AC 2007-2365: ELECTRICAL ENGINEERING WITHIN A MULTIDISCIPLINARY PROGRAM

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Electrical Engineering Within A Multi-Disciplinary Program

Introduction

This year, Arizona displaced Nevada as the most rapidly growing state in the nation. Almost all of this growth is occurring in the Phoenix metro area, which is the area served by Arizona State University (ASU). In order to accommodate the 30,000 additional students expected at ASU by the year 2015, the university is becoming one university with 4 separate campuses: the Tempe campus, the West campus, the Downtown campus and the Polytechnic campus. None of these is a main campus and none of these is a satellite campus. The Polytechnic campus is located in Mesa and the enrollment there is projected to grow from 5,000 to 15,000 over the next decade[1]. As part of this plan, a new engineering program has been created at the Polytechnic campus. In order to avoid duplication of degrees already taught in engineering at the Tempe campus, the new program will accredit through ABET as a general engineering program. An overall description of this "clean slate" opportunity to rethink engineering education has been described elsewhere[2]. Here our focus will be on the development of an electrical engineering systems concentration within this multi-disciplinary degree program. This concentration is not intended to qualify for ABET accreditation under the program specific criteria for electrical engineering.

The Overall BSE Degree Program

After extensive discussions, the founding faculty team decided to build around core values of engaged learning, agility and a focus on the individual. Engaged learning is accomplished by having the main spine of the program be 8 semesters of project work conducted inside an engineering studio. This is an Aalborg style approach[3] in which there is a single project experience every semester, accompanied by formal instruction in separate courses. The overall four-year program of study is illustrated in Figure 1. The spine of projects is the sequence of courses on the left-hand side of the figure.

Another distinguishing feature of our program is the modules, which make up the bulk of formal engineering instruction in the sophomore year. These modules are 1-credit length chunks of standard engineering topics such as mechanics or electrical signals and instrumentation. In each semester of the sophomore year, the student takes 5 such modules. The actual module selection varies from semester to semester and is guided by the project. In table 1 we supply a list of modules and their titles. Students are additionally allowed to take modules as electives. Similar modules have been used at the University of Arizona to provide breadth in the engineering curriculum (http://gecourses.sie.arizona.edu/GE/); the UA modules are not offered in the context of a companion project. Each of the program's concentrations has selected three modules to serve as "anchor" modules. While not required for the degree, these modules are part of the required preparation for that particular concentration.

Figure 1. The four-year program of study for the BSE degree in Engineering at Arizona State University at the Polytechnic campus.

Table 1
One-Credit Sophomore Modules

Course Number	Course Title
EGR 220	Computer Hardware for Engineers
EGR 221	Engineering Mechanics - Statics
EGR 222	Mechanics of Materials
EGR 223	Engineering Thermodynamics
EGR 224	Materials Selection
EGR 225	Instrumentation I
EGR 226	Engineering Applications of LabView
EGR 227	Manufacturing Processes I
EGR 229	Engineering Ethics and Professionalism
EGR 230	Fluid Mechanics
EGR 231	Engineering Mechanics – Dynamics
EGR 234	Structure and Properties of Engineering Materials
EGR 235	Instrumentation II
EGR 238	Feedback Control
EGR 239	Engineering Economics

We pursue our core value of a focus on the individual largely by following the model of Alverno College[4]. At Alverno they stress that the most important aspect of assessment is to assist the individual student in their individual pursuit of the program's goals for students. Program level assessment for accreditation is viewed as an important byproduct. In our implementation the focus on individual assessment involves self-assessment activities, both written and oral, in which the individual student explicitly tracks their progress towards our program's equivalent of ABET a through k. This equivalent consists of the 8 outcomes shown in figure 2. We call to your attention two aspects of figure 2. First, a developmental approach is used in which entering freshmen are evaluated differently than a nearly graduating senior. Secondly, to ease the important process of actually talking to students about these outcomes, the somewhat cryptic ABET letters are replaced by one or two word long names. For example, ABET outcome g becomes our outcome of communication. This allows faculty and students to actually discuss these outcomes without perpetual referencing of the ABET documentation. Details of this scheme have been described elsewhere.[5]

These projects and modules give us a running start at building the core value of agility into the curriculum. The freshman and sophomore years of the program are multi-disciplinary, with all students sharing a common set of projects and courses. However, we also have the third value of a focus on the individual. So, at the upper division, a student will individually select two focus areas: a primary engineering concentration and a secondary emphasis area, which may or may not be in engineering. We have selected three initial engineering concentration areas: electrical engineering systems, mechanical engineering systems and a civil infrastructure concentration centering on land development.

ENGINEERING OUTCOMES AND DEVELOPMENTAL LEVELS

Design–An ability to design a system, component, or process to meet desired needs within realistic constraints.

Level 1 Recognizes need for and can recite information flow in design methods and process steps.

Level 2 Can carry out and communicate design process steps in constraint-based hypothetical design situation.

Level 3 Evaluates design steps and resulting design quality and can revise them to improve a particular design scenario.

Level 4 Can customize design process and communication for varying design situations.

Problem Solving–An ability to identify, formulate, and solve engineering problems.

Level 1 Articulate the problem solving process by making explicit the steps taken to approach a problem.

Level 2 Performs all phases or steps of the problem solving process including evaluation and real or simulated implementation.

Level 3 Independently analyzes, selects, uses, and evaluates various approaches to develop solutions.

Level 4 Applies methods and frameworks of problem solving adapting them to a wide variety of situations and transferring group processes into effective performance in collaborative problem solving.

Professionalism–An understanding of professional and ethical responsibility, a commitment to on-going professional competence and possession of basic professional and organizational success skills.

Level 1 The student exhibits professionally appropriate behavior patterns, understands what it means to define engineering as a learned profession and possesses daily success skills.

Level 2 The student accepts responsibility for their education, can describe the major professional and ethical responsibilities of engineers, the major specialties of engineering and basic corporate structures and purposes.

Level 3 The student can use common moral theories and concepts to guide them in their ethical decision making and has formulated a probable career path that takes into account current trends in both technology and society.

Level 4 The student can effectively guide their own efforts at gaining and maintaining their professional competence and their professional reputation.

Communication–An ability to communicate effectively.

Level 1 Recognizes own needs, strengths, and weaknesses in communication.

Level 2 Can apply individual steps of communication processes.

Level 3 Purposefully uses communication processes to address the needs of their audience.

Level 4 Appropriately employs and adapts communication processes to fully engage an audience.

Perspective–An understanding of the role and impact of engineering in contemporary business, global, economic, environmental, and societal contexts.

Level 1 Understands that technological change and development has both positive and negative effects.

Level 2 Can identify and evaluate the assumptions made by others in their description of the role and impact of engineering on the world.

Level 3 Can select from different scenarios for the future and appropriately adapt them to match both current science and current social, economic and political concerns.

Level 4 Has formed their own model for the probable future of our society and makes decisions about their life and career that is informed by this model.

Engineering Practice–An ability to use the knowledge, techniques, skills, and modern tools necessary for engineering practice.

Level 1 Students are able to describe the essential elements of good engineering practice.

Level 2 Given a problem statement, students are able to identify the necessary tools (e.g., computer software, and workshop or studio hardware), and characterize a plan, that together will produce a technical solution.

Level 3 With direction, students are able to identify an appropriate set of engineering tools and apply them in a real world professional context, to develop a valid solution to a technical problem.

Level 4 Students are able to independently identify the appropriate set of design and analysis tools and apply them within the context of the principles and method of sound professional practice to obtain optimal (defensible) solutions to engineering problems.

Critical Thinking and Decision Making–An ability to think critically, clearly identifying and using evidence, criteria, and values in the decision making process.

Level 1 Articulate the critical thinking process.

Level 2 Identifies assumptions, criteria, and evidence to make informed decisions.

Level 3 Evaluates alternative perspectives, contexts, and the quality of evidence in making informed judgments.

Level 4 Examines and cultivates own value system relative to making informed decisions.

Technical Competence–An ability to apply knowledge of mathematics, science, and engineering as well as collect, analyze, and interpret data.

Level 1 Students communicate, both verbally and mathematically, the engineering and science conceptual principles underlying engineering problems and recognize strengths and weakness in their conceptual knowledge.

Figure 2 Outcomes and Developmental Levels of the BSE Program in Engineering at Arizona State University at the Polytechnic Campus.

In our curricular model we insure that we have satisfied all ABET mandates (with a 3 credit safety factor in engineering topics) as well as all ASU institutional mandates for undergraduate degrees. The net effect is that a student must take 51 hours of engineering courses, 32 hours of math and science, 15 hours of humanities and social science and 9 hours of courses that emphasize communications. There are 21 hours left and this where we allow the student to impose their own "mandates". We illustrate this with the curricular pie shown in figure 3. The individual student therefore makes their own final decision about issues such as a breadth/depth tradeoff. A student could take as many as 72 hours of engineering and engineering technology in our program and minimal amounts of everything else. Should they do this, they can build in novel mixtures of engineering topics such as a 50:50 blend of mechanical and electrical engineering. On the other hand, they could take 51 hours of engineering and 30 hours of work in some recognized area of the humanities or social sciences. Yet another possibility would be to generate a pie-piece with a different curricular flavor such as business, foreign languages or performing arts. This flexibility is in dramatic contrast to many engineering programs where the student is given nearly no flexibility and might find themselves required to take 60 or mores hour inside a single engineering discipline.

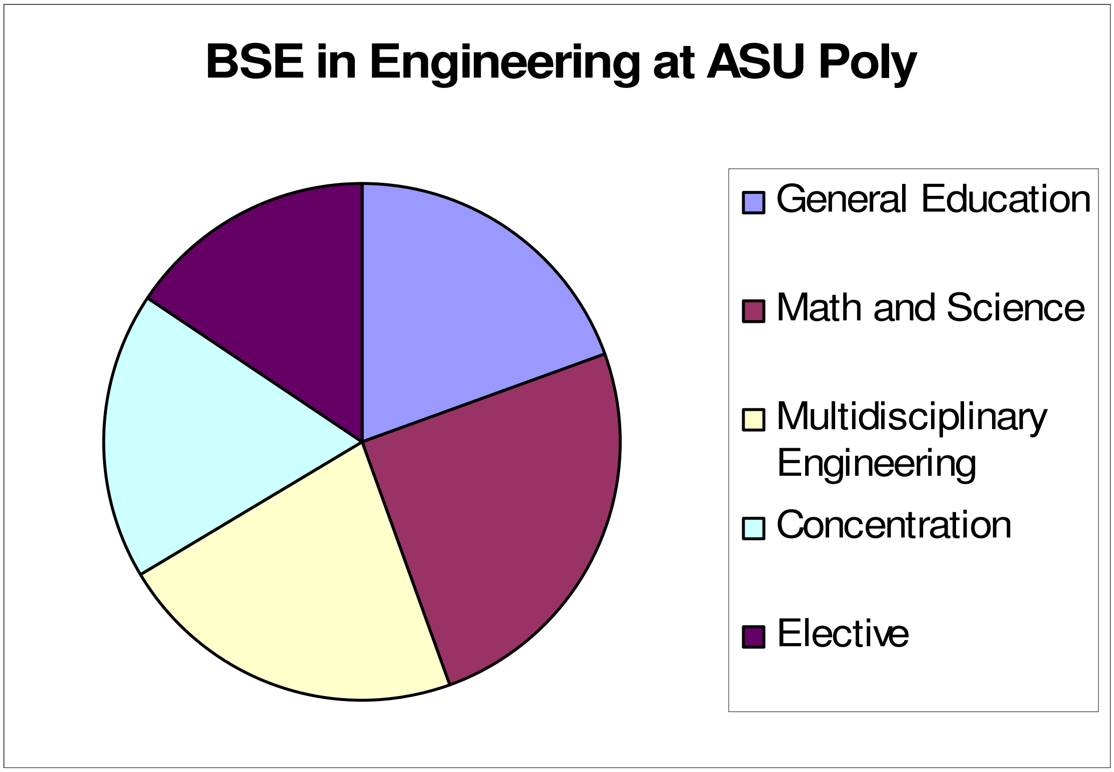

Figure 3. The 128 credit curricular pie of the BSE program of Arizona State University at the Polytechnic campus. The breadth in engineering segment consists of the freshmen and sophomore engineering courses along with the capstone project.

The Concentration Outcome

We started with the end in mind. The first step in developing the electrical engineering systems concentration structure was to create one or more student outcomes for students completing the concentration. Given the context of the concentration within a multidisciplinary engineering degree, a natural outcome was the following:

Outcome: The student will be capable of providing electrical expertise on a multi-disciplinary team.

A similar outcome is being considered for the mechanical engineering systems concentration being developed concurrently. In contrast, the ABET program specific criteria for electrical engineering do not explicitly recognize multi-disciplinary aspects (except for admixtures of electrical and computer technology). While multi-disciplinary teaming appears in the general ABET criteria, its absence from the program specific criteria is often evidenced in curricula by having this be restricted to those courses which one takes before starting the major in electrical engineering. While our concentration will not provide the extensive coverage of electrical engineering seen in a program specific electrical engineering degree, we will focus on those aspects of electrical science and technology that are important in settings where successful multi-disciplinary teaming is mission critical. The multi-disciplinary efforts of the lower division course work in our program will be continued by this electrical engineering systems concentration.

Proceeding in a top-down approach, we next asked about the setting inside of which such a multi-disciplinary team functions. It is a setting such as automation, robotics, helicopters, planes and automobiles where electrical technology plays important roles in system integration. In these settings we mix electrical technologies with other technologies inside one overall system as is illustrated in figure 4. In our concentration, we focus on the interface between the electrical and non-electrical subsystems. Along these interfaces we will be seeing flows of energy and data running between sensors and actuators on one hand and controllers and power sources on the other. While the conventional electrical engineering degree focuses on analysis of the electrical subsystems to a degree impossible for our student, the price paid for that specialization is lack of background in the non-electrical subsystems along with comparatively little project experience in which such mixed technology systems are actually designed, built and tested.

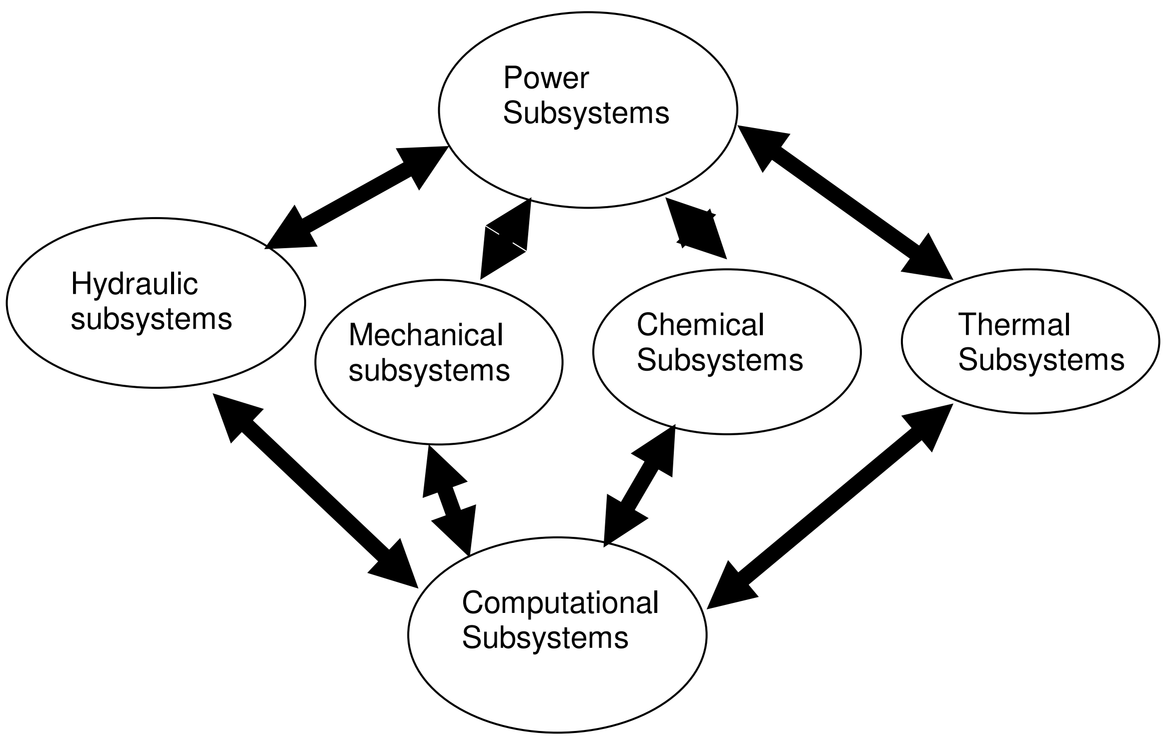

Figure 4. Flows of energy and data in a mixed technology system

What is the electrical expertise needed in such settings? We brainstormed a collection of topics most important for a student to achieve the concentration objective. The brainstormed topics were organized using a mind mapping technique that provides a hierarchical structure to the collection. After generating an initial collection, we held a group discussion with members of our department's industrial advisory board to find omissions and to refine the emphasis in the topic areas. As the curriculum has been developed, we have also restructured the collection to provide detail and reflect common elements between topics. The mind map with the current set of topics and their relationships is shown in Figure 5.

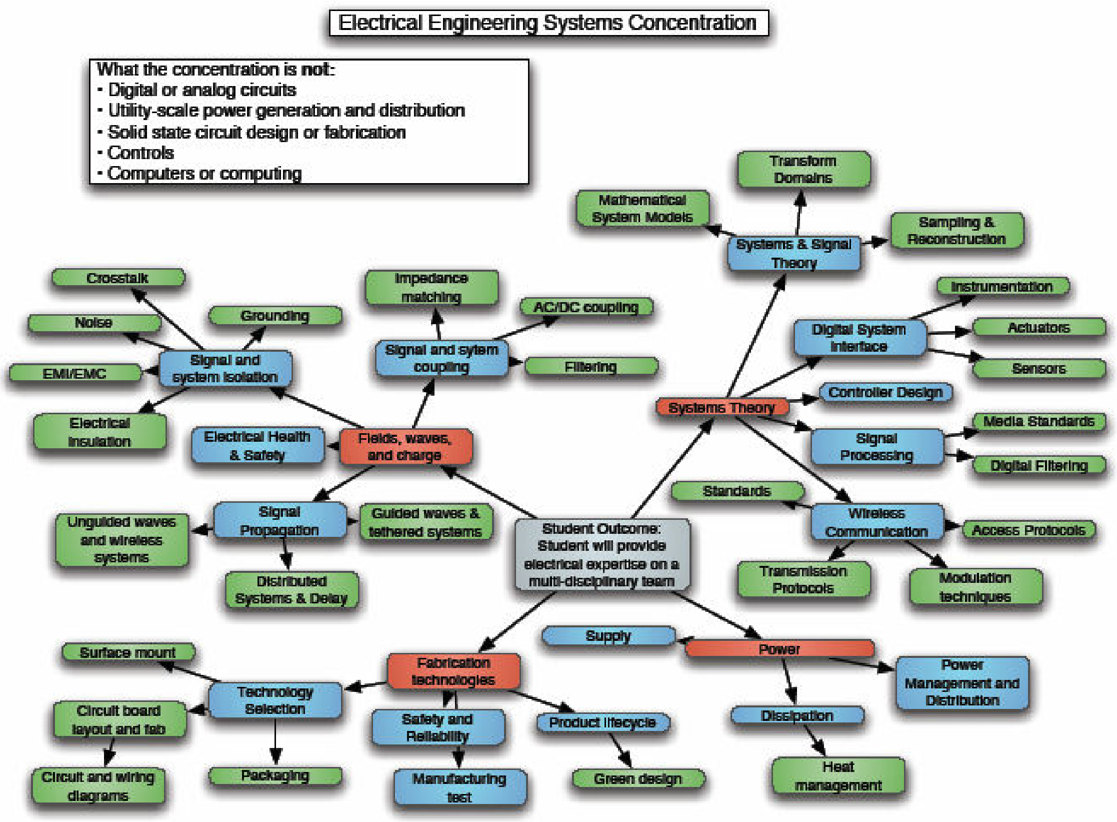

Figure 5. A mind map of topics for an electrical engineering systems concentration

Note that the mindmap has 4 expertise quadrants. On the upper right we find systems theory. On the upper left we find fields, waves and charges. On the lower left we find fabrication technology and on the lower right we find power. The systems theory expertise quadrant traces information flows between sensors and actuators at one end and the immediate digital side of the digital/analog interface at the other end. It also is concerned with some aspects of decision making and control. The fields, waves and charges expertise quadrant involves selecting signal propagation methods (e.g. wireless vs. tethered), signal and system isolation (e.g. electromagnetic compatibility and interference) and system coupling. The fabrication technology expertise involves technology selection (e.g. software solutions vs. FPGA), safety, reliability and quality, system validation, manufacturing and manufacturing test. The power expertise focuses on power generation, distribution, management and dissipation within a system such as an automobile (not a utility-scale system).

What the Concentration Will Not Do

Given the focus provided by the concentration outcome and the resource limitations inherent in the department's desire to offer multiple concentrations, we next developed constraints that described what the concentration would not include. We decided that the following topics, usually part of an electrical engineering degree, will not be included in this concentration:

- Digital or analog circuits
- Utility-scale power generation and distribution
- Solid state circuit design or fabrication
- Control theory
- Computers or computing

While these topics are important, we believe that industrial projects requiring expertise in areas critically dependent on these constraints will most likely require a team member with an electrical engineering degree and expertise in the particular topic area. In several cases, a student in our program could pursue the topic using courses taught as part of the engineering technology degrees or computing studies degrees already offered on our campus. The secondary emphasis areas and unrestricted electives discussed earlier provide the student with 20 credits for such purposes.

Development of Concentration Curricular Structure

The following resources are available to us in the design of an electrical engineering systems concentration in the context of this degree. We can assume that the student has some prior exposure at the sophomore level to elements of instrumentation and feedback control through our selected anchor modules. In addition, the student has taken a year of calculus, a semester of differential equations and a semester of statistics for engineers. The physics exposure ended after the usual first semester focus on mechanics. The student has some experience in construction of simple electrical hardware for robotics. In our first implementation, all three concentrations have agreed to further use a third semester of calculus focusing on vector valued multivariable functions and a junior level, computer intensive linear algebra course.

Then, we can build on this background with two semesters of concentration specific project work in the junior year. Each of these semesters will be accompanied by an embedded one credit module specific to the concentration. We have four course blocks, each of three credits length available for concentration specific activities. Lastly, we can select one additional math or science course that would be required for students taking this concentration.

In the remaining portions of the paper we will describe how we finished the concentration's curricular design. To clarify the discussion that follows, let us share the resulting curriculum in advance. The last two years of the four year program of figure 1 with the courses for the electrical engineering systems concentration are shown in figure 4. In table 2 we provide a list of courses and titles.

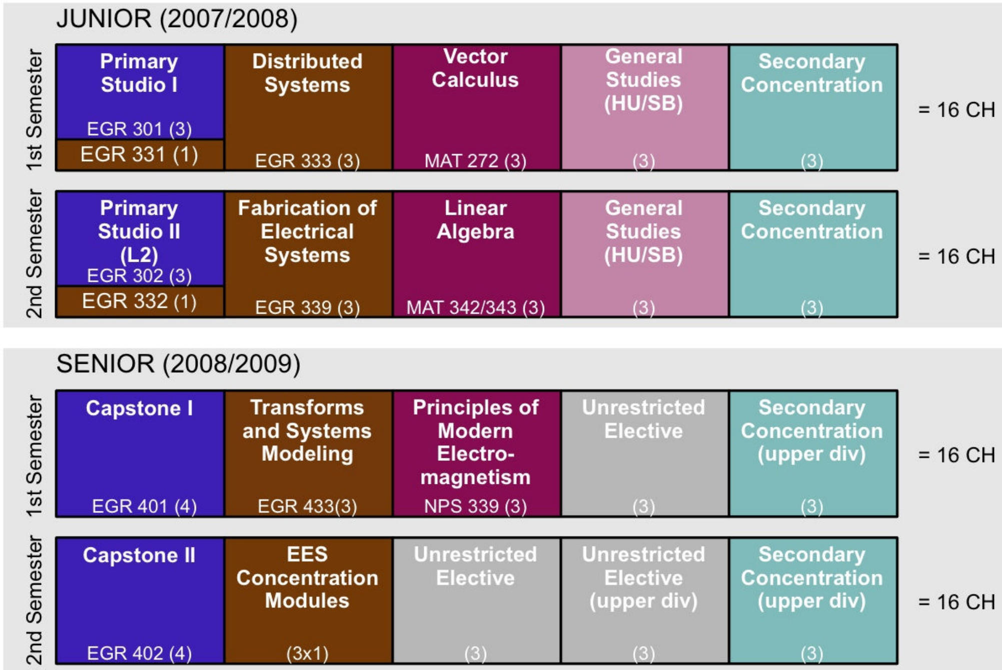

Figure 4. The junior and senior years following the Electrical Engineering Systems concentration.

In figure 4, we see that the spine of project courses on the left is now paralleled by a set of courses covering topics in electrical engineering systems. The projects during the third or junior year will be specific to the electrical engineering systems concentration and will be used by us to relay certain topics to the student. The year-long capstone project is intended to be multi-disciplinary on the other hand and will not be further considered in this paper. The last semester of the column of electrical engineering systems courses is another set of modules. We again use this both to match up topical coverage against the capstone experience and additionally to provide some elective content to the students. Certain of these modules will be developed with an eye towards our two sister concentrations: mechanical engineering systems and civil engineering land development. Immediately to the right of the column of electrical systems courses, is a column which consists mainly of courses in mathematics and science. The remaining portions of the curriculum are electives and general education credits.

Power Expertise Quadrant

Our first estimation is that we can accomplish many of the goals in the power expertise quadrant with a one-credit embedded module. Remember that we are not trying to produce an electrical engineer who will pursue a career in utility scale power distribution. Rather, we are focusing on someone who can provide power to the various parts of a smaller system such as a vehicle. The person will need to know how to select an appropriate power source (battery, fuel cell or generator), distribute the power within the system and know where and how to employ simple heat sinking within the system.

Table 2
Courses for the Electrical Engineering Systems Concentration

Course Number	Course Type	Credits	Course Title
APM 272	preparatory	3	Vector-Valued Multivariable Calculus
MAT 342	preparatory	3	Applied Linear Algebra
EGR 225	preparatory	1	Instrumentation I
EGR 235	preparatory	1	Instrumentation II
EGR 238	preparatory	1	Feedback Control
EGR 301	Required	3	Fall Concentration Project
EGR 302	Required	3	Spring Concentration Project
EGR 331	Required	1	Electrical Implementation Technology
EGR 332	Required	1	Power and Heat
EGR 333	Required	3	Distributed Systems
EGR 339	Required	3	Fabrication of Electrical Systems
EGR 433	Required	3	Transforms and Systems Modeling
NPS 339	Required Science	3	Principles of Modern Electromagnetism
EGR 335	Semi-required	1	Instrumentation III
EGR 336	Semi-required	1	Mechatronics
EGR 337	Semi-required	1	Remote Sensing and Imaging
EGR 434	Semi-required	1	Digital Signal Processing: Media Standards
EGR 435	Semi-required	1	Digital Signal Processing: Filtering
EGR 436	Semi-required	1	Wireless Communication Principles
EGR 437	Semi-required	1	Wireless Communication Protocols
EGR 438	Semi-required	1	Electromagnetic Compatibility and Interference

Fabrication Expertise Quadrant

The fabrication technology quadrant is not a focus on IC fabrication but rather a focus on how one actually implements the electrical part of a mixed technology system such as a robot or vehicle. This expertise quadrant is currently being developed in cooperation with the Department of Electronic Systems and the Division of Computing Studies units based on the ASU Polytechnic campus. The Department of Electronic Systems hosts a well established accredited program in electrical engineering technology and has a more mature facilities base. The Division of Computing Studies hosts accredited degrees in computing and emphasizes embedded computing. In this quadrant, we envision two probable courses. One would be a one-credit module in which we ensure that our juniors learn about ASU facilities, capabilities and their safe use. We wish to avoid having students get well into a project and then discover that we cannot achieve the project goals with our facilities. The other course would be a 3 credit course that covers a larger set of contemporary technologies. It would develop an appreciation for how one chooses between various solution implementations in a real-world setting. Issues such as design cycle time, fabrication and manufacturing costs, quality, reliability, product life cycle and various forms of testing would dominate this course.

The Systems Theory and Fields, Waves and Charges Quadrants

This leaves us with the two projects, three 3-credit engineering courses and one math/science course as the remaining resources which we need to allocate. This allocation needs to address the other two quadrants of the mindmap.

The next step is to set some priorities for this curricular resource allocation. We applied the following process. While each item on the mindmap has an intrinsic importance, they are not of equal importance. To set priorities we first made a matrix whose columns and rows were the individual items listed in the Fields, Waves and Charges quadrant of the Mindmap. The entries in each cell then were a pair-wise assessment of the relative importance of the column versus the row. We then summed each column to obtain a priority score. As a last step we then clumped the items into three categories: high curricular priority, medium curricular priority and low curricular priority

The pair wise comparison is in turn based on a numerical weight of the intrinsic importance of each item. The pair-wise comparison score mentioned above is the difference between these two intrinsic importance scores. To obtain an intrinsic individual importance score for each item, we first scored each item in the following four importance categories: specialization; urgency; commonality and intellectual.

Specialization Would an engineer who is not viewed as possessing electrical expertise be likely to know this? The scoring is 5 for the answer “No”, 3 for the answer “sometimes” and 0 for the answer “yes”.
Urgency Is this a source of urgent problems in the workplace? Does this generate fires that just need to be immediately extinguished? Can errors in this area generate fundamentally flawed systems? The scoring is “5” for usually urgent, 3 for sometimes urgent and 0 for rarely urgent.
Commonality How often will this skill or task appear in the workplace? The scoring is 5 for the answer “commonly done”, 3 for the answer “sometimes done” and 0 for the answer “rarely done”.
Intellectual Is this skill or topic part of a mathematically and scientifically sound understanding of technology? The scoring is 5 for foundational material, 3 for material that is analytical but not broadly foundational and 0 for material that is generally not analytical or foundational.

We then performed a weighted sum of these four scores to produce an intrinsic performance measure for each item. The weights of this sum were generated using our program’s 8 outcomes, shown in figure 2. We took each of the above four importance categories and then scored them against our 8 outcomes. We then normalized these sums so that the largest weight is 1. These were the weights then used to generate the intrinsic importance for a given item via a weighted sum of the importance factors.

The above process established some relative priority levels but completely ignores the issue of difficulty. This is what we tackled next. For each item, we assessed the difficulty of the following task. Given a student who has completed the lower division course-work of our program, how difficult would it be for that student to learn this topic? Three levels of difficulty were assigned: hard, moderate and easy. If no additional coursework past the required first two years is needed, the difficulty is easy. If one more course is needed, then the difficulty is medium. If 2 or more additional courses are needed as part of the prerequisite package, then the difficulty is hard. An identical method was also applied to the systems theory quadrant. The results are summarized in the priority-difficulty tables shown in Tables 3 and 4.

We gain some confidence in this method as it yielded surprising results. When we examine the upper right portion of Table 3, where we find items that are not of low priority and also are not hard, we note that a course in distributed circuits and transmission lines provides an excellent vehicle for the study of most of these items. When we examine the mindmap, and realize that we originally named this quadrant “fields, waves and charge”, we can see that following this analysis has led us in a direction that we did not originally expect. We originally envisioned a quadrant solidly based on Maxwell’s equations. The current analysis however suggests that a substantial amount of the work can be performed using the one-dimensional waves associated with distributed circuits and transmission line analysis.

This theme that structures such as mind maps and priority-difficulty analysis are devices intended to help us think without dictating the solutions continues in table 4. What is not illustrated in table 4 is that it was developed iteratively with the mind map. Our original mind map has a systems theory quadrant of the mindmap that was visibly altered once this analysis was performed. This modification occurred because as the analysis was performed, we realized that the original quadrant description had varying levels of detail and did not reflect the common elements of the topic areas. Table 4 then was developed using the new mind map. In Table 4 we show that the high priority-easy implementation target for this quadrant would be a class in transform analysis.

Table 3
Priority-Difficulty Analysis Results for the Fields, Waves and Charges Quadrant

	Hard	Moderately Difficult	Easy
High Curricular Priority		Noise Guided Waves Crosstalk	Distributed Circuits Filtering Impedance matching
Medium Curricular Priority	Unguided Waves EMI/EMC	Grounding	
Low Curricular Priority			Health and safety AC/DC coupling Insulation

Table 4
Priority-Difficulty Analysis Results For The Systems Theory Quadrant

	Hard	Moderately Difficult	Easy
High Curricular Priority		Mathematical System Models Sampling & Reconstruction	Transform Domains
Medium Curricular Priority		Communication Standards Digital Filtering Media Standards	Sensors Instrumentation
Low Curricular Priority	Transmission Protocols Access Protocols Modulation Techniques		Actuators

To summarize the results of this section, we have decided that at the junior level we can advance our concentration most effectively by offering two courses: a distributed circuits and networks course and a transform theory/systems modeling course.

What Can The Projects Do?

We still have two courses left to allocate: one in engineering and one in math or science. Before we allocate these resources, we ask what topics can be delivered to our students effectively via the two project courses that they will carry out during their junior year. Each of these project courses will be accompanied by an embedded one-credit module of formal instruction. We have already decided that one module will be focused on a survey of our campuses facilities and that the second will be focused on the power expertise quadrant. What about the projects themselves?

We approached this by redoing the importance-difficulty analysis only this time we included only the items not covered by the above allocations of curricular resources and we rethought "difficulty" in the context of a project. It is possible to convey content to students by asking them to carry out projects that require them to think through and apply that content. This is not an effective device for covering a wide range of material but it is very effective at producing students who remember things forever. Projects are good at illustrating real-world problems. They are not an effective device for developing a deeply theoretical understanding however. The principal result of this analysis is that issues related to sensors, actuators, grounding, coupling and health and safety are all easy to motivate in a project context. Given that a mechanical engineering systems concentration is being developed in parallel with our effort, a mechatronics[6] project in which sensors, actuators and microcontrollers are electrically integrated is one natural example of how these issues might be approached in a project setting.

The Last Two Courses

We have three credits of engineering topics and three credits of math or science left to allocate. This is obviously not enough to cover all the topics we have not yet addressed. Our plan is to repeat at the senior level the module approach of our sophomore program. We will develop a set of 1 credit modules that cover these additional topics. Then, we will pick and offer packages consisting of 3 of these modules selected to provide a good match to the year long capstone project experience.

With regard to math and science, we realized that our students have not taken any electro-science courses at all. This means that they actually have a weaker background in electro-science than most of the non-EE majors of their multi-disciplinary team, who were likely asked to take a second semester of introductory physics. We therefore will ask the students to take an upper division course that covers electromagnetic fields, waves and charges. This course will be based on vector calculus. One of the authors has regularly taught the conventional junior level electromagnetics course and observes that even though students are assumed to have taken the second semester of physics, we proceed under the assumption that they remember little of it.

Summary

We have completed a first design of an electrical engineering systems concentration which will be embedded into a multi-disciplinary BSE degree accredited under the ABET general criteria. The outcome we selected was that the student can provide electrical expertise to a multi-disciplinary team. Then, focusing on the settings in which mixed technologies occur and thereby motivate the use of multi-disciplinary teams, we brainstormed the topics needed for this concentration, determined their relative priority and assessed the difficulty of achieving them within the resource constraints of our campus, department and curricula.

The resulting electrical engineering systems concentration is summarized in Table 5. Arizona State University already maintains a separate ABET accredited 120 hour BSE program in Electrical Engineering offered through the Ira A. Fulton School of Engineering at the Tempe Campus and an ABET accredited degree in Electronics Engineering Technology offered through the College of Science and Technology at the Polytechnic Campus. In table 6, we compare these two degrees against the concentration proposed here. As can be seen, these three degrees are easily differentiated from each other.

Table 5
Summary of the Electrical Engineering Systems Concentration

Curricular Resource	Topical Subject Matter
Junior level projects	Sensors, actuators and microcontrollers
1st embedded 1-credit Junior module	Survey of fabrication technologies available on our campus
2nd embedded 1-credit Junior module	Power generation, distribution and dissipation
3 credit engineering course	Distributed circuits and filters
3 credit engineering course	Transforms and Mathematical Systems Modeling
3 credit engineering course	Solution Implementation Selection
3 credit engineering course	Selection of 3 1-credit modules that cover topics useful in the senior capstone project experience
3 credit math or science course	Vector calculus based Electromagnetic fields, waves and charges

Table 6
Comparison of the BSE degree in Engineering, choosing an EES concentration, with the BSE in Electrical Engineering and BS in Electronics Engineering Technology degrees

Characteristic	BSE in Electrical Engineering (Fulton School of Engineering)	BS in Electronics Engineering Technology	BSE in Engineering with Electrical Engineering Systems concentration
Word "electrical" appears on diploma	yes	yes	no
Word "technology" appears on diploma	no	yes	no
Word "engineering" appears on diploma	yes	yes	yes
ABET general criteria	engineering	engineering technology	engineering
ABET program specific criteria	electrical engineering	electrical technology	None
Hours in degree	120	128	128
Hours in electrical major or concentration	66	67-68	26*
Identified specialty areas or niches	Communications & signal processing; Computer engineering; Controls; Electromagnetics; Electronic Circuits; Power systems; Solid state electronics	Electronic systems; Microelectronics; Telecommunications; Alternative energy;	Electrical aspects of mixed technology systems

First occurrence of an electrical major/concentration specific class on 8-semester basis	Semester 1	Semester 3	Semester 5
Humanities & social science	Satisfies university minimum	Satisfies university minimum	Satisfies university minimum
Mathematics and science	33 hours, calculus based	21 hours, non-calculus based	32 hours, calculus based
Hours of electrical content in first 4 semesters on 8-semester basis	16	19	3 to 5
Lower division engineering hours outside of electrical	0	7	18 to 20
Upper division engineering hours outside of electrical	0	3	8
Non-electrical elective content (excluding humanities & social sciences)	3 to 4 hours of technical elective	Up to 9 hours of technical elective	20 hours of elective, none of which is restricted to technical

*Includes 23 hours of upper division and EGR 225, EGR 226 and EGR 235.

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