soon to be published). The DSSS circuit built in this lab is a modified version of one that is used for location and communication of faults in aging aircraft wiring, work supported by NSF, USAF, Navair, NASA, etc. (Drs. Furse, Chung, Lo). Advanced signal processing techniques, such as multicarrier spread spectrum (MCSS), will be soon added (Dr. Farhang).

Numerical Electromagnetics: [Furse Num] Students write software using numerical methods (FD, FEM, FDTD, MoM) to analyze microstrip antennas and couplers and compare the results to those obtained using commercial packages and theory in the Microwave I class. This year, instigated by a desire to experiment with directly integrating the research experience into the curriculum for the NSF planning grant, students were challenged to obtain results for two research publications, in progress. One was to predict how much fraying on a wire can be detected using reflectometry methods, and the other was to analyze a specific modeling question that has plagued the FDTD community (to average or not to average dielectric properties). A TA was assigned to each question, and the entire class (20 students) worked as an integrated team to obtain the necessary results, which were excellent. The students enjoyed the projects, especially the “feel” of seeking an answer to questions that are involved in heated national scientific debates. These papers will include all class members in the acknowledgements and the graduate student TAs as primary authors. As a result, one student who was not previously considering graduate school has applied for a masters’ degree, the one female student in the class surprised herself by taking a major leadership role and loving it, and several students are planning expansions of these results for their final freelance projects. The professor (Furse) was surprised how easy it was (minimal preparation time required), how effective the students were (including finding background literature
in the library), how excited they got, and how much leadership individual students including the TAs have shown, basically claiming “ownership” of their project.

C. Individual Course Design Project:***

The lab (or significant in-class design project) will integrate individual components into a system-level design.

Example: Analog Integrated Circuit Design has been a very popular course in recent years (Drs.Harrison & Brunvand, spanning ECE and CS departments). In this course, students learn to use CAD tools to design and simulate analog and mixed-signal CMOS chips. A major assignment in this course is the “op-amp design contest” where students compete to build the best operational amplifier in a particular category: low-power, high-speed, high output drive, or small chip area. Each student may choose which area they wish to compete in, but all amplifier designs must meet minimum performance criteria in all areas. All designs must be designed at the mask (“layout”) level, and simulations are performed on the extracted circuit.

At the end of the class, students may submit a more advanced project for fabrication through the MOSIS educational program (www.mosis.com). Chips are fabricated by a commercial foundry over the summer, and in the fall students receive credit for testing them and writing a report. Students may work individually or in teams of two. In the Spring 2003 semester, undergraduates taking this class submitted a number of chip designs, including a phase-locked loop, a flash analog-to-digital converter, and a low-battery indicator for a VW Beetle. Parts of research projects were built and tested in this year’s lab including the DSSS method for aircraft wire testing (an NSF project), and components of a transceiver for a wireless data network. [Harrison 1 and 2]

D. Capstone Design Project:****

This design project combines skills from multiple courses and requires multiple students to complete. It often requires skills not taught within our program that students must learn independently or with the help of engineers from industry.

One of the strengths of the electrical engineering program at the University of Utah is the engineering clinics program. This program, initiated in 1986, involves an industrial-university involvement where student teams of generally five senior students work on a project sponsored by an industrial company at a level of $25,000 per project and supervised by a faculty member in the area of specialization of the
project. The project is divided up so each student has a portion of the project. During the course of the project, the industrial sponsor visits with the Clinic team at the University every 2-3 months.

Key:

Multiple Course Integrated Design Project*
Multiple Course Component Design Project**
Individual Course Design Project***
Capstone Design Project****
Engineering-Applicable General Education: *****

Freshman

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**V. Planned Project-Based Design Experiences and Faculty Involvement:**

**Introduction to Electrical Engineering**

Profs: Cotter and Christensen (Bioeng)

Students will be introduced to a variety of physiological sensors as they build a patient monitoring system. At the conclusion of the course, the students will have
built and tested at least three different circuits for measuring vital signs such as
respiration rate, blood oxygenation [oximetry, Barker], and heart rate. The projects
will be integrated by their common theme, and they will cross disciplinary
boundaries with bioengineering. These projects will be expanded in Electronics II.
These projects are related to the research of Dr. Christensen and others in
Bioengineering [Christensen] and Dr. Cotter [Douglas].

Electronics II

Prof: Harrison

We will develop a new series of 6-7 two-week lab assignments that lead the
students through the development and testing of a complete electronic system: an
electromyogram (EMG) amplifier that records electric potentials on the skin
produced by underlying muscle activity and drives a speaker so the students can
"hear" their own muscle activity. The initial labs will focus on the development of
differential amplifiers with high differential gain and low common-mode gain to
suppress the 60-Hz noise present in surface electrode EMG recordings. Mid-
semester labs will introduce design techniques to limit the amplifier bandwidth to
signals of interest (from 10 Hz to 500 Hz for EMGs) and properly compensate
feedback configurations. Later labs will cover the design of a class AB output stage
for driving a small speaker. The final lab assignment will allow the students to test
their EMG-to-audio circuits on themselves using Ag/AgCl surface electrodes.
Circuits will be powered from batteries when electrodes are used to ensure student
safety. The instructor of the class and lab – Prof. Reid Harrison – received an NSF
CAREER award in 2002. This award is entitled “Low-Power VLSI Circuits for Large-
Scale Neural Recording,” and involves research into biopotential amplifiers that are
similar in design and function to the circuits proposed for this class. Developing the
EMG amplifier lab proposed above would tie the student experience in this class
closer to Prof. Harrison’s research topics.

Communication Projects

Profs: Farhang, Mathews, Chen, Shamir

Another example where multiple courses gain from each other is the signal group
courses: Signal and Systems, Digital Signal Processing and Digital Communications.
Knowledge gained in Signals and Systems class (namely, signal modulation and
demodulation) is used in Digital Signal Processing class project where students
develop a digital communication system based on quadrature amplitude modulation
(QAM) signaling. Various aspects of the system including Nyquist pulse shaping and
signal modulation and demodulation are explored in this class project, giving the
students a clear picture of how signal processing techniques are used in
development of modern communication systems. We plan to extend further
applications of signal processing techniques in our digital communication course by
developing the basic modules of a modem based on IEEE 802.11a standard which
include OFDM (orthogonal frequency division multiplexing) modulation/demodulation (Farhang, Furse research) [Farhang 1 and 2] and trellis coding/decoding, where students learn about frequency selective channels, channel equalization, and how coding is used to combat channel fading. (Chen, Shamir research). A new course “Coding” is also planned, which describes different coding techniques for different purposes in a communication system at a broad level, and their integration into one system. This course compliments Dr. Shamir’s research funded by a CAREER award (NSF Grant CCF-0347969). [Shamir 1 and 2]

An additional elective course integrating signal processing and VLSI is planned. This is directly related to the research of Drs. Chen [Chen 1 and 2] and Kalla. Projects are:

1. Design a ready-for-production chip for a wireless communication receiver (such as a RAKE receiver for CDMA systems). The project involves algorithm, architecture, and synthesis-based circuit design. It will span the entire design hierarchy from algorithm design to integrated circuit layout using a mix of tools such as MATLAB (circuit), VHDL (architecture), SYNOPSYS (logic), and CADENCE (circuits). Automated synthesis, place and route tools (SYNOPSIS and CADENCE) will be employed extensively so that the design emphasis will be at the algorithmic and architectural levels. This is a large project that require students to work in teams, thus it will provide an invaluable experience for students to work in a team environment and prepare them for their future careers.

2. Algorithm and architecture optimization for high speed communication decoders. This project aims at VLSI implementations for high speed encoders and decoders used in communication systems. We expect to incorporate such a project into the error-control coding class to achieve the goal of bridging theory and practice. The students will design efficient algorithms and

VLSI architecture for Reed-Solomon codes, convolutional codes, and iterative decoders for powerful codes such as turbo code and low density parity check codes. VLSI implementations of such high speed decoders are of great academic and industrial interests.

Control Systems

Prof: Bodson
Courses on control systems offer great opportunities to integrate knowledge from various fields. For example, the senior-level course ECE5570, titled "Control of Electric Motors," requires students to integrate knowledge in:

* electromagnetics (to understand the principles of operation of electric motors),
* mathematics (to understand nonlinear differential equation models),
* circuit theory (to compute operating characteristics of electric motors),
* control systems (to design drives for the motors),
* programming (to implement control systems in the lab using digital processors).

The junior-level course ECE3510, titled "Introduction to Feedback Systems," also integrates knowledge in control and circuits. For example, students devote two lab sections to phase-locked loops, and implement the devices on a breadboard using electronic components. As part of this project, we would like to expand the labs in ECE 3510 and ECE5570 to further the multi-disciplinary experience of students. This project integrates Dr. Bodson’s specific research into the classroom. [Bodson 1 and 2]

Microwave Engineering I,II, Antennas, Wireless Comm., Numerical Electromagnetics

Profs: Furse, Gandhi, Baird, Chung, Lo, Farhang, Abbaszadeh

These five courses provide an excellent example (described above) of how system-level integration can be implemented between multiple courses that are not taught simultaneously.

Implementation of a Computer Engineering (CE) Senior Design Project Prof: Myers (assist. from Grow)

Recently, we have added a senior thesis option in which students are required to find a supervisor, select a project, and successfully propose that project in both an oral and written form during the Spring semester of their Junior year. These students would then complete their project during their senior year, and they would present their results as part of the ECE Technical Open House. They are also required to turn in a written thesis for approval by their supervisor. Due to the success of the senior thesis option and a desire to add more project management skills into the curriculum, the CE faculty have made the proposal class in the Junior year a requirement for all CEs whether doing a project or a thesis. The specific goals:

1. Gather senior project instructors in the college together to forge closer ties and foster interdisciplinary teams.
2. Increase the involvement of graduate students in the senior projects and in clinics.

3. Explore expanding the clinics to include more computer engineering clinics.

4. Explore industrial support and involvement in the senior projects and clinics.

5. Explore the possibility of service learning activities with Leonardo.

Dr. Myers has already had excellent success with undergraduate students doing research senior projects. Two student projects have resulted in recent research papers [Myers 1 and 2]

Photonics/Optical Communications

Profs: Blair, Nahata, Miller

The ECE Department regularly offers two elective courses in photonics: ECE 5410 Optical Electronics and Lasers and ECE 5411 Optical Communications Systems. The purpose of 5410 is to provide the basic underpinnings of photonics technology and concentrates on fundamental principles and devices. The purpose of 5411 is to be a systems-oriented course where students learn concepts such as system requirements, multi-component integration, system performance, and cost-tradeoffs, all in the context of optical communications systems. For example, during the Spring of 2004, the class is working on a term project relating to the feasibility of fiber to the home (FTTH). This project started the first day of class and is motivated by two FTTH projects in Utah – iProvo which is approved and underway, and UTOPIA which links 18 cities and is currently in the approval process. Fully deployed, these projects will link over 250,000 households and small businesses with high-speed internet/video/data access. The students are doing a feasibility study of broadband to the home, concentrating on five aspects – 1) Motivation and benefits, 2) Broadband technologies, 3) FTTH, 4) Public versus private infrastructures, and 5) Economics. In this project, the students will do complete systems designs of multiple FTTH implementations along with wireless, cable, DSL, and broadband over power-lines solutions. They will address issues such as performance, scalability, current and future services, engineering cost-tradeoffs, and economic benefits. In subsequent years, we will expand on this project to develop a comprehensive report applicable to any broadband to the home project. We will also link the engineering students with students in economics and business.

The development of the photonics teaching laboratory, which will be a focus of this NSF project, has been geared towards providing the capability of developing
photonics systems testbeds. One such testbed is a mock-up of a complete optical communications system. During the Spring of 2005, we plan to implement a comprehensive systems design and testing component to ECE 5411 in which students will design and analyze a simple optical network, simulate the performance using optical network simulation software, then build and test the network in the laboratory. We also plan on using the first course ECE 5410 for students to design and build optical transmitter and receiver modules which will then be integrated into their testbeds in ECE 5411 the following semester. One further goal is to utilize ECE 6440 Photonic Microsystems (which is offered Fall odd years) to design and fabricate integrated optical components such as splitters, active modulators and switches, and wavelength-selective components, which will then be tested by students in ECE 5411.

Project Based System Level Reforms of Solid State and Microsystems Curriculum

Three problems complicate implementing project-based curriculum reform in the solid state and related microsystems areas in ECE. Primarily, students do not gain experience with the full cycle of design, fabrication, and characterization of microelectronic or other microsystem chips until the last semester of their final year, too late for senior capstone projects and for connecting with other courses. Secondly, the infrastructure and device technology base needed for fabricating chips suitable for integration with other project courses in ECE can present a formidable, resource intensive barrier. Thirdly, the late-in-the-day exposure to chip making and device technology resource constraints also impede connecting the solid state undergraduate curriculum with meaningful research, which in ECE typically does not get going until after one or two years of graduate training in the "basics".

We have been working to overcome these difficulties by renovating the College of Engineering Microfab labs, recasting the two semesters of semiconductor labs and lectures into a team-based project format, and developing a projects course that implements microdevice technologies suitable for use in teaching and research. The ECE Curriculum Reform Project in solid state and microsystems will have medium term goals of connecting the present chip design and fabrication projects to other ECE courses and a longer term goal of reorganizing the Junior-level courses in modern physics and thermodynamics to teach these topics with a just-in-time methodology using, as examples, semiconductor devices, integrated optical waveguides, or microsensors for microchip fabrication projects. A second component will be to use the Microfabrication Projects course to introduce students to research based on microelectronics and other microsystems.
Physics of IT: Modern Physics and Thermodynamics Profs: Miller, Solzbacher, Blair

This would be a new course, probably cross listed with Materials Science and Physics, that not only prepares students for advanced courses in solid state devices, but also reinforces connections with E&M and optics as well as information theory and how these fit into modern IT. This course coverage would replace the current modern physics and thermodynamics courses. A system design lab would be included, with system implementation taken up in the senior year solid state and microsystems project courses.

Semiconductor Device Physics and Semiconductor Device Engineering Profs: Miller and Solzbacher

These two existing courses cover the basics of how things work and how to make a chip in the lab. In the second semester, students design, fabricate and test an IC, where each lab section works as a team to meet the design specification. In spring 2003, each of the seven teams made a ring oscillator and a common source amplifier (see Figure 1). The revamped junior course in the physics of IT should enable more sophisticated integrated circuits to be designed and fabricated, which would allow easier connection to projects in other courses.

Figure 1: Cadence layout and electron micrograph of the CMOS project chip developed by teams in the second semester, Semiconductor Device Engineering course. (Prof Miller)

Microfabrication Projects Profs: Miller, Rasmussen, Solzbacher, Nahata, Harrison, Kalla, and Harvey

This new course has been piloted twice and configured so students can design, fabricate and test a microsystem, where example technologies include microelectronics, integrated optics, and microfluidics as well as combinations of these. This course both provides a venue for senior projects in microsystems, and
students have been explicitly developing basics device technologies for use in research projects.

VI. Integrated Education: General Education and Support Classes

The General Education Requirements of the University and ECE Department are:

<table>
<thead>
<tr>
<th>Category</th>
<th>Requirement</th>
</tr>
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<tbody>
<tr>
<td>Fine Arts</td>
<td>Two classes</td>
</tr>
<tr>
<td>Humanities &amp; Diversity</td>
<td>Two classes</td>
</tr>
<tr>
<td>Social and Behavioral Science</td>
<td>Two classes</td>
</tr>
<tr>
<td>Physical and Life Science</td>
<td>Automatically satisfied</td>
</tr>
<tr>
<td>American Institutions</td>
<td>One class</td>
</tr>
<tr>
<td>Writing</td>
<td>Automatically satisfied</td>
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</table>

The incorporation of the Ethics requirement (by the department) and the Diversity requirement (by the university) provide a good example of how the general education requirement and classes can be tailored to better serve engineering students.

Suggested Ethics Classes (taught by Philosophy) today are:

- Current Moral Issues
- Ethics
- Business and Professional Ethics
- Bioethics
- Environmental Ethics
Examples of Diversity Classes are:

LING 3460  Language In Society
LING 3600  Intercultural Comm
MGT 3800  Business & Society
SOC 3200  Diversity Service Learning
PSYCH 4450 Intergroup Relations
POL S 3340  Diversity/Workplace

As a result of the curriculum review spawned by the NSF planning grant, we have identified several collaborative general education projects with other colleges and are planning to implement three of them in fall 05.

<table>
<thead>
<tr>
<th>Fine Arts</th>
<th>Artistic Engineering (F05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humanities (F05)</td>
<td>Ethics &amp; Diversity (the ELEAP program)</td>
</tr>
<tr>
<td>Social and Behavioral Science</td>
<td>Project Management,</td>
</tr>
<tr>
<td>Marketing/Entrepreneurialism (F05)</td>
<td></td>
</tr>
<tr>
<td>Physical and Life Science</td>
<td>Automatically satisfied</td>
</tr>
<tr>
<td>American Institutions</td>
<td>One class (possibly Engineering Law)</td>
</tr>
<tr>
<td>Writing with ELEAP</td>
<td>Automatically satisfied in conjunction</td>
</tr>
</tbody>
</table>

We initially anticipated significant political and practical difficulties in making any changes to the General Education program but were pleasantly surprised how anxious the other colleges were to get involved. We were lucky, though. Interdisciplinary interactions were announced this summer as a major component of the university strategic vision.
We are utilizing and helping to expand two small university programs that were already in place. The Engineering Learning and Aptitude Program (ELEAP) provides freshman engineers with the opportunity and training in. Some programs (such as ELEAP) were already in place and being utilized by other departments, and small revisions or expansions have made them suitable for us. Another exciting program is the Center for Engineering Leadership (CLEAR) which provides direct mentoring between communication seniors who are experienced at public presentation and engineering seniors who are preparing both oral and written reports for their capstone design projects. Student presenters are videotaped, and critiqued to help improve communication skills. The Mechanical Engineering Department has been the first department to utilize this newly funded facility, and Electrical and Computer Engineering is excited to join in as well.

We anticipate integrating the general education classes and actually utilizing the skills learned in these classes in the projects throughout the curriculum. For instance, the writing class will be taken early enough to be used throughout the curriculum. The business classes will be taken in the junior year and integrated with the senior projects. Not only will the juniors receive a basic business introduction, but they will get to test it out on a realistic project. They will also have the chance to see a senior project in action, so that they have an idea what to expect in their senior year.

**VII. Expected Outcomes: Enhanced System-Level Design Capabilities and a Better Education**

We anticipate the following positive results from this project:

**Increased freshman recruitment and retention**

It has been shown that an exciting freshman design project significantly improves freshman retention. In addition, our own senior exit surveys indicate that many freshmen who leave the program, especially those who are “non-traditional”, women, or minority students, as these groups tend to prefer education that they perceive as relevant, society-oriented, and immediately applicable.
Increased student motivation

Our student population is somewhat unique for social reasons. A majority of undergraduates are married and are supporting families. Most work at least part time, and many work full time or more. Many take a year off in the middle of their studies for missionary or other work. As a result, most students take 5-7 years to graduate. Maintaining student motivation in this over-committed student population is a significant challenge, and many professors have noted this problem. Our students’ exit surveys indicate that they particularly like the courses that already have system-level projects, and that they desire additional system-level design projects, noting that these are the projects that keep their interest and perceived understanding of the material.

Increased knowledge acquisition and retention

The nature of our student body also leads to significant challenges in knowledge retention. Students often have a span of multiple years between taking a prerequisite and the class that needs it. The ability to incorporate knowledge into projects across multiple classes is expected to significantly improve retention, as knowledge is continually renewed and utilized.

Increased system-level design understanding

Our Industrial Advisory Board, recruiters and student employers, and the students themselves have noted the value of system-level understanding and the limited capability that our students have in this regard. This is not unique to our university and is a common concern in engineering education. This project formally demonstrates design at all levels of the curriculum and formally teaches project management in the junior year to expand the technical aspects of system-level design through a formal framework for evaluating and managing all aspects of a system.

**VIII. Implementation Plan**

Never underestimate an excited and collaborative faculty in a university backed by a state legislature with a strong and demonstrated commitment to engineering. We have the energy, skills, and partnerships to implement this program and to share it
with other departments in the country. We have built sizable momentum through the planning process and are excited by the responses we are getting from our students, other departments, and our administration. We are having fun. The success of this project will depend on a department-wide effort to integrate system-level design consistently throughout the curriculum. While this idea is very popular amongst the faculty, the limiting factor is the time that it will take to modify the existing projects and programs that are already in place. In order to make this feasible, we will hire a lab technician specifically to assist professors in developing and prototyping the system-level projects to be incorporated in the lab. This person will also help to build or acquire whatever specialized components, control software, etc. are needed for the projects. Rather than the traditional lab technicians who focus on keeping the lab equipment up and running, this person will actually work directly with professors and their TAs to create new system projects. For perpetuation of the project-based curriculum, the university has agreed to make this technician a permanent position if the implementation grant is funded.

This project will provide funding for five full system design projects to be implemented each year for three years, for a total of 15 projects. A set of projects has been instigated by a professor or set of professors, and one month of summer salary will be provided to give the professor time to develop the project sometime during the 3 year grant period. In addition, this professor will have an advanced teaching assistant full time during the summer and part time during the school year to develop the project and the associated curriculum materials (lab manuals, tutorials, textbook sections, demonstration materials, etc. as needed), and also to conduct the laboratories the first year. In large classes where it is not feasible for one TA to support all of the lab sections, this TA will assist in supervising and training additional TAs. This advanced TA will typically be a PhD student who plans to go into academia and wishes to gain more experience with teaching and curriculum development. We anticipate that these PhD students will receive extensive mentorship and gain valuable teaching skills as a result of this project. Funding is also provided for Stephanie Richards, professor in the Center for Teaching & Learning Excellence, and a TA to assist her in assessing the program and providing faculty support and training.

In addition, many projects may be developed as part of our senior design sequence. Seniors will help to design the hardware for proposed projects for future years, providing the time and capability necessary to accomplish the initial design. This method worked very effectively at Utah State University, where the PI previously implemented successful system design projects in her courses and is being used this year at UofU. This provides a particularly poignant and exciting link, as the senior students provide valuable perspective and experience in the exact learning
environment that we are working to change and improve. Their feedback and
designs have proven to be invaluable in the development of projects in the past, and
we wish to utilize their valuable resource. In addition, it tends to create a
substantial "student buy in" to the process, and provides a very positive learning
and teaching environment in which to work.

Some projects will be done in individual classes, others will be integrated between
multiple classes, and some will be done in individual classes utilizing the projects
built in other classes. Full flexibility in how system integration is accomplished
within an individual project is provided, as there are a wide variety of good ideas
throughout the department, and we would like to accommodate and compare
several different methods.

In the process of integrating system-level design into our courses, we have observed
that this naturally integrates research into the curriculum, as faculty and TAs are
most comfortable adapting a project from their research into the classroom rather
than dreaming up an entirely separate project. This concept requires a
reassessment of the material being taught, a reduction of elimination of material
that is less pertinent to today’s engineers, and an inclusion of additional, highly-
relevant material. The concept of “just in time” teaching is also naturally
implemented, and the projects inherently lend themselves to active, small-group
learning. Improved teaching methods such as these will be formally discussed at
faculty meetings throughout the year, utilizing existing expertise throughout the
university to provide faculty training. In essence, this will be “just in time” teaching
for faculty members who are experimenting with and implementing changes in their
individual classes.

The planning grant received this year lead to collaborative course discussion, plans
for changes to be implemented this fall, and consideration of the material being
taught throughout the curriculum. It also lead to collaborative research connections
within the department and across departments. The idea of change is in the air, and
this department is already giving it a try. We see ourselves as a good, solid state
school, and if we can successfully implement these changes, we are excited to help
other schools and other departments do the same. Integration of system-level
education impacts students at all skill levels, providing additional challenges and
thought-provoking open-ended designs for our best and brightest students, and
giving context and meaning for the students who struggle to learn. The hands-on
system-level education reaches students with diverse learning styles, many (such as
the kinesthetic and global learners), who have been neglected in traditional
engineering education. We are excited to try these changes, and our students (after
seeing a note posted reminding them to sign up simultaneously for two courses to be integrated this fall) are very excited as well. We think that this has the potential to be a truly remarkable new program, and our early experiences are very exciting and fun, both for the students and for the professors.

We also recognize that this project appears to be a massive undertaking, which indeed it is. This truly requires a dramatic and extensive change in our curriculum. Virtually all professors in the department are directly involved, and the university, administration in several colleges, and our industrial liaisons are highly supportive. The time for a significant change is NOW, and we are already well started down the road to making a full project-oriented curriculum a reality for our school. We have a young department, several new professors welcoming development ideas for new courses, and several older professors looking for a relief from the mundane. We are excited about this project and the responses we are getting from our students. We need the National Science Foundation support to act while our departmental culture is ready for change.

Matching Support from the University of Utah

The University of Utah administration is demonstrating their support of undergraduate curriculum reform through committed matching funds (letters of commitment are attached):

Permanent Lab Technician Position for Curriculum Development and Support
$60k / year (permanent)

In this proposal, we are requesting support for a lab technician (engineer) who can help faculty develop and prototype the projects to be used in the classes. This person will augment the day-to-day lab support that we already have and will work directly with faculty in the design of the system-level projects. The Vice President for Academics has agreed to make this a permanent lab technician position to provide long-term, continued support for course development within the ECE Department.

Base Educational Equipment Fund (BEEF)  Est. $66-132k/year

The BEEF program allows departments to add to or upgrade their teaching lab equipment. $66k is normally provided per grant, and $33k in matching funds from
industry is required. Over the past 5 years, the ECE Department has received $557k (an average of 2 grants per year). We anticipate similar ongoing support for the specific equipment needed for new system design labs.

**IX. Assessment:**

We will be formally assessing each of the expected outcomes, both before implementation of the program and throughout the project. Dr. Stephanie Richardson, Center for Teaching & Learning Excellence, who has formal training and ongoing research in assessment strategies, will direct the assessment effort, with full cooperation and collaboration with the teaching professors. Her support is funded through the NSF grant. Today, we assess every course every semester with a fairly traditional student survey. We assess student skills with exams or written reports. But we recognize that by integrating courses with the intent of teaching system design, that traditional assessment approaches are insufficient. Collaborating professors need assistance identifying exactly what they will measure, and how they will measure it. Our department seeks exposure to new and novel ways of assessing teaching and learning. A graduate student in education will be actively involved, which will lead to his/her thesis research, while helping us understand and implement creative assessment strategies for this creative program. As individual professors are assisted in finding effective and comfortable ways of assessing student progress, this will quickly propagate throughout the department, as most good ideas do.

We propose to assess this as a descriptive exploratory field test of this innovative model of teaching. We will first be implementing these methods in the Signals and EM integration effort in Fall 2004.

Hypothesis 1: Students will demonstrate an increase in critical thinking and system-level understanding following the laboratory.

Hypothesis 2: Students will demonstrate more teamwork and peer support.

Hypothesis 3: Students will report an enjoyable learning experience.
Measures:

H1. Critical thinking test

(eg. Watson-Glaser Critical Thinking Appraisal. Other measures will be used for triangulation)

H1. Instructor evaluation

H1. Scores on exams

H1. Follow-on alumni surveys assessing motivation and perceived system-level understanding

H2. Self-evaluation of teamwork

H2. Team rating tool [Stefanou]

H2. Observations of team activity (refine & itemize)

H3. Course evaluations with comments

H3. Test of self-confidence [Stefanou]

H3. Test of performance fear

H3. Surveys of incoming freshmen (to assess recruitment) and follow-on surveys of students who leave the program both before and after implementation of this curriculum.

Note that several of these assessment methods are already utilized as part of our ongoing assessment process that is utilized for continual improvement and ABET accreditation review. Other methods are new to this department, and can provide a framework in which to improve our assessment techniques. Several professors in our department have experimented with novel assessment methods including [Furse Portfolios].

X. Broader Impact on Education
The University of Utah is but one school in a massive world-wide community of engineering education centers. The immediate impact of this program is of course of great interest to our students, but we do not want that impact to stop there. A major career goal of the PI of this grant is to significantly change engineering education so that it is more relevant in today’s complex engineering environment, and to make it more appealing to students with a diverse variety of thought patterns, backgrounds, learning styles, interests, and skill sets. To accomplish this, it is critical that the methods and ideas that are found to be successful for our department are also adopted by others. We have some experience with this already, through dissemination and assistance supporting the WLAN project. This requires:

- Dissemination

  o Communication through journal articles and presentations at professional meetings is a traditional dissemination method that can have slow and sparse impact, but will be done for the long-term viability it provides. The electromagnetics/signal processing integration is scheduled for publication in the IEEE AP Magazine this summer.

  o Website [ECE] with all on-line materials for labs, projects, classes, methods, etc. to make replication and adaptation easy for other departments. We have this in place for most of our classes already, and we will link it into a general program-specific website. Existing department resources will support this effort.

  o Information on our efforts will be broadly disseminated at the ECE Department Heads’ annual retreat, thereby reaching nearly every department in the country. This will be either through a formal presentation or short brochures with links to the website for more detail.

  o A potential collaboration with a textbook publisher is currently being negotiated. This would provide a CD to compliment a textbook or set of texts.

- Ease of Adaptation

  o The website will include:

  § Well-written, on-line lab materials.

  § Complete lists of equipment, parts, etc. and instructor’s manuals for the lab.

  § Course notes, etc. and syllabus that supports the lab, with instructor’s notes on what information is needed when.

  § Student tutorials (for equipment and the lab in general).
• Faculty Support

We will be glad to support other faculty as they adopt and implement the system-level projects.

Integration of system-level education in the undergraduate electrical engineering curriculum provides an ideal opportunity to change the overall environment of a standard engineering curriculum, provide students with significantly improved engineering understanding, more motivation, and a better ability to implement their knowledge. The changes proposed in this project are within the scope of most engineering programs, and can be realized within a relatively short period of time. The changes are significant, but realistic. The few system-level design experiences that our students already have are so positive that expanding and emphasizing this excellent learning opportunity throughout the entire curriculum is virtually guaranteed to appeal to students, faculty, and employers at the University of Utah and beyond.