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Electrical and Computer Engineering as a Unified Discipline

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Abstract

Departments of Electrical and Computer Engineering (ECE) (and departments with similar names) emerged during the past twenty years in response to the growth of computer engineering as a distinct discipline. Most ECE departments still offer two separate bachelors degrees in electrical engineering and computer engineering, and ABET has two distinct accreditation requirements for programs in electrical engineering and programs with "computer engineering" in their titles. This paper argues that this distinction between "electrical engineering" and "computer engineering" is no longer useful or helpful in undergraduate ECE education. We believe all ECE students need a solid, unified foundation that cuts across the traditional boundaries and that advanced courses should be associated with more refined distinctions than the binary classification of EE vs. CE. We present a new ECE core curriculum that eliminates the outdated EE/CE distinction and describe how this core better prepares ECE students to pursue advanced courses and careers in all sub disciplines of ECE.

Introduction

Despite the large number of "electrical and computer engineering" and similarly named departments at US universities, there are currently only 14 universities offering accredited BS degrees in Electrical and Computer Engineering.[1] Most universities continue to have separate BS degree programs in Electrical Engineering (268) and Computer Engineering or Computer Systems Engineering (165).[1] Our university introduced the BS in ECE as a single degree over 15 years ago.[2] This curriculum, which we continue to follow today, offers students enough flexibility to choose among many options, either specializing in a particular sub discipline or taking a broad range of courses from across the wide spectrum of topics that fall under the ECE umbrella. Nevertheless, we implicitly retained the traditional distinction between EE and CE by naming our two sophomore core courses: "Fundamentals of Electrical Engineering" and "Fundamentals of Computer Engineering." We now believe that for several important reasons making this explicit distinction between EE and CE is not useful at the undergraduate level, and that we will better serve our students by presenting our field in a more unified manner. This paper describes our reasons for thinking it is even more critical now than ever before to remove the EE vs. CE distinction, and how we plan to do this through changes in our core curriculum.

Does ECE = EE + CE?

> "Many authorities believe that the two fields of "electrical and electronics engineering" and "computer science and engineering" have now established

separate identities, although they still have much in common. Because of the breadth of the field, however, general statements about "electrical engineering" include electrical, electronics, computer engineering, computer science, and related areas of arts and sciences in the broadest context and application." *Sloan Career Cornerstone Center*[3]

CE has attained a distinct and well-defined identity. Computers permeate technology and all of society. More importantly computers and computation represent a fundamentally important tool and way of thinking the importance of which rivals the introduction and use of electricity and electrical systems. These computational tools with their associated software have extended the ability of people to address and offer solutions to problems in the sciences, engineering, and society in general. The complexity and sophistication of computer hardware and computer systems made it impossible to prepare students for careers in the burgeoning computer industry in four-years if the curriculum includes the full complement of EE traditional courses (circuits, devices, communication, control, signal processing, power, electromagnetics, etc.). It also became clear that CE is something separate from computer science (CS) and could not simply be absorbed into the CS curriculum. Nevertheless, the close relationship between CE and certain traditional sub-disciplines in EE (not to mention the often non-intellectual reasons for defining academic boundaries) made it natural at many universities for CE to become a program in the EE department.

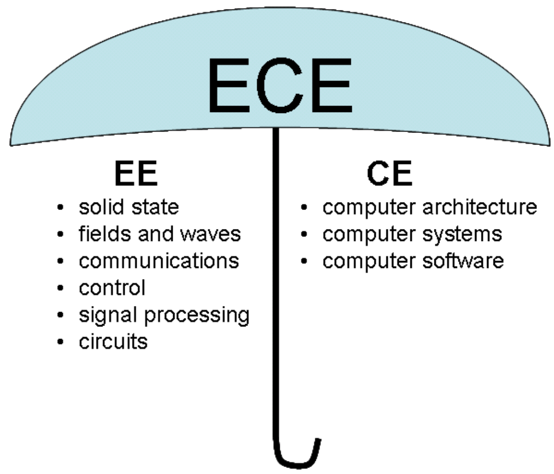

Figure 1. A traditional view of EE vs. CE.

The reasons for EE departments turning into ECE departments are clear. The question is whether maintaining ECE as simply an umbrella for two distinct undergraduate disciplines, as illustrated in Figure 1, is useful. We have found that our students (and faculty) use EE vs. CE as a highest-order distinction for identifying courses and their technical interests. Perhaps there was a time when this was reasonable, when the concepts, abstractions, and tools used on the EE side of the discipline could be easily distinguished from the concepts, abstractions, and tools used on the CE side of the discipline, but we believe times have changed.

ECE as a Unified Undergraduate Discipline

By an undergraduate discipline, we mean a domain with a common intellectual core that prepares undergraduates for productive and satisfying careers. Students need the background to adapt to *and lead* change. The curriculum should provide a solid foundation for the duration of a student's professional life, which will span several decades. With this in mind, there are several reasons we believe that ECE should be defined and widely recognized as a unified undergraduate discipline.

Breadth of ECE Technologies

It would be difficult today to describe any of the most interesting or important problems, challenges, or technologies that practitioners of ECE address as falling cleanly into either EE or CE. We can see this in any of a large number of examples, some of which are shown in Figure 2. For example, engineers involved in today's energy systems must of course understand the most traditional concepts associated with power systems (generation, transmission, distribution, etc.), but must equally importantly understand a broad range of enabling technologies, including sensor networks, communications, real-time systems, network and software security, and how all of these technologies come together in a modern power system. It would be difficult to claim that all of these technologies fall into either EE or CE, or that a well-educated engineer who intends to make the greatest impact in this area should be knowledgeable in only the subset of ideas that neatly fit into either the EE or CE category. Said another way, neither the area of power systems nor the people that must be expert in power systems fit into either EE or CE.

As another example, current designers of digital systems may be comfortable with the label of "computer engineers" and may work at a level of abstraction that does not require a deep understanding of the underlying physics of the logical devices comprising the systems they design. However, the advance of digital technology in both speed and size has stretched digital systems to operate where idealizations relied on in the past no longer hold, however, and concepts and ideas that were once viewed as the domain of "applied physicists" must be recognized and understood by the designers of emerging digital circuits.

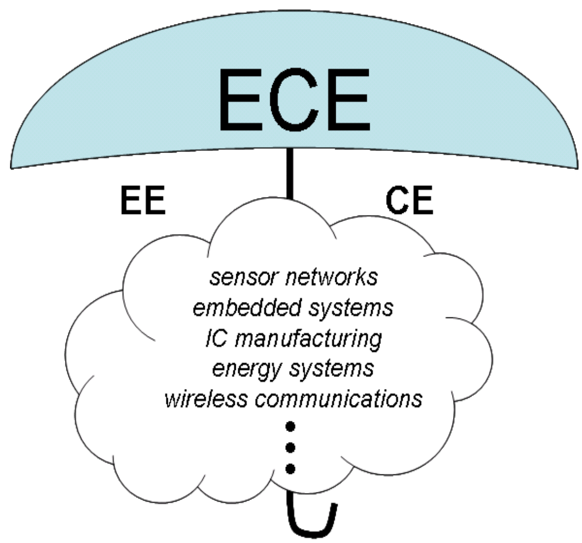

Figure 2. Areas that don't fit into just "EE" or "CE".

Similarly, the technologies designed by engineers traditionally considered "electrical" are increasingly depending on computing technology in nontrivial ways. For example, the design of a read/write head in magnetic data storage systems relies heavily on computer simulation. Knowledge of advanced parallel computer architectures, for example, in terms of both hardware and software, is needed to perform the amount of heavy computation for these sophisticated systems.

The Breadth of an ECE Career

In addition to the fact that the technologies associated with the ECE discipline no longer neatly fit into EE or CE, the range of concepts required to address technological challenges is more dynamic today than it has ever been in the past. Engineers in ECE technologies cannot expect to maintain a successful career that focuses on just a narrow aspect of ECE, and those with a narrow background will have limited prospects for the future. They will either be relegated to working on an ever shrinking range of legacy systems, or they themselves will become obsolete.

Engineering Students Need the Flexibility from a Common ECE Core

Given the breadth of the ECE discipline and our experience over fifteen years of offering a single ECE degree we feel that students require a number of structural characteristics in an ECE curriculum, including: 1) a strong core that introduces them early to the breadth of concepts within ECE; 2) the opportunity to pursue depth in areas of interest within ECE, but which may be different for different students; and 3) the opportunity to bring into their studies educational pursuits that extend beyond engineering.

Over years of observation we have seen time and again students who think that their interests in ECE are on the "EE-side of things" (to use their words) discover that they prefer the "CE-side of things" and visa versa. This is perhaps no more than a local manifestation of a common phenomenon; namely, people change their opinions about a subject both to the good and to the bad as they understand it in more detail. Thus students need a rigorous core that introduces at some depth the broad spectrum of ECE concepts from devices and fabrication, circuits, information processing, hardware design, and computer systems. Having been offered this solid core and associated mathematics, computer science, and science foundational courses, students must then be given the flexibility to pursue more advance courses that provide breadth and depth in areas of greatest interest to the individual. This structure gives students the ability to pursue particular sub disciplines in ECE and does not limit them so that they are unable to move and grow into new areas over time as their careers demand.

An Undergraduate ECE Curriculum

The difficulty with ECE is that the "umbrella" covers such a wide number of technologies and sub disciplines, some of which seem to require such different foundations, that it seems impossible to create a curriculum that does it all. If one decides the curriculum should be the *union* of everything needed to do *anything* in ECE, it is clear much more than four years (and maybe even more than one lifetime!) is needed. On the other hand, taking the *intersection* of what's needed to do specific things in each of the sub-disciplines as they are narrowly defined leads to an empty set—one might conclude there is no common core.

It was this dilemma that led us to create our ECE current curriculum fifteen years ago, and we believe the overall structure of that curriculum is still the correct structure. Our curriculum has four distinct elements beyond the general engineering and university requirements illustrated in Figure 3: *core, breadth*, *depth/coverage*, and *capstone design*. The core is the small set of courses that *all* ECE students take. Beyond that, students make choices: two breadth courses from five areas, 2 depth/coverage electives, and a capstone design course. The large number of free electives makes it possible for students to pursue a wide range of alternatives ranging from deep specialization in a particular technical area to complementing their ECE education with a broad education in another field, including preparation for professional careers in areas such as medicine or law.

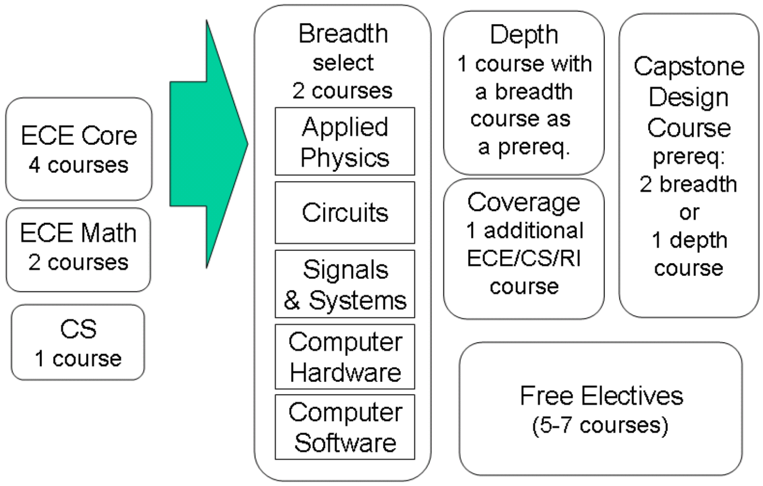

Figure 3. Structure of the ECE curriculum beyond the engineering core and general education requirements.

The Breadth areas shown in Figure 3 cover traditional domains in ECE, but students are required to take courses in only two of theses areas, reflecting our belief that the field of ECE is far too large to expect all students to follow exactly the same paths through the curriculum. Additional ECE courses that can be taken for Depth, Coverage, and as free electives, cover the many exciting domains of contemporary ECE, including, nanotechnology, sensors, digital communications, control systems, multimedia, advanced signal processing, advanced computer architecture, networks, computer security, embedded systems, computer systems, data storage systems, electronic computer aided design, rf circuits, vlsi fabrication processes, etc.

The student's ECE experience culminates in a Capstone Design Course which offers an opportunity to apply their knowledge to develop and implement a complete system in an area of his or her choice. Figure 4 lists our current set of Capstone Design Courses. We have found that students often organize their course choices around the goal of enrolling in a particular Capstone Design Course.

- Sensor Systems Design
- Antenna Design for Wireless Communications
- Data Storage Systems Design
- Integrated Circuit Design Project
- Digital Systems on a Chip Design
- Rapid Prototyping of Computer Systems
- Network Design and Evaluation
- Advanced Digital Design Project
- Embedded Systems Design
- Digital Communications and Signal Processing Systems Design

Figure 4. Capstone Design Courses

The ECE Core

The primary change we are now undertaking in our curriculum, reflected in Figure 3, is to enlarge and modify the core so that it provides a more comprehensive, unified foundation that includes all elements of ECE, not just an introduction to some of the fundamentals of EE and CE.

The crucial question is; what constitutes the core? Although we don't believe there is a single correct answer to this question, and the answer must evolve as the field evolves, our new core covers the topics shown in Table 1, which we submit as a reasonable starting point for any university contemplating the creation of a unified ECE curriculum. The table also shows how these topics are distributed among our freshman introductory course and the four core courses with titles that are prefaced by “Fundamentals of ECE:” These courses are described briefly as follows:

Introduction to ECE (freshman course):
Provides an overview of the field of ECE and introduces some of the fundamental tools needed to solve problems in this field.

Fundamentals of ECE:

A. Electronic Devices & Circuits: Provides an introduction to semiconductor devices and circuit analysis with links to digital electronics and signal processing.

B. Signal & Information Processing: Provides mathematical and computational tools for processing signals and information, including sampling, impulse response, convolution, frequency response, and filtering, in terms of both time-domain and frequency-domain analysis.

C. Structure and Design of Digital Systems: Provides a foundation and working knowledge in the application, operation and implementation of digital systems.

D. Introduction to Computer Systems: Provides concepts underlying how programs are executed on computer systems, exposing to students what goes on beneath the abstractions they are taught in programming classes and how those underlying realities affect the correctness and performance of programs.

Table 1. Topics for a unified ECE core and their distribution into a set of core courses.

		Fundamentals of ECE:			
Topic	**Intro**	**A**	**B**	**C**	**D**
semiconductors		X			
semiconductor processes		X			
energy storage devices		X			
diodes	X				
transistors		X			
DC circuits	X	X			
RLC circuits	X	X			
transistor circuits	X	X			
op amp circuits	X	X			
sinusoidal steady state		X			
frequency response	X	X	X		
filters		X	X		
noise and random signals			X		
convolution			X		
sampling	X		X		
discrete-time Fourier analysis			X		
gates and logic devices				X	
logic circuits	X			X	
sequential circuits	X			X	
data representation					X
ISA/assembly language				X	X
computer architecture	X			X	X
computer memory					X
computer I/O and systems					X

Giving Students Guidance

Over the years we learned from our students and alumni that students need guidance to take full advantage of an ECE curriculum. In contrast to a more tightly prescribed curriculum in a narrow domain, such as a CE or EE curriculum, students in our ECE curriculum are faced with a number of choices as early as the spring semester of their sophomore year. We have instituted several things to help them identify their specific interests and select courses that will prepare them for their futures. All ECE sophomores register for a 1-unit seminar course, Emerging Trends in ECE, which provides general advice about the options available in ECE. Sophomores are also assigned a faculty advisor who helps them identify the direction they want to take in their curriculum. At the end of their sophomore year, they are assigned a faculty mentor in their field

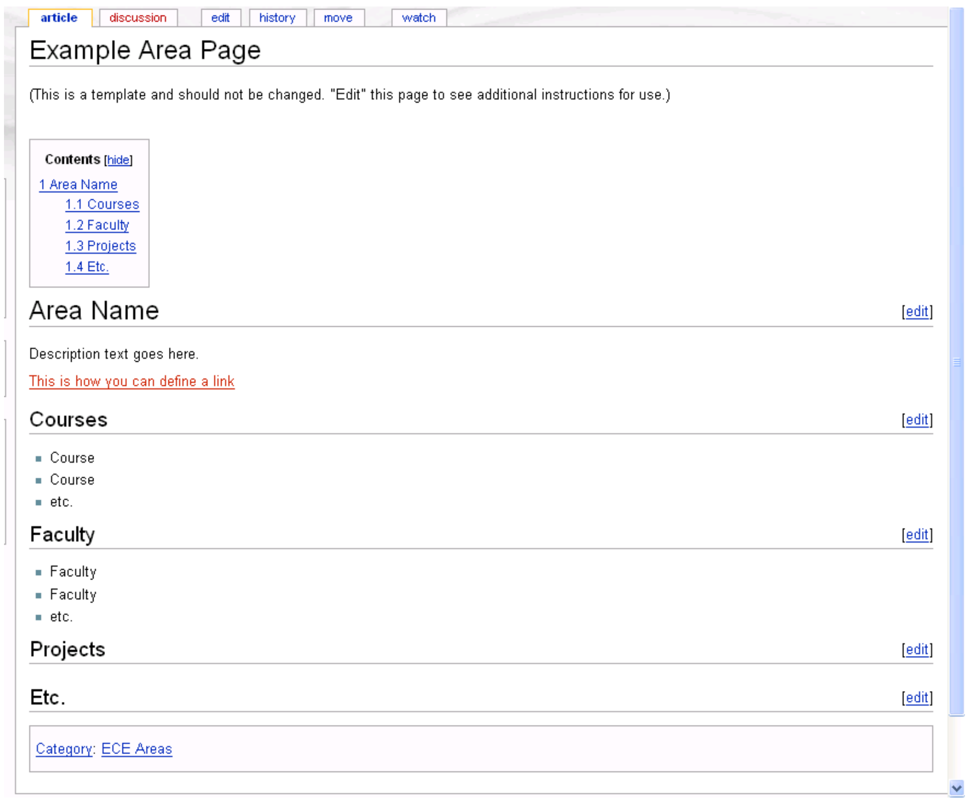

Figure 3. A Wiki page for undergraduates to learn about an area of ECE.

of interest to give them more specific guidance about course selection and career planning.

We are currently implementing a new innovation in student advising, a web-based Wiki area in which students will find information about all kinds of options in ECE. Faculty provide information about career options as well as what courses students should take if they want to pursue a career in a particular area. Figure 5 shows the structure of one of these Wiki pages.

Conclusions and Recommendations

As noted in the introduction, although the concept for creating a single degree in ECE is not new, this model has not been embraced by many universities. We believe the need for such a unification are even more pressing today than when the proposal was first made over fifteen years ago. We also believe that computation and computers are of an importance in terms of their impact across academic disciplines and society and that this constitutes a fundamentally important development in engineering, science, and society. A certain convergence has occurred in the fundamental knowledge and skill sets required for productive careers in any of the many sub disciplines that fall under the ECE umbrella, making the traditional EE/CE division less useful.

Some may say that an alternative to the approach advocated in this paper is to simply allow flexibility within EE and CE curricula so that students can obtain the background they need from other areas to pursue their interests. We believe this approach fails to recognize the breadth of the common fundamentals required in both EE and CE, and the inability of students to recognize what fundamentals they need in the early stages of their undergraduate experience. It is much better, in our opinion, to provide students with the structure and guidance they need to acquire these fundamentals, and then allow them the freedom to make informed curricular choices later in their academic program.

Complete and seamless integration of EE and CE, as proposed in this paper, not only benefits the students in providing them the knowledge with both sufficient breadth and depth for them to prosper in the real world after graduation, it also provides flexibility in designing core and advanced ECE courses to adapt to the rapidly changing technology world. As technologies continue to advance, the content of each course is bound to change, but the discipline of ECE, without the boundary between EE and CE, will last and stand the test of time.

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