ECE Curriculum in 2013 and Beyond: Vision for a Metropolitan Public Research University

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***Abstract*—In this paper, the authors discuss the anticipated curriculum of electrical and computer engineering (ECE) programs in the year 2013 and beyond for a prototypical metropolitan public research university. Assumptions are made regarding the evolution of the relevant technology addressed by the curriculum, the nature of metropolitan public universities in the next decade, and the nature of the learning environment, technology, and educational focus based on present trends. A 128-credit-hour curriculum is proposed that addresses these challenges.**

***Index Terms*—Directions in electrical engineering education, engineering curriculum reform, future engineering education.**

I. Introduction

ELECTRICAL and computer engineering (ECE) education is rapidly evolving as a result, in part, to the fundamental changes in the technological underpinnings represented by this field and the enormous changes in educational delivery made possible by the same technological advances. Predicting the future evolution of any complex dynamic system is a perilous endeavor, usually remembered more for the egregious errors in prediction rather than its successes (e.g., the predicted end of the road map for transistors at 1-μm feature size or the prediction of the limited market for personal computers). However, with that cautionary note, trying to envision the future is an essential part of any strategic planning and an essential one in the context of trying to provide a road map for the evolution of engineering education in the face of transformative changes occurring in society as a result of the information revolution beginning in the latter part of 20th century and continuing through the present.

In considering the curriculum of ECE departments in the year 2013 and beyond, the authors look at what changes have occurred in ECE education over the past 30 years, what has been added, and what has been dropped from the curriculum. Many topics disappeared when, and sometimes belatedly after, they became technologically obsolete, at least in a widespread commercial sense. For example, vacuum tubes are rarely covered in modern ECE curricula, having been superceded by what are now standard courses in solid-state devices and integrated circuits (ICs). Advances in semiconductor electronics have become drivers themselves for curricula in other core Electrical Engineering (EE) areas such as power (power electronics) and microwave/electromagnetics (microwave ICs, radio frequency design, etc.). Skill-enhancing courses relative to engineering drafting and slide rule or hand calculator usage have all but vanished, replaced by exposure to desktop tools, web browsing, and simulation/CAD tools (e.g., PSPICE and Matlab). Computer programming is still a required skill as much now as it was 30 years ago. However, object-oriented languages have now superceded scientific languages such as Fortran in undergraduate curricula, and the platforms on which students work are distributed personal computers/workstations rather than centralized mainframe computers with punch-card readers. Computer Engineering, as a field distinct from either EE or Computer Science came into existence primarily during the past 30 years. Core areas of EE, such as Signal Processing and Communications, differ radically in 2003 from the same areas taught during the early 1970s, primarily in terms of the dominance of digital technology in replacing many or most analog applications in these areas. At the same time, analog design, in the context of mixed analog–digital circuits for high-speed communication systems, has reemerged as a critically important area in last decade; however, the focus has switched substantially from discrete bipolar design in the 1970s to integrated complimentary metal–oxide–semiconductor (CMOS) design over the past decade. Clearly, in the examples given, the digital revolution has had a profound effect on the curriculum evolution in ECE education.

The ECE curriculum in 2013 and beyond will by necessity be shaped by the dominant technologies that emerge over the next decade. Future technology predictions routinely appear annually, for example, in IEEE SPECTRUM [1]. Longer range predictions have been reported by Battelle, who compiled a list of top ten strategic technologies for the year 2020 [2]. Likewise, Siemens also presented their "picture of the future" in terms of technology trends affecting various areas of life in the future [3]. These technology forecasts can be roughly divided into areas related to BioX, NanoX, InfoX, Energy, and Environment. One of the largest new growth areas impacting ECE education relates to the interface between biotechnology and electrical/computer/information science and engineering. As the baby boomer generation reaches retirement, this interface will, at a minimum, be a major economic focus. Bio-information technologies are expected to grow enormously in terms of genetics-based medicine, nanoscale diagnostic systems, biosystem sensing, and monitoring, and super sensing capability through the interface of biology and electronics, including the brain–computer interface. Information and communications technologies will become inseparable and will permeate all areas of life in terms of intelligent goods and appliances, ubiquitous embedded interconnected computing systems continuing the present trend of decentralization and

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distribution of computer systems. The human–machine interface will greatly expand with voice and gesture recognition that will greatly transform how one interfaces with machines. In terms of the underlying semiconductor technology enabling rapid advances in computational speed and capacity, 2013 will probably see the end of the road map of CMOS scaling of traditional microprocessor-based architectures. However, alternate nanoscale technologies will be emerging that more closely mimic biological systems in terms of self-growth and repair, intelligence, and decision making, etc., that interface with more conventional architectures. In addition, nanoscale devices will become important as interfaces to biological systems that operate both inside and outside the body. Finally, power generation and distribution will become much more distributed in nature and more environmentally friendly. Power distribution systems themselves will increasingly be dominated by knowledge-based information systems that control the power distribution network for optimum delivery and reliability. In addition, the "green revolution" will certainly continue requiring cleaner and more environmentally compatible manufacturing of all goods.

With this introduction, the authors attempt to follow the trajectory of the evolution of ECE education to the present in order to extrapolate the anticipated curriculum in 2013 and beyond with consideration of the anticipated evolution of technological advancement discussed in the previous paragraphs. This extrapolation is applied within the context of a large metropolitan public university, such as Arizona State University (ASU), Tempe, and the corresponding constituencies served by an ECE program in this environment. Consideration is also given to the nature of the science and engineering learning environment in how this environment may shape the curriculum of the future. Within the spirit of this special issue of the IEEE TRANSACTIONS ON EDUCATION, a 128-h undergraduate curriculum is proposed, geared toward anticipated technological advancements in terms of the core EE knowledge and specialization areas, as discussed in Section IV.

II. THE METROPOLITAN PUBLIC UNIVERSITY IN 2013

The vision for ECE education in the year 2013 and beyond is, to a large extent, dependent on the nature of the university within which the program resides and the mission of that university in ten years. As discussed previously, the perspective of the present paper is from that of an EE/ECE department that is part of a large public metropolitan research university, such as ASU. While the cultural environments of different metropolitan universities may be unique to each institution, the following features are common to most:

- an increasingly diverse (included here are cultural, linguistical, economic, physical ability, and, for engineering programs, gender diversity) student population that will continue to grow over the next decade because of the continued urbanization in society;
- a local industrial base that overlaps at least one or more ECE subdisciplines and, hence, employs a number of part-time and continuing education students.

For a university to serve its constituent population effectively in this environment, it will have to be inclusive of a variety of learning styles and specific educational needs relative to workplace training.

Based on present trends, there will also be strong growth in nontraditional higher education programs offered through distance education providers that target some of the partial needs of students relative to their backgrounds and learning needs, for example, within their work environment. Hence, there will be many students entering the university with a hybrid background of online and classroom experience at various stages of the program.

Within the context of having to serve a diverse student population within the metropolitan setting, the authors assume the following in 2013 and beyond.

- The residential campus will continue to be relevant, i.e., the unique intellectual community that comprises the present American university campus as well as the socialization process of students as part of this learning community will continue to be valued as much as the program content itself.
- The networking of students and faculty will still remain important; whereas distance education delivery will necessitate less and less face-to-face contact, faculty and student interaction will still be necessary on the urban campus.
- Departments will still exist administratively, but the interfaces will be less visible. This situation, in part, is driven by the need for students to have more interdisciplinary skills to meet future technology trends and workplace demands.
- The minimum level of computer literacy of incoming students will increase; whereas the math and science preparation will likely remain the same, if not decline.
- Engineering will be viewed more as new liberal arts in the future economy.

ASU recently inaugurated its sixteenth university president, Michael Crow, who has articulated his vision of what he terms ‘the new American University" [4]. While much of this vision is specific to ASU, in many aspects, it may, in fact, serve as a blueprint for the evolution of the metropolitan research university over the next decade. Therefore, it provides the contextual basis for our vision for ECE education in 2013 and beyond. This vision is basically a recognition of the listed common features of metropolitan research institutions and the assumptions in the bulleted list above, as well as the realization that the future development of the new model of the American university must go beyond the present research extensive university model existing today. This vision articulates several "design imperatives" for the evolution of ASU as a model metropolitan university.

1) *Intellectual Fusion*—The traditional disciplinary organization of universities may not be the optimal way to organize knowledge, to organize the institution itself, to teach students, or to solve the social, economic, and technological challenges confronting institutions in the regions in which they are located. Programs that involve multiple departments and schools bring together scholars from dif-

ferent disciplines and have unique strengths that will be better suited to address tomorrow's problems.

2) *Social Embeddedness*—In cultivating the excellence of academic programs, its relevance to society—especially regionally—must be considered. The university must become an integral part of the community and a lifelong presence in the lives of its alumni and the general citizenry.
3) *Pasteur's Principle*—A research university is inherently committed to the principle that teaching is most effectively carried out in a context that encourages the creation of new knowledge—teaching and research are intrinsically aligned. What educators must begin to do—and what current academic culture sometimes fails to do—is to consider the purpose behind the work.
4) *A Focus on the Individual*—Traditional assumptions about teaching and learning are no longer adequate. Educators must take every advantage of both traditional methods and new approaches that make students an intimate part of the research process and the creative act, bringing an intensity to education that is often lacking.

III. Future Science and Engineering Learning Environment

Much has been learned in the last 20 years about how people learn—and much of that new knowledge does not align well with current teaching practices. Bringing present teaching practices into alignment with research-based best practices will be a very fruitful pursuit in future years. A good review of the research on learning can be found in *How People Learn: Brain, Mind, Experience, and School*, edited by Bransford *et al.* [5]. Gollub and Spital [6] have recently distilled the primary conclusions of that book to the following seven points.

1) Learning is facilitated when knowledge is structured around major concepts and principles.
2) A learner's prior knowledge is the starting point for effective learning.
3) Awareness and self-monitoring of learning ("meta-cognition") are important for acquiring proficiency.
4) Learners' beliefs about their ability to learn affect their success.
5) Recognizing and accommodating differences in the ways people learn are essential.
6) Learning is shaped by the context in which it occurs.
7) Learning can be strengthened through collaboration.

So what might the future of EE education portend? In the context of the evolution of the metropolitan university discussed in Section II and following current trends, the following can be expected.

- The instructor will become less a "talking" head and more of a facilitator of learning. Student-to-student collaboration becomes extremely important in this transition of pedagogical styles (Gollub and Spital's item 7) above). This shift is difficult for faculty, but it is a shift that the literature [7] and engineering education leaders, such as Karl Smith and Richard Felder, have been espousing for more than 15 years. The authors' experience with cultivating this change within ASU explains that at least three years are required for a faculty member to make this transition from teacher-centered instruction to learner-centered instruction. A one-size-fits-all faculty development program will not be very effective; different types of training have to be designed to address the people at different stages in the change process [8].
- Instruction will be guided by a better understanding of pre-held and instruction-generated misconceptions. The work of Hestenes, *et al.*, on the Force Concept Inventory [9] clearly confirms Gollub and Spital's item 2) above. The Foundation Coalition, of which ASU is a member, is developing "Concept Inventory" assessment instruments for EE subdisciplines, such as circuits, signals and systems, waves, electronics, electromagnetics; and these should be very helpful in convincing faculty that conventional teaching strategies are not as effective as often perceived.
- EE laboratory courses will become less "cookbookish," tending toward projects wherein students will be given a goal, some instrumentation, and instructions to design the experiment and conduct it. In time, these experiences will become an integrated part of the courses to which they are traditionally appended.
- Assessment will become more "authentic." This assessment is part of what Gollub and Spital's item 6) above is all about. The almost total reliance on the traditional textbook problems that appear at the end of the chapters to illustrate the principles of that chapter will become less than it is today. Problems will tend to be more like those encountered in engineering practice, where students will have to sort out what is wanted, what is known, and what has to be assumed or estimated. Problems will not have single right answers; rather, there will be many solutions, a few of which will be correct.
- Rapidly advancing technology will cause increased tensions in the following areas.
  - There will be increased tension between student presence in the classroom and telepresence through technology. Why should students physically come to class at, perhaps, their unproductive times when they can just as easily watch a talking head or engage an interactive module on the World Wide Web—and do it at a time most productive to them?
  - There will be increased tension between traditional media (e.g., calculators and overhead projectors) and new media (e.g., interactive modules, three-dimensional (3-D) graphics with zoom and rotate, and virtual instruments). Two-dimensional images and linear sequential computations often lead to misconceptions for students. If students can interact with a 3-D digital figure or image, or if they can use one of the many "solvers," students can obtain a better understanding of the material.
- Stronger connections will be made between subjects to make learning more contextual (Gollub and Spital's items

1), 5), and 6) above). The authors' work in the Foundation Coalition has found that the following subjects complement each other when integrated:

- — English and engineering;
- — physics and mathematics;
- — engineering and mathematics;
- — engineering and physics;
- — engineering discipline (and subdiscipline).

- Technology breakthroughs are made by people working at the boundaries of disciplines. Giving students opportunities to experience these boundaries can be very worthwhile.
- Subdiscipline integration unites common themes. The integrated "engineering sciences" of Texas A&M University [10] and Rose–Hulman Institute of Technology [11] are good examples of this integration.
- Gullob and Spital's items 5) and, especially, 6) are important for valuing and responding to the increased diversity of the student body. Students come to the university with different backgrounds and experiences; a meaningful context for one student may not be a meaningful context for another. The outcome from this challenge is that all are going to have to work harder as faculty to insure that they address the needs of all students.

IV. The Four-Year B.S. Electrical and Computer Engineering Degree in 2013 and Beyond

Based on the discussion in the preceding sections, the authors now advance what is believed to be a model for the ECE curriculum in the year 2013 and beyond. To preface this model, they first summarize the main differences between the typical ECE curriculum of the 1980s with that portended in 2013 and beyond in Table I.

Many of these changes are currently underway and are the type envisioned by the engineering accreditation reform that led to EC2000 and the flexibility and assessment inherent in this process [12]. The implications of such change in future curriculum suggest less discipline-specific courses in favor of more multidisciplinary design courses, and more flexibility in the curriculum to allow credit for more nontraditional endeavors, such as internships, undergraduate research experiences, and international work/study abroad experiences.

A. General Studies and the Engineering Core in 2013

The EE curriculum of 2013 must be as current and as relevant as possible in an effort to satisfy the needs of the student, academic, and metropolitan constituencies. Certainly, one of the objectives of the ABET (Accreditation Board for Engineering & Technology) continuous improvement process will still be to enable an orderly and persistent method to revise and update engineering curricula.

At ASU, as with many schools, a coordinated and vigorous program has been undertaken to develop vital research efforts in several key areas that should still be relevant in 2013 and beyond. As discussed previously, these areas focus on the convergence of bio, nano, and info technology in terms of research areas of the future and energy and environmental development. In addition, a growing focus will be on the systems as a whole, with emphasis on system solutions for problems and the manufacture of systems and components.

For a variety of pedagogical and logistical reasons, it is most sensible to align the educational objectives and learning outcomes of the engineering curriculum with the goals and aspirations of the coordinated university research mission. Since the research thrusts listed previously will almost certainly be viable until and beyond 2013, one must ask whether the existing engineering core is appropriate to produce the required alignment. These authors believe that a revision is definitely in order.

The current core for many electrical (EE) and computer engineering (CE) students consists of the following math, science, and engineering science courses primarily taught at the lower division (actual hours for the most part taken from the current program at ASU):

- *Basic Sciences* (15 h)
  - — Chemistry 4 h;
  - — Physics I, II, III 11 h.
- *Mathematical Studies* (24 h)
  - — Calculus I, II, III 12 h;
  - — Differential Equations 3 h;
  - — Linear Algebra 3 h;
  - — Probability and Statistics 3 h;
  - — Discrete Math (CE) 3 h.

  or

  - — Advanced Math (EE) 3 h
- *Engineering Sciences* (28 h)
  - — Introduction to Engineering Design 3 h;
  - — Programming C^{++} 3 h;
  - — Digital Design Fund 3 h;
  - — Electrical Networks 4 h;
  - — Mechanics 4 h;
  - — Electronics 4 h;
  - — Electronic Materials 4 h;
  - — Intermediate Engineering Design 3 h.

This list of course areas totals 67 h, which is more than half of the 128 h required for the Bachelor of Science in Engineering (B.S.E.) degree; there are an additional 21 h of general-studies courses (including 6 h of English). The remaining third of the EE/CE program of study consists of elective courses in the major, discussed subsequently in the paper.

The prospect of putting additional courses into the core or the major to address education in the bio/nano/info/manufacturing arenas is a nonstarter; therefore, the only possibility for meeting the new directives must include some replacement and/or repurposing of the courses listed previously. Rather than trying to track separate EE and CE curricula in the future, the authors assume for the sake of simplicity that there will be one ECE degree satisfying the basic ABET accreditation requirements. One possible approach to redefining the core might appear as follows:

- *Basic Sciences* (16 h)
  - — Integrated Science I 4 h;
  - — Integrated Science II 4 h;
  - — Macroscale Physics 4 h;
  - — Nanoscale Physics 4 h.

TABLE I
TRADITIONAL CURRICULUM AND DELIVERY IN ENGINEERING COLLEGES (LEFT) VERSUS THE SAME IN 2013 AND BEYOND (RIGHT)

Old Curriculum	New Curriculum
Disciplinary Model of Content Historical Topics to cover, e.g, Physics, Chemistry, Mathematics, Engineering Sciences, followed by Engineering Design	**Interdisciplinary Model for Content** Problems to solve: Bio-XX, Nanotechnology, Systems, Environment, Energy, Entrepreneurialism, Information Technology, Arts Integrated into Design problems
Engineering Design as a Course	**Design Integrated Throughout**
Practice in the Profession Follows Graduation	**Practice in the Profession is Part of the Course of Study**
Curricular Structure • Constrained/linear course offerings in major • Students take general studies first, professional program later. • Menu of general studies courses	**Curricular Structure** • Interdisciplinary • Integration of topics viewed with different disciplinary lenses • General studies integrated with professional studies
Pedagogy • Talking head • Teacher centered • Well-defined problems • Individual work • Low-level cognition (recall, recognition)	**Pedagogy** • Talking students • Learner-centered • Authentic problems • Mixture of grouping options • Higher order thinking
Aesthetic of an Educated Citizen • Ability to spout trivia • Narrow discipline • Narrow set of skills • One job for rest of life	**Aesthetic of an Educated Citizen** • Ability to think deeply, flexibly • Interdisciplinary • Upgradeable for life (Lifelong learning) • Many jobs, portability

- *Mathematical Studies* (24 h)
  - — Calculus I, II, III 12 h;
  - — Probability and Statistics 3 h;
  - — Differential Equations/Linear Algebra 3 h;
  - — Discrete Math 3 h;
  - — Advanced Math Elective 3 h.
- *Engineering Sciences* (23 h)
  - — Information Science and Engineering 6 h;
  - — Programming (C^{+n}) 3 h;
  - — Electrical/Electronic Circuits 4 h;
  - — Mechanics (Bio- and Nano-) 4 h;
  - — Materials (Electronic and Bio-) 3 h;
  - — Integrated Design for Manufacture 3 h.

This revised core is actually a contraction of the existing one (63 versus 67 h) and would permit additional technical electives. A discussion of some of these core blocks is given in detail hereafter.

1) New Courses: To ensure some measure of competency in critical sciences and technology, two introductory *integrated science* courses are to be added as a required science course for electrical and computer engineers. Rather than having separate biology and chemistry courses, the courses in integrated science might take the form of biochemistry or biophysics. This integrated approach is recommended because it can serve as a universal and common platform for the study in a variety of EE directions. Engineering applications based upon the integrated science can be embedded at a later point in the curriculum. This integrated sciences approach can be viewed as addressing the stated goal of *intellectual fusion* in connection with the vision of a metropolitan university discussed in Section II.

Similarly, a year long sequence at the freshman level on information science and engineering is proposed, with a backbone of digital design using a platform-based approach. This sequence would serve as an integrated design and information science approach in the freshman year which introduces students not only to digital design, but information theory, robotics, signal processing, multimedia, and real-world applications, including the arts. Such a sequence would have roots in current platform-based efforts, such as the Infinity Project, currently appearing in high-school and freshman programs [13] as well as efforts to bring digital signal processing into the freshman year, such as the digital signal processing (DSP) First program at Georgia Tech, Atlanta, [14]. The trend to bring digital design and information theoretical concepts down to the freshman level is already in progress because of the lack of advanced math and physics prerequisites required, the success in engaging students early in the major, the exposure to design early in the curriculum, the exposure to real-world systems, the success in retention, etc. Given the increasing sophistication of entering students relative to information technology, and projecting ten years in the future, expectation that the freshman experience will evolve in this direction is natural.

From the standpoint of a metropolitan university with a diverse freshman population, care and structure must be imposed on such a freshman program to provide a focus on the individual stated in Section II. The approach currently being employed at ASU in the current engineering freshman design is a cohort-structured multisection approach to enable students of different learning styles with a peer support group. In fact, the present structure of the freshman design sequence at ASU evolved from the Foundation Coalition experience discussed previously and embodies many of the themes addressed in Table I in terms of learner-centered education. The future information and science freshman sequence envisioned here would expand on that model to have sections tailored possibly to the diverse backgrounds and learning styles expected in the future metropolitan setting, with the goal of reaching a more common technical level and understanding by the end of that year.

2) Repurposed Courses: Some substantial revision of existing courses should be carried out in all three areas of the core. In the area of basic sciences, one could easily envision replacing the current three-course sequence in physics with two modernized courses—physics at the macroscale (which could include energy, work, mechanics, and electromagnetics) and physics at the nanoscale (including atomic physics, bonding, and materials). In the area of mathematical studies, linear algebra material could readily be embedded in the differential equations course; discrete math in some form will be required for a true ECE degree; and the advanced math course could be customized by the student from a menu of relevant topics (discrete math for computer engineering, complex analysis for controls engineering, partial differential equations, and vector calculus for solid-state- and electromagnetics-oriented specialization). This approach again embodies a spirit of intellectual fusion articulated previously.

In the engineering science area, the separate networks and electronics courses currently taught are predicted to evolve into a single course accessible to both ECE majors and other engineering disciplines. Much of the focus in introductory networks courses on multiple-solution approaches (nodal versus mesh versus superposition, etc.) will most likely be superceded by simulation with focus on main concepts, which would allow nonlinear electronics to be brought into the introductory course to free up more hours in the curriculum. The mechanics courses (statics and dynamics) could follow the framework for the physics core courses and contain mechanics at both the macro and the nano scales. Similarly, the materials course could contain topics integrated across the sciences so that biological, electronic, and bioelectronic materials are covered. The advanced "cornerstone" engineering design course could be repurposed to include manufacturing topics, such as design for recycling or supply chain issues.

Likewise, increasing coordination of the general-studies electives (which currently at ASU are broadly divided between humanities/fine arts and social/behavioral sciences) with the objectives and outcomes of the engineering program as a whole will likely occur. Most general-studies requirements in engineering programs require choosing from a shopping list of courses to fulfill balance in the humanities and social sciences, in addition to basic literacy requirements, as indicated in Table I. However, some alignment of the traditional humanities and social sciences with the technological career path of an ECE degree is anticipated. In particular, students should be required to choose from courses that provide a contextual and ethical perspective to the uses and abuses of technology in society today. Hence, at least one 4-h course is anticipated to be devoted to the societal impacts of technology as well as required courses in micro/macro economics. Similar alignments of the humanities and the engineering major are expected, such as in the areas of multimedia and the arts. Grounding of students in the social sciences and arts is a necessary prerequisite for fulfilling the design imperatives 2 and 3 of a metropolitan university, stated in Section II in terms of Pasteur's Principle and Social Embeddedness. The authors are certainly sympathetic to need for more rather than less liberal arts grounding in future graduates of ECE programs.

B. Upper Division Electrical and Computer Engineering Curriculum

In Section IV-A, the authors considered the evolution of the lower division core and general studies to reflect the blurring of traditional engineering disciplines and the alignment of general studies to support technical education. The upper division of ECE education is still expected to mirror subdisciplines within ECE, however, in some cases different, and in other cases blurred relative to the present subfields, such as electronics and communications. In addition, within the context of a metropolitan public university, more emphasis will shift toward more engineering education outside of the classroom in terms of work-study, internships, cooperative partnerships with industries as part of the degree program. Furthermore, the ABET continuous improvement process will allow the refinement (or redefinement) of the overall educational objectives (and the course offerings to meet these objectives) in close consultation and interaction with industrial and governmental constituencies.

At present, the typical EE and CE upper-division programs arising from a traditional ECE department is generically the following:

- *Major Studies*
  - — Microprocessor/Assembly Language;
  - — Electrical Networks II;
  - — Signals and Systems;
  - — Electromagnetics (EE);
  - — Energy Conversion/Machines (EE);
  - — Data Structures (CE);
  - — Computer Organization (CE).

Following these major study areas are technical elective courses that develop breadth and depth in any two areas that typically include controls, communications and signal processing, electromagnetics/microwave, solid-state electronics and circuit design, power systems, and computer engineering (digital design, architectures, and networks).

What will be the replacement structure in 2013 and beyond? The current convergence of biotechnology and ECE suggests that new elective areas will emerge or at least modifications of the existing ones will occur. Material taught in elective courses related to semiconductor devices and processing will almost certainly broaden into nanoelectronics inclusive of bioelectronics, sensors, biocompatible processing, hybrid systems, etc. Electronic circuit design geared toward biotechnology applications will also fall in this focus area, such as biocompatible circuits and sensor circuits. A convergence of communication systems and embedded system technology also suggests a new area emerging between the current signal processing/communications and computer engineering subdisciplines. The trend toward distributed, heterogeneous embedded systems integrated into everyday life will place emphasis in the curriculum on internetworking and communication as much as on individual architecture. Vastly enhanced computational performance and data capacity will also transform DSP today toward more perceptual-based applications relative to image, speech, and other intelligent recognition that facilitate the human–machine interface. What are presently separate curricula in microwaves and antennas versus analog–digital design will have to converge as clock speeds and bandwidth continue on a sort of Moore's law increase, and computer design and layout tools used presently in the analog–digital design world by necessity transform to adapt to the high frequency world. Discrete component circuit design will become increasingly rare in the curriculum except at the introductory level. Power engineering will also substantively transform because of widespread replacement of conventional systems by solid-state power electronic components, increased emphasis on network modeling and computer-aided system design, centralized power sources replaced by distributed nonconventional systems, and enhanced environmental concerns on energy production and distribution.

Having stated all of the above, how would this information translate into an upper level curriculum? First, DSP will, by necessity, move down the curriculum toward the freshman level as discussed in the previous section so that the junior course in signals and systems will evolve toward an applied DSP course. System design across all areas in 2013 and beyond will be performed in terms of functional behavioral descriptions in some high-level protocols. Hence, the teaching of assembly language will probably disappear at the sophomore level, replaced by system-level design based on platform systems using high-level functional descriptions that are generic to multiple subdisciplines of ECE. The junior level will then have similar but evolved versions of the same topics taught presently but within the context of underlying physics and mathematical modeling relevant to higher level system design. The problem of increasing the number of subdisciplinary areas is the inflexibility of 3–4 h blocks of semester courses (this is a little less problematic in quarter-based systems). Distance and online education pressures also emphasize smaller learning blocks rather than larger; therefore, many of the blocks below will be taught as 1 h or less modules to allow mixing and matching of knowledge toward particular system challenges that define a senior design experience more geared toward heterogeneous systems design rather than narrow disciplinary problem solving. Hence, the proposed curriculum in 2013 and beyond for the major area of ECE is (without attempting to specify exact hours for given topics) follows.

1) Required Courses Major (21 h):

- Functional Behavioral Design/Embedded Systems (Sophomore);
- Discrete Signals and Systems (Sophomore, replacing Networks II);
- Digital Processing and Control (Junior, replacing analog signals and systems);
- Waves and Propagation (Junior, similar to present electromagnetics with decreased emphasis on electro–magneto–statics);
- Mixed Signal Design (Junior, analog–digital IC design);
- Power Electronics/Energy Generation (Junior, evolution of current energy conversion course based on synchronous machines toward power electronic solutions, alternate source energy generation, economics/environmental topics);
- Data Structures (Sophomore, evolution of current course);
- Embedded System Design (complete system description, including communications, hardware, software design).

2) Elective Courses Major (23 h): An elective structure, including a capstone design sequence during the senior year, is still anticipated to be the paradigm in 2013 and beyond. However, the disciplinary boundaries defining the elective areas will transform into new areas or repurposed traditional areas. The specialization areas include the following:

- Nanotechnology (convergence of materials, solid-state devices, bioengineering [15]);
- Hybrid Circuit Design (convergence of electromagnetics, high frequency/radio frequency circuits, packaging, mixed-signal analog–digital at very high clock rates);
- Digital Communications (digital wireless, optical, wireline communication systems);
- Embedded Technologies (communications, internetworking, embedded architectures, software–hardware interfaces, system-on-chip solutions);

- Digital Processing and Control (multidimensional pattern recognition, image processing, perceptual signal processing, voice recognition, linear/nonlinear digital control systems, multimedia in the arts and entertainment);
- Energy systems (power electronic systems, intelligent digital system controlled power networks, alternative energy sources/environment).

The capstone design process will continue to be a year-long sequence that overlaps multiple disciplinary areas, for example, in the design of autonomous sensing networks (combining embedded, hybrid design, digital communications). There will be increased emphasis on system design that is built on common functional behavior platforms independent of disciplinary area. Furthermore, within the mission of the program within the metropolitan university context as stated in Section II, this capstone design will be a threaded intern program with local industrial/government concerns, which will be actively, rather than passively, involved in the educational program of their future employees, leveraged by the metropolitan university setting. Additional hours freed from the curriculum with less required disciplinary courses will provide additional hours for fulfilling this mission of social embeddedness of the program. Its students will participate in cooperative industry programs and/or international study/intern programs, for example the ASU Engineering Ambassadors to China program [16], which leverages the multinational nature of many local corporations in the metropolitan environment. This elective/design block completes the 128 h of the program.

V. Summary

In summary, the authors have proposed a prototype ECE curriculum based on 128 semester hours for ten years in the future and beyond. In some sense, the names given to courses or groups of courses does not differ substantially from present-day courses. That outcome is not unexpected, assuming that the core disciplines of EE and computer engineering will not disappear. Indeed, the majority of courses offered at least in EE have similar names to those taught in the 1960s (which is more than 30 years back), even if the content is dramatically different. One main change envisioned is the evolution of semiconductors and bioengineering into a nanotechnology-oriented stream, built upon a fusion and repurposing of sciences at the lower division. The second major change is the reorientation of how information sciences is taught, beginning with the freshman level, emphasizing a system-level and nontraditional architectural approach.

In terms of the relationship of the new curriculum to that of a future metropolitan university, the proposed program is based on the new ASU design imperatives described previously that are embodied in the following manner.

1) *Intellectual Fusion*—The EE curriculum will have a stronger tie to integrated science and represent the convergence of disciplines in several high-technology areas.
2) *Social Embeddedness*—The ECE program will have even stronger ties to the technology communities—regional, national, and global—through program content, distance learning approaches, and internship/co-op interactions.
3) *Pasteur's Principle*—The program will not confine its ties to just the technological portion of society, because it will make ethical issues and social consequences in engineering an integral part of the curriculum and will engage all the communities in dialog in these matters.
4) *Focus on the Individual*—The program will be customizable in content, in pedagogy, and in delivery format to meet the needs and learning styles of each student.

In particular, at Arizona State University (ASU), the model of a new metropolitan public research university is expected to have the following features.

1) **Inclusiveness**—All students who express an interest in engineering will be invited to enter the university. A variety of options will be available, spanning from analytical research-oriented programs to hands-on practice-oriented programs.
2) **Industrial Interaction**—There will be stronger interactions with local and regional industrial concerns in both curriculum design and delivery and not just in cooperative and internship positions. This kind of interaction is beginning to take shape at ASU, for example, the new Center for Embedded and Internetworking Technologies (CEINT), a joint ASU/industry consortium that is defining research, education, and commercialization in the embedded systems arena.
3) **Community Service**—There will be more student involvement in community projects, especially those that can be used as senior capstone design projects.
4) **Community College Interactions**—The community college system in Arizona is one of the largest in the nation, and strategic partnerships with the system will be used to provide additional avenues for Arizona high school students in their technology and engineering education. ASU and the Maricopa County Community College District have one NSF Advanced Technological Education (ATE) program in place, and others are planned.

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