Experiences in the Transition from an EE major to an ECE Major

John A. Orr, Richard F. Vaz
Worcester Polytechnic Institute

1. Introduction

With receipt of program accreditation by ABET, retroactively effective to graduates of the class of 2001-02, the transition from WPI's 100-year old Electrical Engineering major to a new degree program in Electrical and Computer Engineering is almost complete. For some time there had been recognition on the part of both students and faculty at WPI of the growing importance of *computer* engineering to the profession traditionally known as *electrical* engineering[1]. On July 1, 1992, the name of the department was changed to "Electrical and Computer Engineering," in recognition of the substantial role of computer engineering in the undergraduate and graduate curricula and research activities. For many years within the Electrical Engineering major at WPI, the largest area of student interest has been the computer engineering specialty, and in academic year 1995-96 the department established a formal concentration in computer engineering, partially in response to student requests.

This paper presents the background which led the WPI ECE faculty, in consultation with students, alumni, and advisory board members, to conclude that replacing the EE major with the ECE major is appropriate now and for the foreseeable future. It also describes the new ECE curriculum with the inevitable depth vs. breadth tradeoffs, the transition plan from EE to ECE, the preparations for the initial accreditation visit, and the results of the visit.

2. Background

When the decision was made in 2001 to move to the ECE major, only four US universities offered accredited majors in ECE. However, since that time it appears that a small trend has emerged; at present the ABET web site lists accredited ECE programs at 12 universities (including WPI). The following universities offer only ECE (not EE, computer engineering, or similarly-named programs) as their accredited major:

- Baylor University
- Carnegie Mellon University
- University of Minnesota, Duluth
- New York Institute of Technology
- University of Rochester
- Rowan University
- Rutgers University

The following universities offer ECE together with another related major, as indicated:

- University of California, Berkeley, with Computer Science and Engineering
- University of Colorado, Boulder, with Electrical Engineering
- Duke University, with Electrical Engineering

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- Lafayette College, with Electrical Engineering
- Worcester Polytechnic Institute, with Electrical Engineering (to be phased out)

Carnegie Mellon University should be credited with initially developing and implementing the concept of the ECE major. CMU changed to the ECE major in the context of a complete redesign of their undergraduate program and curriculum, with redevelopment of most courses and a change in student schedule to a semester plan with only 4 courses, each typically of 4 credits[2]. WPI performed a complete university-wide curricular overhaul approximately 30 years ago, and this current change in the electrical engineering major can be thought of as a "fine tuning" which remains faithful to the educational principles upon which the "WPI Plan" was founded: to graduate broadly educated technical professionals who can bridge the gap between theory and practice[3].

3. Motivation

One motivation for the change from EE to ECE was the recognition that computer engineering—in the broad sense, including such topics as networking, digital signal processing, and embedded computation—is not only of fundamental importance in its own right, but is also now integral to the discipline that has traditionally been called electrical engineering. A second motivation was rooted in WPI's philosophy of undergraduate education: the department sought to ensure that its BS graduates emerged with a broad background in the fundamentals of both electrical and computer engineering, rather than seeking an early specialization at the expense of breadth.

The faculty concluded that the ECE major is more appropriate for the undergraduate degree than the traditional EE or Computer Engineering majors for three basic reasons:

1. The first and most significant reason is that it represents appropriate background both for professional practice and for graduate study in much of what has traditionally been referred to as "electrical engineering," particularly including the rapidly growing computation/communications area.
2. Second, the faculty concluded that the two areas are so intertwined as to be inseparable in the context of a good-quality undergraduate education. That is, it is simply impossible to function effectively as a traditional "electrical engineer" without having at least a basic understanding of the principles of digital computation and digital representation of information. Similarly, it is impossible (or at least highly ill-advised) to pursue "computer engineering" without an understanding of the basic principles of fields, signals, circuits, and systems from an electrical engineering perspective.
3. Finally, the faculty felt that the ECE title will help counteract a persistent misunderstanding of what "electrical engineering" is, and what electrical engineers do.

The alternative of offering a computer engineering major as a separate option in addition to the existing electrical engineering major was seriously considered. This option was rejected for three reasons:

1. the concern that students would pursue excessively narrow, overly specialized programs of study;
2. a belief that ECE really **is** a single, broad discipline; and
3. a practical desire to avoid splitting the ECE faculty and students into two groups.

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A probable reason for the small number of ECE programs until now is that under past accreditation criteria, separate requirements existed for electrical engineering and for computer engineering, so that in a combined program students were required to satisfy both sets of requirements. However, ABET's current accreditation criteria (commonly referred to as "Engineering Criteria 2000")[4] which address outcomes rather than specifying curricular components allow considerable flexibility in designing an ECE major.

There is an unquestionable loss of depth when the option of breadth across electrical and computer engineering is chosen. After considerable discussion, the WPI ECE faculty came to the conclusion that this breadth is in fact *appropriate* for an undergraduate engineering program, and that the MS level is the place for specialization[5]. Perhaps more importantly, as stated above, the faculty believed that a high-quality electrical engineering program *must* include a significant amount of computer engineering, and that a high-quality computer engineering program *must* include significant electrical engineering outside the computer engineering area. The Undergraduate Program Committee (UPC), in monitoring the administration of the Computer Engineering concentration, noted that this concentration tended to cause overspecialization and narrowing of focus at the expense of breadth within ECE.

The possibility of developing an ECE major had first been raised explicitly in late 1995, when the ABET criteria for ECE programs were distributed to the department faculty. The UPC began seriously considering the implementation of an ECE major in the 1998-99 academic year. As part of this consideration, a survey was conducted in the fall of 1999 of all ECE undergraduate students regarding a number of issues, including areas of focus and preferred name of major. The survey results confirmed the UPC's concern regarding excessive focus: nearly half the students surveyed indicated a single area of focus within ECE; of those, over 60% focused on computer engineering.

In the survey of undergraduate students, respondents were allowed to choose from a number of options for a preferred major (see Table 1). An ECE major was the most popular choice, with the existing EE major a close second. There was little interest in a Computer Engineering major.

Table 1 Student Interest Survey

Possible Major	**Percent Preferring**
Electrical and Computer Engineering	53.7%
Electrical Engineering	31.7%
EE with Computer Engineering concentration	10.3%
Computer Engineering	4.3%

The ECE department External Advisory Board was also consulted during the decision-making process. The Advisory Board is a group of approximately 12 members, primarily from industry, but with some representation from other universities. The board meets twice yearly, and this change was discussed on several occasions, with the board members expressing strong support.

As summarized above, the reasons for the change from EE to ECE simply represented the faculty's view (supported by students and advisory board) that this best represented the current

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and near-term future practice of our profession. Further, the faculty felt that the BS degree in ECE should be appropriate for a considerably wider range of further study and ultimate professions than has typically been the case for either EE or Computer Engineering degrees. Hence, students with a wider range of career goals may ultimately be attracted into the new ECE program than traditionally were attracted to rather narrow EE or Computer Engineering programs. This possibility is significant for two reasons. First, a solid educational foundation in the natural sciences and technology (particularly information technology) is of growing importance to many, if not most professions. Obvious examples include medicine and most aspects of business. Second, there is good reason to fear that at least in the US, traditional engineering jobs will not be growing in numbers, and may in fact shrink, as engineering very rapidly becomes a profession practiced globally. Electrical and computer engineering are particularly susceptible to transfer overseas compared to some other engineering branches, such as civil and structural engineering.

These latter thoughts and concerns did not form the basis for the change to ECE, but for the longer term we believe that it is important to make undergraduate engineering programs accessible to, and attractive to, those students who do not necessarily see themselves as pursuing a traditional engineering career. With a range of post-BS professional programs and career paths, the decision to select an engineering major would no longer be based solely on the hope for a favorable engineering job market four years later. If potential students understand that their options include fields such as law, business, medicine, and education, the possibility of a downturn in the need for entry-level engineers will seem less ominous.

4. What Constitutes a Computer Engineering Education?

In developing an ECE curriculum the logical starting point would be the typical curricula for electrical engineering and computer engineering majors. It is interesting to note that, to the authors' knowledge, nothing which could be referred to as an "EE Model Curriculum" exists. There is, however, an emerging model curriculum for computer engineering. The draft ACM/IEEE model Computer Engineering curriculum[6] presents a detailed "Body of Knowledge" for computer engineering graduates. This list is rather lengthy, and inevitably in a hybrid program some topics from both electrical and computer engineering will not be addressed. Nevertheless, having such a list is helpful in designing the ECE curriculum. Also quite helpful is another, more general statement from the same reference on the desired characteristics of all Computer Engineering graduates:

1. *System Level Perspective* Graduates must appreciate the concept of a computer system and the processes involved in constructing or analyzing it. They must have an understanding of its operation that goes to a greater depth than a mere external appreciation of what the system does or the way(s) in which it is used.
2. *Depth and Breadth* Graduates should have familiarity with topics across the breadth of the discipline, with advanced knowledge in one or more areas.
3. *Design Experiences* Graduates should have completed a sequence of design experiences, encompassing both hardware and software elements, building on prior work, and including at least one major project.

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4. *Use of Tools* Graduates should be capable of utilizing a variety of computer based and laboratory tools for the analysis and design of computer systems, including both hardware and software elements.
5. *Communication Skills* Graduates should be able to communicate their work in appropriate formats (written, oral, graphical) and to critically evaluate materials presented by others in those formats.

Following are comments on each of these characteristics as they relate to our ECE program:

1. This is an appropriate outcome for ECE students, expanding beyond the concept of a *computer system* to the systems containing analog and digital, electronic and mechanical components which characterize the field of work in ECE.
2. Breadth now extends across the fields of computation, digital and digital electronics, continuous and discrete signals, communications and controls, and electromagnetics.
3. As described in Section 7, design has historically been a major component of the Electrical Engineering program, with senior projects which are considerably more intense and realistic than in many other programs.
4. Again, this is completely appropriate, with tools ranging from ECE CAD tools to symbolic math and numerical analysis suites.
5. This is directly applicable.

5. Development of the ECE Major

In 1999, the Undergraduate Program Committee (UPC) began the detailed process of developing an ECE major, with the following main points being considered:

1. satisfaction of the ABET criteria for ECE programs,
2. Preventing overspecialization; that is, enforcing breadth and ensuring sufficient course coverage across electrical and computer engineering.

Following is a summary of the UPC's process for the decisions reached in each of these areas.

5.1 Adhering to ABET criteria

At the time the UPC began serious consideration of the ECE major, only four accredited ECE major programs were in existence, at Carnegie Mellon, U. C. Boulder, U. Minn. Duluth, and Rutgers. The UPC reviewed these programs of study and by November, 1999, the UPC had developed a set of proposed distribution requirements meeting nearly all of the ABET criteria. The only accreditation requirement which appeared problematic was the requirement for discrete mathematics. The UPC discussed three options for meeting the discrete mathematics requirement:

1. Conclude that the existing computer engineering courses presently include sufficient discrete math with appropriate distribution among courses so that students selecting any allowed combination of computer engineering courses will receive a sufficient amount of discrete math;
2. Require an existing discrete mathematics course (CS/MA2201) of all students; or,
3. Modify the computer engineering courses to include the needed discrete mathematics concepts.

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A subcommittee of the UPC studied the issue by looking into the content of CS/MA2201 as well as coverage of discrete math concepts in the existing ECE curriculum. It is interesting to note that an initial problem was that the ECE faculty did not have a common understanding of the topics and concepts that comprise "discrete mathematics". This was overcome with a review of the literature presented by a subcommittee member, followed by faculty discussion. While option one was tempting, it was not felt to be accurate. The UPC consulted with colleagues from WPI's Computer Science department regarding their experience with CS/MA2201. The subcommittee reported that CS/MA2201 was not a good option: the course did not cover all of the topics necessary for ECE students, and spent considerable time on topics not of high value to ECE students. Conversely, most of the required discrete math concepts were already covered in ECE courses. For those concepts not already covered, material was identified to be moved to make room for the necessary discrete math concepts in the introductory computer engineering course EE2022. As explained in the "Implementation and ABET Visit Results" section below, this aspect of the major proved difficult to implement, and has already been modified.

5.2 Enforcing breadth within the subdisciplines of ECE

In developing the proposed distribution requirements, the UPC addressed the issue of overspecialization as revealed in the student survey. The distribution requirements for the ECE major specify that students must pass three courses from a list of electrical engineering courses, and two courses from a list of computer engineering courses. Both lists of approved courses are at the middle or advanced levels, assuring that students also complete the introductory core of courses which address the breadth of ECE topics. These requirements enforce breadth while allowing students the flexibility to pursue a focused course of study if so desired. Details on courses included in each list are available on the WPI ECE web site. The current web site is: http://www.wpi.edu/Pubs/Catalogs/Ugrad/Current/eedept.html

The process for development of the ECE major involved extensive discussions within the ECE faculty, with the Computer Science faculty, as well as involvement of the ECE Advisory Board, feedback from the student constituency, and consideration of practices at other universities with accredited ECE majors. As a result of this process we have made the necessary modifications to our curriculum and developed a set of distribution requirements that allow our students the traditional flexibility of the WPI education, while adhering to the requirements of the ABET criteria for ECE programs.

6. Details of the Major

Following are the Program Outcomes identified for the ECE major:

1. Preparation for engineering practice, including the technical, professional, and ethical components,
2. Preparation for the future changes in electrical and computer engineering,
3. A solid understanding of the basic principles of electrical engineering, computer engineering, and the relationship between hardware and software,
4. An understanding of appropriate mathematical concepts, and an ability to apply them to ECE,

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5. An understanding of the engineering design process, and ability to perform engineering design, including the needed teamwork and communications skills,
6. Demonstration of in-depth understanding of at least one specialty within ECE
7. Demonstration of oral and written communications skills,
8. Understanding of options for careers and further education, and the necessary educational preparation to pursue those options,
9. An ability to learn independently,
10. The broad education envisioned by the WPI Plan, and described by the Goal and Mission of WPI,
11. An understanding of engineering and technology in a societal and global context.

These outcomes are in line with the ABET criteria, and relate this major to the WPI philosophy of education. Following are the academic requirements for the ECE major. Not listed are WPI-wide requirements in general studies. The term "course" refers to a standard 3 credit hour semester course.

Mathematics: 7 courses, including differential and integral calculus, differential equations, discrete math (see discussion in Section 8), and probability and/or statistics.
Physics: at least a 2-course sequence.
Chemistry or Biology: at least 1 course in either.
Additional Math and/or Basic Science: beyond the minimums listed above, at least 2 additional courses in math or science.
Engineering Science and Design: At least 15 courses (or project credits) within the Electrical and Computer Engineering area. These must include at least 3 courses from an approved list of Electrical Engineering courses and at least 2 courses from an approved list of Computer Engineering courses. Must include 1/3 unit of Capstone Design Experience. Beyond the 15 courses referred to above, the program must include at least two computer science courses, with at least 1 course at the sophomore level or above, and at least one engineering course outside of ECE.

Note: The approved lists of electrical engineering and computer engineering courses do not include the introductory, prerequisite courses in these topics so students are assured of substantially more course material in both the electrical and computer engineering areas than the 3 course/2course minima imply.

7. Notable Features

For thirty years a major feature of the WPI educational philosophy has been project-based education. Recently in the ECE department this aspect has been updated and enhanced in ways which complement the new ECE major.

ECE Design Course[7] Although the ECE major at WPI has no explicitly required courses (all of the ECE requirements are listed in Section 6), this sophomore-level course is a *de facto* requirement, as most ECE faculty will not advise senior design projects for students who have not successfully completed it. This course provides an intensive, formative design experience, and focuses on preparing students for future ECE design by emphasizing design as a process,

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while simultaneously requiring students to demonstrate basic ECE knowledge in an application context. Students are given open-ended design challenges, and must work independently in small teams to develop and fully document a working prototype for a commercially viable product. Students begin with market research, develop customer requirements and technical specifications, choose between design options, and implement, test, and demonstrate their designs. During the term, they learn about design as a process, with emphasis on nontechnical aspects such as economics, ethics, reliability, safety, manufacturability, and responsiveness to customer needs. They participate in weekly design reviews, keep extensive laboratory notebooks, develop formal written reports, and present their work in front of an external audience.

Senior Design Project: All WPI students must complete a 9 credit-hour senior project in the major discipline (Major Qualifying Project, or MQP); for ECE students, this project is almost always a design project that constitutes the capstone design experience. The project does not take place as part of a course; small teams of students work independently under faculty guidance to address real problems, typically posed by external organizations. About 30% of these projects take place off-campus at WPI Project Centers, in locations such as the NASA Goddard Space Flight Center, MIT Lincoln Laboratories, the WPI Silicon Valley Project Center, and the WPI Limerick, Ireland Project Center. Student design teams take projects from initial conception through to delivery of useful solutions, with extensive documentation and attention to the process of conducting a design project.

Interdisciplinary Project: All WPI students must also complete a 9 credit-hour interdisciplinary project in which they address a problem relating technology or science to social structures and human need. The intention is to help students understand, as professionals and citizens, how technology affects and is shaped by society. This project, known on campus as the Interactive Qualifying Project or IQP, typically takes place in the junior year, and often involves issues surrounding the environment, public policy, sustainable development, and appropriate technology. Over 70% of these projects take place at WPI Project Centers located around the globe, including programs in Australia, Costa Rica, Denmark, England, Namibia, Hong Kong, Italy, Puerto Rico, and Thailand. Over 50% of WPI ECE graduates complete this project in a location outside of the continental US.

8. Implementation and ABET Visit Results

This ECE major was formally approved by the WPI faculty at the end of the 2000-01 academic year, and it became available to students meeting its requirements in the 2001-02 academic year. Two students did meet the ECE requirements and elected to graduate with the new (unaccredited) major. With at least one graduate, the program was eligible for an accreditation visit, and the visit for the existing engineering programs was scheduled for the fall of the 2002-03 academic year. Both the new ECE and existing EE programs were visited, and the results were quite positive for both programs.

The report of the ECE visitor noted many program strengths, but did indicate one problem area: discrete mathematics. Review of the course material had not demonstrated sufficient amounts of discrete mathematics in the computer engineering courses. Upon review and reflection, the ECE

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faculty agreed with that conclusion. In spite of good intentions, the desired discrete math content had not been integrated into the existing courses. Further, the faculty came to the conclusion that it would be difficult to consistently carry out this integration of discrete math with other topics in these courses. Hence, the conclusion was reached to add a requirement for students to complete a free-standing course in discrete mathematics. A benefit of this approach is that it will indicate to students that this is an important and distinct area of mathematics, just as calculus is important to other areas of ECE. A difficulty, as indicated above, is that the current discrete math course is not felt to be optimal for either ECE or CS students. Hence, further work is required in this area of the ECE major.

9. Conclusions

On September 24, 2003, the ECE faculty voted to drop the Electrical Engineering major, effective with the 2004-05 academic year. Faculty will work with students remaining on the EE major to modify their programs of study to meet the ECE degree requirements. Overall, the implementation of the ECE major has progressed quite smoothly. The change to a required course in discrete mathematics was made for good reasons; however the faculty are aware that simply requiring a course does not necessarily result in optimal learning outcomes. As noted previously, the existing discrete math course seems sub-optimal for ECE students. To address this problem the appropriate ECE, Computer Science, and Mathematics faculty have committed to work toward the development of either a modified course or a new course which better meets the needs of ECE students.

The faculty believe that this move to a broad undergraduate major is appropriate to the future of the profession. Any particular technical skill is subject to either obsolescence or outsourcing, but a broad undergraduate education in the electrical and computer engineering discipline will serve as the foundation for both careers and further study in many thriving areas.

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Author Biographies

JOHN A. ORR is Professor of ECE and past head of the ECE Department at WPI. Dr. Orr has electrical engineering degrees from the University of Illinois at Urbana-Champaign (BS and PhD) and Stanford University (MS), and professional experience at Bell Telephone Laboratory. He is a Fellow of the IEEE and is active in engineering education and communications/digital signal processing.

RICHARD F. VAZ is Associate Professor of ECE and Associate Dean for Interdisciplinary and Global Studies at WPI. He received the BS, MS, and PhD degrees in EE from WPI. His interests are in educational methods and assessment, internationalization of engineering education, and service and experiential learning. He has won WPI's campuswide awards for teaching and for advising.

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