Michigan Engineering 2020

The Commission on Undergraduate Engineering Education: Curriculum for the 21st Century

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Cover

The cover depicts CoE undergraduates in some of the many different learning environments that should be available to them.

Table of Contents

Executive Summary

Our educational programs are challenged by a changing world. It is widely recognized that engineering will play a critical role in the success of the State of Michigan and of the United States in the 21st century. But our current educational programs are the result of a Cold War driven curriculum focused on science, math, and analysis. Today fewer than 11% of our nation's jobs are in manufacturing, yet as it stands engineering education was designed to produce the engineering employee of the post-World War II industrial manufacturing economy.

The 21st century market demands innovation and requires engineers who can create new classes of product and service. Even in large companies engineers are being asked to serve as internal consultants or entrepreneurs who can radically improve the company's processes and products. In many cases success will be due not to engineering, but rather due to the design, the emotional reaction of the customer, and to the social appropriateness of the product. This speaks to a need for our students to learn to look at society and identify needs, and understand the value they can bring to as engineers addressing that need.

Engineering services are becoming available worldwide, and routine engineering analysis is becoming a commodity that can be bought anywhere from cheap, high quality providers in India, China, Russia or other once inaccessible lands. At the same time, the global impacts of climate change have created an imperative to address environmental quality and sustainability as a core element in the creation of engineering technology. This globalization of competition and globalization of human impact changes the value our students must bring to the world. Where in the past we hoped that our graduates might consider economics, now our graduates must consider the lifecycle impacts of a system. Where once we hoped that our graduates would analyze thermodynamic efficiency, now our graduates must also help analyze the ethical and social impacts of their technologies.

The loss of interest in engineering among U.S. students is yet another concern: few students enter engineering; few students believe it is worth the extra effort to complete an engineering degree; and many who begin, fail to finish. It is equally of concern that we are failing to attract, retain, and deploy the talents of women, Hispanics, African Americans, or Native Americans in engineering careers. It is distressing that good students who depart from engineering often cite poor teaching and inadequate advising as the reason for their leaving. The Millennial Generation is now entering our classrooms after years of having their cognitive development shaped by 21st century information sources characterized by the inexpensive just-in-time delivery of information and rich multi-media content. Their strengths in learning are likely very different from those of the faculty who teach them.

In the face of these changing needs, the College charged the Commission on Undergraduate Engineering Education to study the current state of our curriculum, and to make recommendations for the future. The full report, *Michigan Engineering*

2020, contains an examination of many of the elements of Curriculum 2000 that were instituted during our last major curriculum review in 1997. In addition it provides a set of core educational attributes that our students must develop in order to prepare them for the jobs of the future, and provides 8 actionable recommendations. This executive summary contains the key points of these recommendations, but for details of each recommendation, and for the data and arguments to support them, you must consult the full report.

To prepare our students for the jobs of the 21st century, whether they continue in engineering or pursue other paths after graduation, our undergraduate programs must support our students in developing:

- An ability to recognize and define a problem, and the vision to see a solution
- An ability to identify, understand, and solve ill-defined problems even in the face of uncertainty and imperfect information
- Strong quantitative and qualitative problem solving skills
- A mindset and skills that support continued learning both during and long after their CoE career
- Personal attributes of success including:
    - high personal expectations
    - persistence
    - the ability to work in teams
    - the ability to plan a project and carry it out
    - the ability to gather resources and overcome barriers to success
    - the ability to manage risk
- An understanding of the human, social, and environmental dimension of engineering practice
- A drive and capability to make a difference by bringing their solutions into production

Our graduates must understand that solutions, especially for society's most critical needs, are not just technical in scope but depend on many disciplines working together, and that as engineers their core contribution will be to bring data driven, quantitative problem solving skills to the table. Equally, we need to understand that our students have many varied aspirations, and that our primary duty is to provide them with a foundational education that they can carry forward into any of the career paths they may follow over the decades of their careers.

We have identified the following general areas of knowledge and skills that our graduates need in order to develop the attributes just enumerated, and we believe that the College must make curriculum design decisions around these core needs. When our students graduate they must have developed:

- Theoretical tools: Mathematical modeling; analysis; science; engineering science; understanding of suitability of tools/ideas to a task

- Design & Reasoning concepts: problem recognition & definition; specification; solution generation; systems thinking; solution evaluation; creative application of ideas & experience to new problems; troubleshooting
- Practical knowledge and Wisdom: tools for working with quantitative data; estimation skills; measurement science; specifying tolerances; statistics; rules of thumb; heuristics; practicality of design; usability; respect for reality
- Collaboration skills: teamwork; project management, task definition and implementation; communication (including technical, cross cultural, non-technical)
- Contextual knowledge: Human, social and global understanding; human needs, human differences, human attitudes; social norms and human values; business knowledge; ethical reasoning; environmental dimensions of engineering practice
- Important personal characteristics: Persistence; healthy skepticism and self-criticism tempered by optimism; an ability for decision-making; high self-expectations

Our curriculum needs to be organized to revisit these key skills and areas of knowledge repeatedly during a student's time here, with increasing levels of sophistication at each visit, and with an increasing shift of responsibility for learning and accomplishment to the students. Our curriculum also must be organized to create excitement for students so that the enthusiasm they bring to college can be built on and enlarged. Finally, we must teach our students to become expert learners; we must explicitly model learning processes for them, give them opportunities to practice and demonstrate self-learning, and demand that they do so.

At the same time, our students also need flexibility to pursue their varied aspirations and to support the varied careers that they will have, so we must work diligently not to over prescribe their curriculum.

Considering these goals and the current state of our curriculum we make 8 actionable recommendations to move us towards a 21st century engineering school. The full details of these recommendations, including arguments and data supporting them, appear in the body of the full report. In synopsis the recommendations are:

1. **Increase experiential and open-ended content throughout the curriculum**
   1.1. *Introductory experiences:* All Engr 100 and 101 classes should include hands-on project-based learning experiences in which students deal with ambiguity, design, and engineering problems.
   1.2. *Increasingly challenging open-ended experiences throughout the curriculum:* Departmental curricula should each year engage students in the analysis of increasingly ambiguous problems, and with problems that require them to work on projects (as teams or individuals) that demand research, discovery of information, and surmounting barriers of insufficient knowledge and resources, and that include some amount of prototyping and testing.

1.3. *Curriculum Committee oversight:* The College Curriculum Committee should exercise proactive oversight of all undergraduate programs, and require regular reports on how students engage in experiential learning with departmental programs and in the required college curriculum.

1.4. *Resource needs:* Such programs will require resources and creative faculty involvement, so the college should: invest in a competitive program to fund educational development proposals from faculty to create these experiential courses; review departmental development of such experiences in yearly planning and budget processes; recognize faculty who undertake critical, effective curricular development; re-examine budgetary processes around support for GSIs and Instructional Aides (including seeking gifts to endow some GSI positions); support the necessary classroom and laboratory spaces; and seek to develop additional external partners as clients for in-class projects .

2. Curricular and Pedagogical Innovation

2.1. *Enhance faculty development programs:* The College should expect faculty to engage in their own development as educators through workshops, conferences on teaching, or through the study of the literature on engineering education pedagogy and on how students learn. Programs are especially needed to help faculty efficiently learn to teach the use of open-ended problems in engineering classes, and to integrate ethics, sustainability, and technical communications into their classes.

2.2. *Enhance student instructor development:* The development recommendations in Recommendation 2.1 also apply to GSIs and undergraduate Instructional Aides. In addition, and consistent with the recommendations of the Grad Task Force, we should encourage GSI positions for students with academic ambitions, and develop additional budgetary structures and funding to support this, including endowed GSI positions, as suggested in Recommendation 1.4.

2.3. *Establish the culture needed to be innovators in engineering education and support engineering education research:* The College should be an innovator in engineering education to enhance our reputation as a leader in engineering and education, and to provide us with the talent needed to create the changes in curriculum and educational practice that are necessary to keep the college at the forefront of education for the future. The College's Faculty, Department Heads, Curriculum Committees, Advisors, and Administrators need to make curricular investments and changes based on data and evidence of effectiveness. The College should therefore foster research into engineering education on the University of Michigan Campus. Where appropriate, individual faculty should consider adding engineering education to their research portfolios.

3. Honors Program

3.1. *First Year Honors Program:* The College should establish a first year Honors Program. Students would apply during their senior year in high school, in parallel with their UM application. The first year Honors Program would require students to take some number of accelerated or honors classes (e.g.

the applied math honors sequence, honors physics sequence, or accelerated computing class).

3.2. *Upper Class Honors Program:* The College should create an Honors Program for second year and upper division students. Application to the program would be for declared students and rely on high UM GPA, and possibly other application criteria (e.g. an essay). Students in the program would be advised by a distributed set of departmental Honors advisors who would help students develop Honors Plan that could flexibly include research, project team activities, or completion of appropriate minors, all with high GPA.

3.3. *Honors Program office:* To support the first year and upper division honors programs as well as EGL, an Honors Program Office must be created, and an honors coordinator must be charged with creating a community of honors students through appropriate programs.

4. Sustainability and Ethics Education

4.1. *Sustainability and connections of engineering to society:* Each department curriculum should develop substantial specific milestones in sustainability that all students must meet for graduation. Such milestones could be achieved in a College-wide course, be based on outcomes embedded in departmental courses, or achieved through courses in other units.

4.2. *Professional ethics education:* Each department curriculum should develop substantial specific milestones in engineering ethics that all students must meet for graduation. As with sustainability, such milestones could be achieved through stand-alone courses or be based on outcomes embedded in departmental courses.

4.3. *College ethics and sustainability courses:* The College should support the development of an elective course in Sustainability for Engineers that can be used to meet these sustainability milestones. The College should similarly develop an elective course in Ethics Case Studies for Engineers that introduces ethical case studies in a range of disciplines, provides students the opportunity to discuss the interface of engineering with society, and to study important engineering failures and successes from a societal perspective.

4.4. *Provision of teaching resources:* The College should collect materials for distribution on the web to assist departmental implementation of engineering ethics and sustainability education in existing courses. Much of this material exists at similar sites throughout the country, and the proposed site could be a gateway to some of these remote sites.

4.5. *Curriculum Committee oversight:* The College Curriculum Committee should exercise proactive oversight of all undergraduate programs, and require regular reports on how students engage with ethics and sustainability objectives.

5. Technical Communications

5.1. *Engineering Technical Communications Center:* The College should establish an Engineering Technical Communications Center. This center, which should incorporate both physical space and virtual online elements, can house the

Program in Technical Communications and expand support for Communications Across the Curriculum efforts by providing professional and peer consulting to students, by holding workshops, by helping faculty in developing technical communications content for their courses, by providing online resources, and by providing instruction in College classes.

5.2. *Departmental feedback on technical communications:* The College must develop an annual review system by which departments can provide feedback on technical communications instruction in their courses, and on specific technical communications faculty.

5.3. *Introductory course for transfer students:* The College should develop an elective course for transfer students to learn technical communications. Objectives for such a course might touch on teamwork and introductory professional ethics.

6. Curricular Changes to Support Flexibility

6.1. *Flexible common math and science core:* All College of Engineering students should master core material in calculus, linear algebra, differential equations, physics, and chemistry. This core should be defined by its educational objectives and outcomes. All programs must accept an approved standard set of courses to meet the common core, but those students who have declared a major should be allowed to substitute for standard core classes other appropriate mathematics and science classes, subject to Curriculum Committee approval. This will give students the opportunity to best optimize their core courses once they have declared a major.

6.2. *Intellectual breadth:* The current 16 credit hours of humanities and social science and current general electives requirement (which varies widely fro program-to-program), should be replaced with a block of 28 credit hours with the following requirements:

- *At least 12 credits must be taken from LSA units, excepting courses in mathematics or physical science. At least 3 of these credits must be from upper division LSA courses. At least 6 of the 12 LSA credit hours must be taken from classes that satisfy the LSA HU/SS distribution requirement.*
- *At least 4 additional credit hours must be from courses outside the College of Engineering (Art & Design, Business, LSA, Public Policy, SNRE, etc.)*
- *The remaining 12 credit hours may be from any field, subject to the General Electives restrictions set by the College Curriculum Committee.*

6.3. *Modifications to the undeclared First Year:* Students should be encouraged to declare a program by the end of their second term in the college, and should not be allowed to register for a 4^{th} term unless they have declared a program or received a waiver.

6.4. *Retire the 4x4x8 model:* We recommend that departments and the Curriculum Committee no longer follow this model, but rather design the credit hour content of classes as merited by the content and workload of the course. But due attention must still be paid to student workload in order to ensure that students have a good prospect of graduating in 8 terms, recognizing that we also expect our students to be active participants in the wider, extracurricular life of the college.

6.5. *Advising:* The College should undertake a systematic improvement in advising, involving both faculty and staff in the process. This should include a departmental commitment of faculty and staff time, and should include review of the effectiveness of advisors so that advisors can improve their approaches, and we should include advising effectiveness in faculty and staff reviews.

7. **Interdisciplinary Programs:** We should provide faculty leadership for the interdisciplinary BS program and use it to explore innovative engineering curricula.
8. **Undergraduate Educational Objectives:** We should revise the current mission and objectives of the college to read:

   A UM undergraduate engineering graduate will be prepared to generate value for society through a lifetime of technical and professional creativity. Our graduates will display reasoning skills developed through problem definition, problem solving, quantitative expertise, a respect for measurement and data, and the wisdom of experience. Our graduates will use these reasoning skills to:

   - *Contribute in entry-level technical engineering practice*
   - *Pursue graduate education in engineering, either following a path towards a professional masters degree and practice, or a doctoral degree*
   - *Pursue careers in law, medicine, education, or other fields, bringing engineering problem solving skills—honed through practice in problem definition and quantitative problem solving—to bear in those disciplines*

   Michigan Engineers will grow into leaders in all of these areas of endeavor and will be able to develop into successful managers, leaders, entrepreneurs, and philanthropists.

The key to the future of our undergraduate engineering educational programs is the increased used of authentic experiences in which students can practice the skills of creative and critical thinking, problem identification and definition, dealing with ambiguity and scarce resources, and understanding the impacts of their work on society. Hands-on work, design with prototyping, and the use of open-ended and project based learning can all provide these experiences. Through such experiences they can experience working with a client, and they can learn what it means to make a difference. Likewise they must come to understand the interaction between engineering and society, and how engineering can creates both value and unintended impacts. Through all of this, our will become better motivated to continue their engineering academics and to pursue professional practice.

The College should start a wider conversation with all our faculty members to engage them in identifying the most important next steps to achieve this end. Our 8 actionable recommendations should receive attention from the college faculty, the college executive committee, and the college leadership to identify necessary resources and devise changes in resource priorities. The commitment will require focus for several years to bring about the change in culture that is required to increase the focus on professional practice within our curriculum and to drive pedagogy by scholarship and data.

Introduction

As the College of Engineering moves forward, we must re-examine our core and disciplinary curricula with an eye towards preparing our students for the challenges of the next decade. As we do so, we must be cognizant of their varied aspirations – be it as future engineers, lawyers, entrepreneurs, business persons, social activists, researchers, or one of a host of other career paths. We should contemplate our commitment to curricular and pedagogical innovation, and to providing our students with a multidisciplinary education suited to the flat-world in which they will live and to which they will contribute.

A number of reports and studies over the last 10 years have called, both explicitly and implicitly, for a re-examination of the purposes and structure of undergraduate engineering education. *Educating the Engineer of 2020* (National Academy of Engineering 2005) is the result of a National Academy study to understand what engineering education should "be like today … to prepare the next generation of students for effective engagement in the engineering profession in 2020." Among the recommendations of this report are that from the first year on "the iterative process of designing, predicting performance, building and testing should be taught," that our colleges of engineering should value and pursue engineering education research as a means to make our educational system systematic and rigorous; that we should teach students how to learn, so they can learn without us; and that we should introduce interdisciplinarity into undergraduate programs.

In 2009 our alum and colleague Prof. Sheri Sheppard of Stanford University led a group in publishing the result of their study of engineering education institutions, including the University of Michigan (Sheppard, et al. 2009). This report provides an excellent and thoughtful analysis of design principles for engineering curricula, and while echoing many of the recommendations of Educating the Engineer of 2020, re-emphasizes the importance of designing curriculum "that has, as its core, the knowledge, skills and understanding of professional practice." They emphasize frequent and early introduction not only of design, but also of meaningful hands-on experiences that do more than merely illustrate foundational principles, but rather that require students to deal with ambiguity, develop practical ingenuity, and practice creativity.

A number of other reports exist that present similar conclusions, including *Educating Engineers for the 21st Century* (Royal Academy of Engineers 2007), and *Engineering for a Changing World* (J. Duderstadt 2008). The recent report from the American Society for Engineering Education, *Creating a Culture for Systematic and Scholarly Engineering Educational Innovation* (Jamieson and Lohmann 2009), especially emphasizes the need to study our own pedagogical practices, learning environment and curricula in a scholarly way, so that we can have the data and theoretical foundation needed to apply the engineering process to the engineering educational system itself.

Preparing students for the jobs of the future

It is widely recognized that engineering will play a critical role in the success of the State of Michigan and of the United States in the 21st century (The National Academies 2007). But our current educational programs are the result of a Cold War driven curriculum focused on science, math, and analysis. After 50 years of evolution the UM engineering curriculum, like that of many of our peer schools, is strongly aligned along disciplinary lines, has become focused on engineering science, and is packed full of technical courses with no room for addition and little room to maneuver. Today fewer than 11% of our nation's jobs are in manufacturing (J. J. Duderstadt 2005), yet engineering education as it stands was designed to produce the engineering employee of the post-World War II industrial manufacturing economy. Our educational programs are challenged by a changing world.

The economic drivers for the 21st century are different. The 21st century market seeks innovation and demands engineers who can conceive and create whole new classes of product and service; it is a market in which even the distinction between product and service is disappearing. Even in large companies engineers are being asked to serve as internal consultants or entrepreneurs who can radically improve the company's processes and products. In many cases success will be due not to engineering, but rather due to the design, the emotional reaction of the customer to the product, and to its social appropriateness (Pink 2005). This speaks to a need for our students to learn to look at society and identify needs, and understand the value they can bring to addressing that need. As one of the College of Engineering Advisory Council members has expressed it, "there's too much talk about problem solving—it's about identifying opportunity" (College of Engineering Advisory Council Breakout Notes 2007).

Engineering services are becoming available worldwide, and routine engineering analysis is becoming a commodity that can be bought anywhere from cheap, high quality providers in India, China, Russia or other once inaccessible lands (Friedman 2007). At the same time, the global impacts of climate change and a desire, even an imperative, to address environmental quality and sustainability demand a new approach to understanding the desirability of a technology. This globalization of competition and globalization of human impact changes the value our students must bring to the world. Where in the past we hoped that our graduates considered economics, now our graduates must also consider the lifecycle impacts of a system. Where once we hoped that our graduates would analyze thermodynamic efficiency, now our graduates must also help analyze the ethical and social impacts of their technologies.

The loss of interest in engineering among U.S. students is yet another concern: few students enter engineering; few students believe it is worth the extra effort to complete an engineering degree; and many who begin, fail to finish. It is distressing that those who depart for other than academic performance often cite poor teaching and inadequate advising as the reason for their leaving (Aldeman 1998). If this was true in 1998, it will only be exacerbated now, 10 years on, as the Millennial Generation enters our classrooms after years of having their cognitive development driven by 21st century information sources characterized by the inexpensive just-in-time delivery of information and rich multi-media content. It is equally of concern that we are failing to attract, retain, and deploy the talents of women, Hispanics, African Americans, or Native Americans in engineering careers.

Within this context, the Commission on Undergraduate Engineering Education was charged to study and make recommendations on the future of our undergraduate curriculum. While the recommendations are forward-looking, we also reflect on previous curricular initiatives (e.g. Curriculum 2000), and also on the practical realities of resources and university culture.

Our Fundamental Thesis

To prepare our students for the jobs of the 21st century, whether they continue in engineering or pursue other paths after graduation, our undergraduate programs must support our students in developing:

- An ability to recognize and define a problem, and the vision to see a solution
- An ability to identify, understand, and solve ill-defined problems even in the face of uncertainty and imperfect information
- Strong quantitative and qualitative problem solving skills
- A mindset and skills that support continued learning both during and long after their CoE career
- Personal attributes of success including:
    - high personal expectations
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    - the ability to work in teams
    - the ability to plan a project and carry it out
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Our graduates must understand that solutions, especially for society's most critical needs, are not just technical in scope but depend on many disciplines working together, and that as engineers their core contribution will be to bring data driven, quantitative problem solving skills to the table. Equally, we need to understand that our students have many varied aspirations, and that our primary duty is to provide them with a foundational education that they can carry forward into any of the career paths they may follow over the decades of their careers.

Comparative Advantages

Once we understand our students' aspirations and the needs of a 21st century global society, we must also recognize that the University of Michigan and the College of

Engineering have a number of strengths relative to our peers that we can capitalize on to allow our graduates to develop their capabilities. These strengths include:

- People, including students, faculty and staff
    - Our faculty are highly creative and leaders in various aspects of engineering and science
    - Our faculty, staff and student bodies are diverse, allowing diversity in modes of thought and attitude, which research has shown to be advantageous for problem solving environments (Hong and Page 2004)
    - Our students come to us highly accomplished academically, and ready to be challenged as young engineers
    - Our students are highly engaged in community service activities
- Institutional breadth of intellectual endeavor
    - A world class College of Literature Science & the Arts
    - A world-class Medical School
    - A world-class Business School
    - A School of Natural Resources and the Graham Environmental Sustainability Institute
    - A School of Education including a Higher Education focus
    - Co-location on North Campus with creative disciplines in the School of Art & Design, the College of Music, Theater & the Dance, and the Taubman College of Architecture and Urban Planning
- A broad research scope of high quality
    - Broad and deep research enterprises within the College and beyond
    - Strong support for undergraduate research (e.g. UROP, SROP, SURE)
- A collaborative environment and culture
- Outstanding curricular elements and faculties
    - A good Technical Communications Program
    - International ties to support study, work, and volunteer opportunities abroad
- Co-curricular and Extracurricular programs and infrastructure, including
    - Minors in LSA
    - Engineering Global Leadership honors program
    - International Minor
    - Entrepreneurship Program
    - Multidisciplinary Design Program
    - Student project teams
    - Wilson Student Team Project Center

It would be wise and efficient to capitalize on these strengths in developing our undergraduate educational experiences. We should be looking for opportunities to allow our students to work across the disciplines of the university, for this provides an opportunity that few of our peers can match.

Structure of this report

In the remainder of this report, we first provide a review of those elements of Curriculum 2000 that have achieved some degree of institutionalization within our programs. This includes some analysis and review of elements that need strengthening or changing. We then briefly review some more recent innovations in co-curricular programs. Then we provide recommendations at two levels: we provide a detailed but high-level view of the design elements that we believe our curricula should be judged against, and we provide 8 actionable recommendations that we believe should be implemented by the departments of the College and by the college leadership to move our undergraduate educational experiences toward the design specification.

Process

In developing the recommendations in this report we have reviewed literature on the current state of pedagogy in engineering education, and a number of reports and journal articles on the future needs for engineering education, as well as higher education more broadly. As the Commission began its work, the report of the Carnegie Foundation for the Advancement of Teaching, *Educating Engineers: Designing for the Future of the Field* (Sheppard, et al. 2009), was released. Dr. Sheri Sheppard is a ME professor at Stanford and a UM CoE alumna, and this book was based on a study of many engineering schools including ours. This book therefore resonated strongly with the Commission members as we carried on with our work. Our high level view on engineering curriculum design is clearly influenced by it. Our design and recommendations are also influenced by discussions with faculty from across the college.

We have also reviewed the College's alumni surveys, senior surveys, and employer surveys. In February 2009 we held a focus group with a number of employers of our students, and a focus group dinner with alumni of the college in order to gather insights into the successes and challenges faced by our former students as they enter the workforce. We have sought departmental program advisor input, and have vetted a draft version of the recommendations at a CoE faculty meeting and with the College's Engineering Advisory Council, a group of alumni, business people, and academics that advise the College on our connections to the broader world.

The Program in Technical Communications prepared for us two internal reports on their work: *Communication Across the Curriculum and the Technical Communication Program* (Technical Communications Program Curriculum Committee 2009) and *Administrative Issues for Technical Communication Review* (Olsen 2009).

Reflection on Curriculum 2000

As part of looking forward to the College of Engineering Curriculum for the next decade, we have looked back at the accomplishments of previous curriculum reports within the College. In 1986 the Commission on Undergraduate Engineering Education, chaired by Prof. Jack Lohmann, made a series of general recommendations for reform but the lack of specificity of these recommendations led to only marginal progress(Commission on Undergraduate Engineering Education 1988). In 1996 a Curriculum Task force, chaired by Associate Dean Mike Parsons, met and produced the Curriculum 2000 report(Undergraduate Curriculum Taskforce 1996). This document provided the foundation for all of today's undergraduate programs within the College. The key drivers for Curriculum 2000 were:

1. For students graduating in 1996, the mean time to graduate was 4.7 years, and this was deemed too long
2. The undergraduate curriculum in the 1990s was seen as packed and in need of review in order to remove unnecessary technical content, inject necessary non-technical material, and increase flexibility. This also acknowledged that our students needed to work in flatter, global companies, would involve more than technical analysis, and that their career aspirations would in many cases be outside engineering
3. The anticipated changes to ABET accreditation processes in ABET Engineering Criteria 2000

To address these drivers the Curriculum 2000 report made 21 recommendations requiring changes to the common core structure of the curriculum, changes to the first year curriculum, introduction of some specific curricular programs and courses, increases in flexibility, and mechanisms for influencing the teaching of mathematics, physics, and chemistry.

Comments on Curriculum 2000 Drivers

In this section we will review the drivers for Curriculum 2000, time to graduation, the packed curriculum, and new ABET criteria, in light of today's realities.

Time to graduation

A key driver for the changes recommended in the Curriculum 2000 report was the excessive time required to complete a BS degree in Engineering in the late 1990s. Historical data since 1996 show that the time to graduation has fallen monotonically, and most students are able to graduate in 8 full terms (4 years).

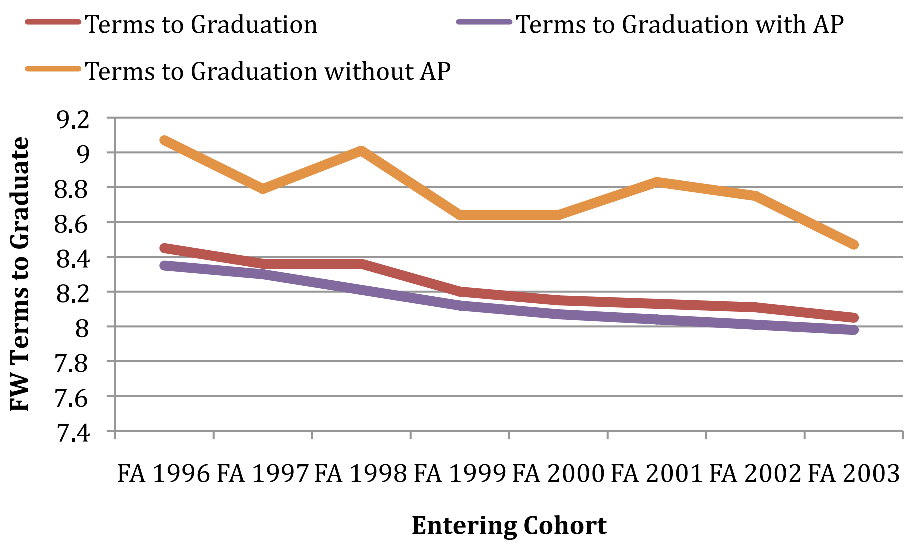

Figure 1. Mean number of Fall & Winter terms required to complete a BSE degree in the College of Engineering as of Fall 2008: overall, for students with, and for students without, AP credit.

As we can see in Figure 1, the time to graduation has been reduced over the last 10 years. The mean is still not down to 8 terms, even for students who have taken AP credit, but the attention focused on this issue by the departments and the College centrally do appear to have had a positive impact. External pressures have also played a significant role, as tuition increases over these same years impose a significant pressure for faster completion, high school preparation and admissions strategies have changed, and the quality of the entering student cohorts (as measured by test scores and high school GPA) has generally been rising.

Since 1996, 75% of our graduates have completed in 8 terms or fewer, 90% in 9 terms or fewer, and 98% in 10 terms or fewer (see Figure 2). Note that these are fractions of graduates; overall 80% of the students entered the college in 2002 completed an engineering degree within 6 years, while 90% completed a UM degree within 6 years. This loss of 20% of our incoming class is significant, and is even higher for under-represented minority students. Only about 55% of our entering minority students complete a degree in the College of Engineering.

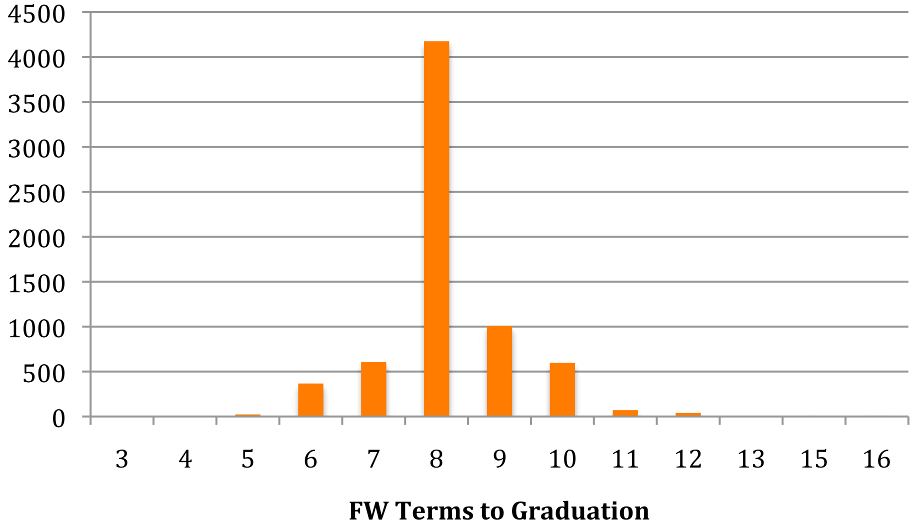

Figure 2. Distribution of number of fall & winter terms to graduation for all students entering as first year students since 1996.

We note in Figure 1 that students with AP (or other credit by test) graduate on average 0.5 term earlier than students without credit by test. On average over the entering cohorts from 1996 – 2003 the fraction of graduates who entered with AP credit is 17% and there is no trend up or down in this fraction; nevertheless the number of terms to graduation for both groups has been declining. The net result is that our students now complete their degrees earlier, but the reduction is not because of AP credit.

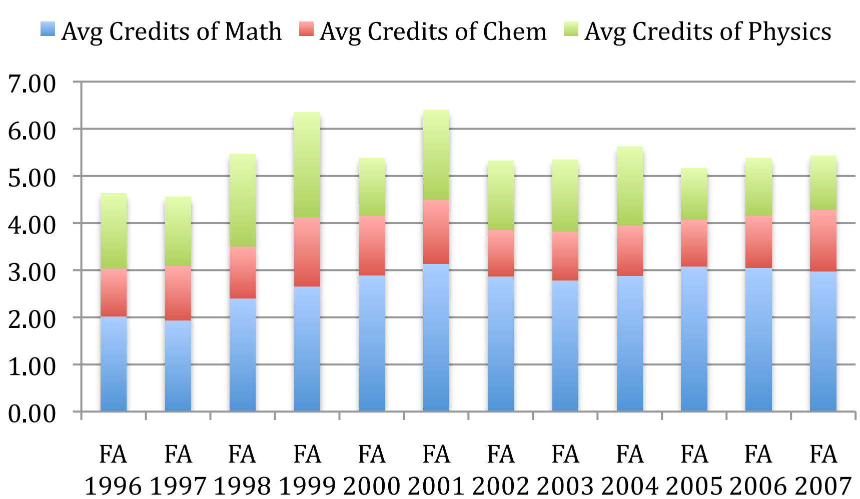

Figure 3. Science and math test credit awarded to CoE students by entering cohort, for those students who brought in AP or test credit. Notice that the number of test credits has been fairly level since 2000.

Equally, in Figure 3 we see that the number of math and science credits brought in by our graduates has been fairly stable since the 2000 entering cohort, after an increase in math-by-credit in the late 1990s.

Curriculum

The curricular needs identified in 2006 remain valid today: our students need to be skilled in technical communication, they need to know how to work in teams, and they need to understand the impact of technology on the wider world and society. The importance of these curricular needs are still echoed in national reports (National Academy of Engineering 2005), and by our alumni and the employers of our students. To quote from the CoE Advisory Council report out (College of Engineering Advisory Council Report Out Summary 2009)

> "Students need to think global. Most engineers coming out of college today are thinking about U.S. companies, employers, competition and the environment in general. They are not thinking about China, Asia, Europe, etc. Students need to develop their communication skills which would give them a clear edge over most of the engineers that come out of engineering colleges. … Industry wants a more well-rounded engineer, one who is ready to interact with other people and someone who can communicate and articulate their engineering goal or idea to an audience of laymen. This is a serious weakness across all U.S. engineering colleges. Students need to elevate the discussion and talk non- technically."

Equally, our faculty, alumni, and employers argue for the primary importance of engineering problem solving skills and critical thinking, calls echoed widely for higher education in general(Bok 2006). As a college we do not seem to have a clearly articulated vision of how these problem-solving skills are to be taught or measured. While many of our faculty members probably have implicit or instinctive pedagogical approaches to this, we proceed largely on instinct and ignore the large and growing educational literature on effective practices.

Beyond the needs identified before, we must note some additional drivers. In our interviews with employers (Holloway 2009), they have identified the need for our students to be broad problem solvers and critical thinkers. But in addition, they emphasized that graduates need a high profile accomplishment or talking points on their resumes to get them through the first cuts and into their first position. Examples of such accomplishments included knowledge of field specific software tools, leadership experience, and displays of initiative that came with solving real problems driven by client needs, be it for a student organization, a residence hall group, or a student design activity. In discussions with the College of Engineering Advisory Council the council (College of Engineering Advisory Council Report Out Summary 2009) identified multidisciplinary experiences, business education, international experiences and global thinking as particularly important, along with an understanding of sustainability and the development of a "can-do" and creative attitude as the next tier of important educational attributes. They encouraged that we take advantage of opportunities within our classes to provide contextualized education on professional ethics. They also emphasized the importance of giving our students some practical experience and hands-on opportunities, and of providing the flexibility and support to allow students to figure out what they are good at and to excel in that unique area of strength.

Finally, the changes in information technology are a key new change in the curriculum driver; these changes affect both how students learn, and what they need to learn. The students entering the College of Engineering today have been raised in the Internet age when most facts can be found quickly and on a need-to-know basis. This increases the need for students to develop critical thinking skills—to evaluate information, interpret it within a theoretical model, perform analysis, and draw inferences—but lessens the need to treat college as *the* place in which to transfer raw information from faculty to student. Yet it challenges us to help students find the will and skill needed to identify missing information, and then to find it. The new technologies also change the way in which our students learn, and generally make them less like faculty in their approaches to learning.

ABET

The ABET criteria under which we are accredited since 2000 are quite flexible. The criteria no longer contain requirements for specific numbers of credit hours in any category. The general ABET structure is now that we must work with our constituents to establish our own educational objectives, with some general framework appropriate to engineering and to each engineering discipline, and have processes in place to ensure that our students are achieving some specific set of outcomes implied by those objectives. It is possible that we have not taken full advantage of this flexibility.

The college has undergone two ABET accreditation reviews since Curriculum 2000 was instituted. Individual programs have had concerns and weaknesses identified in these reviews, but these concerns and weaknesses are not generally attributable to Curriculum 2000 issues, with the exception of concerns or weaknesses raised over student advising issues. Rather, the concerns have generally focused on the processes of establishing educational objectives and outcomes, assessing that the outcomes have been met, and feeding back assessment data to improve the curriculum and learning process. Concerns have also been raised over advising, and faculty professional development and engagement.

Comments on Some Specific Curriculum 2000 Recommendations

In this section we will comment on the Curriculum 2000 recommendations and observe the extent to which they have or have not been met.

The 4x4x8 Model

Curriculum 2000 Recommendation 1 was the 4x4x8 model, in which students were expected to take 4 courses, of 4 credits each, for 8 terms of 16 credits each to complete the 128 credits required for graduation. The theory behind this model was that students would complete more efficiently if they only had 4 classes to deal with at any one time – leading to four homework sets to deal with, only 4 mid-terms likely, etc.

Department curricula were realigned to varying degrees to conform to this model but the model was never fully achieved (or fully achievable, given that many classes in LSA are 3 credits). In recent years some departments have moved away from this model, and the curriculum committee has not held programs to the model. A review of sample programs reveals that most programs have some terms with 4 classes, and some terms with 5 classes, have terms containing anywhere from 14 to 17 credits, and classes having anywhere from 1 through 5 credits, with 3 and 4 credits the most common. Figure 4 shows the number of classes taken by our students in Fall 2008 and Winter 2009; in aggregate over the two terms 50% of our students took 5 courses or more, and 50% took 4 or fewer.

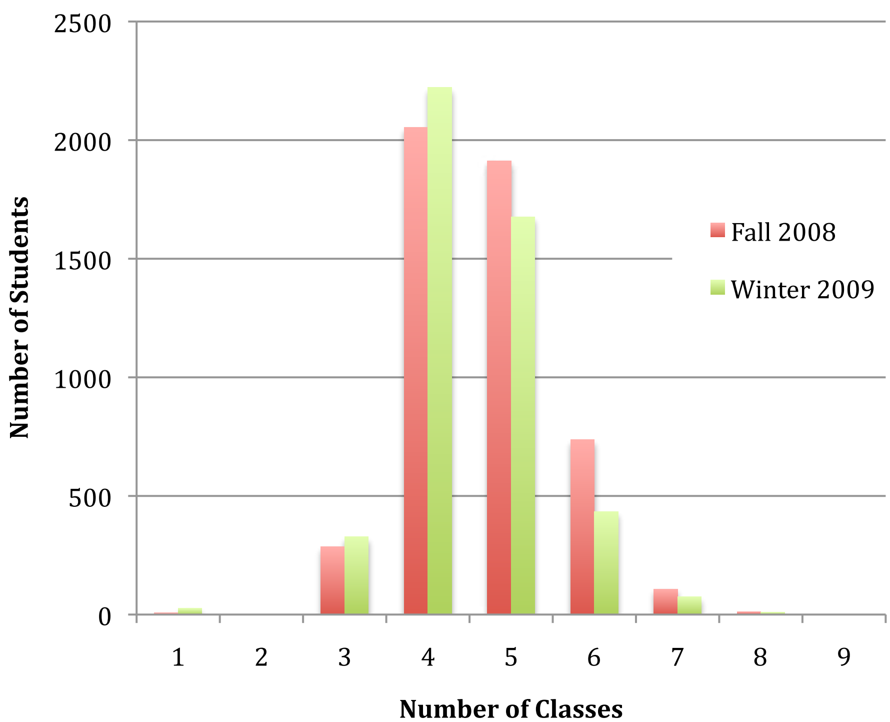

Figure 4. The number of classes taken by full time CoE students in Fall 2008 and Winter 2009. (Students taking 1 and 2 courses were taking high-credit study abroad placeholder courses.)

Despite the 4x4x8 model not being fully implemented, despite students not following it in practice, and despite curricula explicitly moving back towards 3 credit hour courses, the time to graduation has reduced steadily over the last 10 years. There does not seem to be any compelling evidence that would support slavishly maintaining this model into the future.

Technical Communications

In alumni survey data technical communications is consistently rated as important as problem solving. In the survey of graduates from 2003 & 2004 problem solving was rated as 4.4/5 in importance, while problem solving was rated as 4.5/5. While the alumni rated their preparation in problem solving as 4.4/5, they rated their preparation in technical communications as only 3.75/5. The importance of this skill was echoed in both our focus group with employers, and our focus group with alumni, and past alumni surveys (Passow 2004) have also echoed its importance.

Technical communications instruction is implemented in the Communications Across the Curriculum model. This begins with explicit focus in Engr 100, *Introduction to Engineering*, for entering first year students, and continues in required technical courses that offer some technical communications component. Many of these classes are team taught (to varying degrees) by departmental faculty members and faculty from the Program in Technical Communications (see Table 1). Technical Communications (TC) faculty members work in some 40 different course sections each year, some rather large, and many focused also on group work. It should also be noted that one department has also employed an outside consulting firm to provide technical communications instruction in one class, and others have provided technical communications instruction using their own faculty.

Table 1. Technical Communications Program Instruction

	Aero	BME	CEE	ChE	EECS	IOE	ME	MSE	NAME	NERS
Advanced	481 405	450	402	487 460	TC 496/497	481 424	495	–	491 475 470	442
Intermediate	305 245	–	345 351	360	TC 300	TC 380	395	–	310 270	–
Basic/core	ENGINEERING 100									

The system is highly idiosyncratic, with TC faculty members working very different systems from department to department. For example, TC faculty members work in two courses in ME (ME 395 and ME 495) but 5 or 6 courses in NAME. In one department there is no engagement (MSE), and in one the engagement is spotty (NERS). The course effort also can vary greatly, with TC faculty grading weekly assignments in some courses, while in others they are grading only 3. The system as it stands cannot respond easily to changes in enrollment or changes in departmental needs; for example, the introduction of a new design course can leave TC unable to respond to the new need because there is no new TC faculty member to engage with the new course; the sudden increase in enrollment in one department cannot be easily covered when another department experiences a similar increase. In some departments (EECS & IOE) the system has evolved to include a junior level TC course, with involvement in senior design classes, while in others it is deeply integrated. The different models lead to a wide range of costs for TC teaching in departments, from a low of $90 per student credit hour in one department to a high of $270 per student credit hour in another (Olsen 2009).

Despite the variety of Technical Communications Program participation, alumni surveys show that graduates recognize an increased emphasis on technical communications in all programs, and in two ABET reviews since Curriculum 2000, technical communications has not been identified as a concern. Indeed, employers have singled out our graduates' communications skills as top among the Big10+ schools (Holloway 2009).

In reviewing the Communications Across the Curriculum program the following list summarizes the needs raised by the internal review of the Program in Technical Communications:

- Greater consistency within each department
- Greater consistency across departments
- Less fragmentation of content within some department
- Increased resources
- Addressing the needs of transfer students who do not take ENG 100

In seeking departmental faculty input on Technical Communications, departmental representatives raised the following concerns about the current status of the program:

- Lack of coordination among classes
- Lack of consensus on how to assign and weigh TC grades
- Lack of continuity in TC faculty
- Departments have no say in who gets assigned to CAC classes
- Students do not sufficiently value TC content and faculty

Other Curricular Threads

Curriculum 2000 recommended a number of other curricular threads including threads in computing, professional ethics, and the environment. A recent review (Bielajew, et al. 2008) of Engr 101, *Introduction to Computers and Programming*, concluded that "In many departments, students do not receive instruction in programming beyond ENG 101," indicating that the Computing Across the Curriculum thread had not really been implemented. This report suggested that there needs to be support for introducing projects that require programming in sophomore or junior courses (and programming, as opposed to simply using computer tools for analysis).

Similarly, there is little evidence that the curricular threads around ethics and sustainability were implemented in most departmental curricula beyond the first year. This absence is notable in a few dimensions. First, the events of the past few years speak directly to the importance of both understanding a professional's ethical responsibility to society and the importance of viewing technology through a lens of sustainability. Beyond that, student interest in deploying energy for the benefit of society, and in developing sustainable technologies are evident in their creation of groups such as MHeal and BLUE Lab. Finally, in our focus group with employers they emphasized three areas in which they held our students' breadth to be important: understanding business, understanding how technology fits into society, and understanding energy and the environment.

First Year and Core Program

Curriculum 2000 led to a significant overhaul of the first year curriculum for our students through Recommendations 7 and 8 (Undergraduate Curriculum Taskforce 1996). These changes included the introduction of Engr 100, *Introduction to Engineering*, and 101, *Introduction to Computers and Programming*, as required courses, and the institutionalization of Engr 110, *The Engineering Profession*, as an optional course to help students understand the engineering profession and the disciplines with the College. In addition, recommendations were made concerning the introductory physics, math, and chemistry curriculum.

Engr 100 – Introduction to Engineering

This course was designed to be the foundation of the Communications Across the Curriculum program and to replace English 125 as the foundational communications course for our students. It was also intended to provide students with an opportunity to engage with engineering design, both as a means to engage students in the engineering process from the start of their college education and to provide them with meaningful technical material on with to write and present reports. Over time this class has evolved several sections that go beyond a paper study and that provide instead hands-on experiences and even a full design-build-test cycle with prototyping and testing of student designs. In 2004 the Strategic Planning Implementation committee recommended that department involvement in the first year program be increased, and Engr 100 has been a key course for this involvement.

Engr 101 – Introduction to Computers and Programming

Engineering 101 was introduced as part of Curriculum 2000. It displaced a previous suite of programming courses, and was first taught in 2007, and was reviewed by a faculty committee in 2008 (Bielajew, et al. 2008). One observation from that review was a comment on computer languages: specifically that relatively few students used C++ after Engr 101, yet at the same time a survey showed that students generally understood that the programming language was immaterial to the basic concepts. Students did generally believe the course to be useful (87% believed programming was a useful skill, and 77% agreed that being able to think algorithmically was an important cognitive ability). This agrees with surveys of practicing professionals (CACHE Corporation 2003), who have generally held that the improved problem solving ability that comes from the course is very important to an engineer.

A larger concern for students was the lack of standardization between the sections of the course. However, faculty teaching the course have defended the quality of instruction that has come with allowing instructors latitude to innovate. Some changes that have come out of the report include the creation of an advanced section (Engr 151) for students ready for a more significant challenge, and the provision of additional instructional aides for the course.

Engr 110 – The Engineering Profession

Engineering 110 introduces students to each of the programs and most of the undergraduate degrees within the College of Engineering.   About 425 students per year take this optional course. Our curriculum does not allow a student to declare until they have 15 credits at Michigan, and our practices generally discourage students from declaring until the end of the first year. Engr 110 is a primary source of information for students to declare their major. Data also show (see Table 2) that the course is positively correlated with retention of students into the second year. A deeper analysis (Veenstra and Herrin 2009) show that Engr 110 improves retention for students whose high school rank was 96% or less, and whose college gpa is between 3.0 and 3.5 (remembering that most of these are students struggling with their first B grades), and may improve retention for students with lower grades as well (where low numbers make statistical significance hard to ascertain).

Table 2. The fraction of students returning in their second year.

Cohort Term	*Students not taking Engr 110*	*Students taking Engr 110*
FA04	90%	95%
FA05	92%	93%
FA06	91%	96%
FA07	90%	95%

Student feedback on the course remains positive, with the primary request for students that they learn more about what they will be doing as practicing engineers, should they complete their degree and go to work for an engineering firm.

Math and Science Core

Curriculum 2000 made a series of recommendations (Recommendations 10—15) regarding the Mathematics and Science core curriculum. It was recommended that we work with the math department to create a math sequence well suited to engineering students. This was aligned with the Math department's development of the Math 156, 256 Applied Math Honors sequence in Fall 1996; this sequence was itself based on pilot sections of the Honors Calculus sequence taught since Fall 1994 in response to a CoE request. A recent study of this course (Mesa, Jaquette and Finelli 2009) has shown that once confounding variables (in particular AP math scores) are accounted for, students taking the applied math honors sequence do not have a higher GPA in subsequent courses, although they do show a slight increase in their commitment to finishing an engineering degree. There has been some difficulty in getting students to elect this sequence, because of a perception that it might adversely affect the student's GPA, and a concomitant reluctance of advisors to strongly advocate students taking the sequence. In fact the data show a similar GPA for students taking the two different tracks, but this does not show the student's concerns to be false. Given the lack of evidence that the course improves student's academic performance, it is difficult to argue that they are making the wrong decision.

Curriculum 2000 also recommended that we work with Physics and Chemistry to create a physics and chemistry sequence that would require only 8 and 4 hours respectively. This was not achieved. The Curriculum 2000 report also suggested that biology should be allowed as an alternative to chemistry. Despite some attempts to move in this direction, this also has not been achieved, although two programs, Chemical Engineering and Biomedical Engineering, do require biology. In Curriculum Committee debates on this topic, the split between departments that would find biology useful and those that would not has each time been resolved in favor of chemistry, perhaps because all the programs that find biology useful also find chemistry useful.

Another set of recommendations was to appoint faculty as liaisons to the math and science departments in LSA. These liaisons were appointed initially, and made progress on the math courses, for example. Eventually the practice of appointing these liaisons was discontinued, probably because the benefits were not seen to be commensurate with the cost of the appointments.

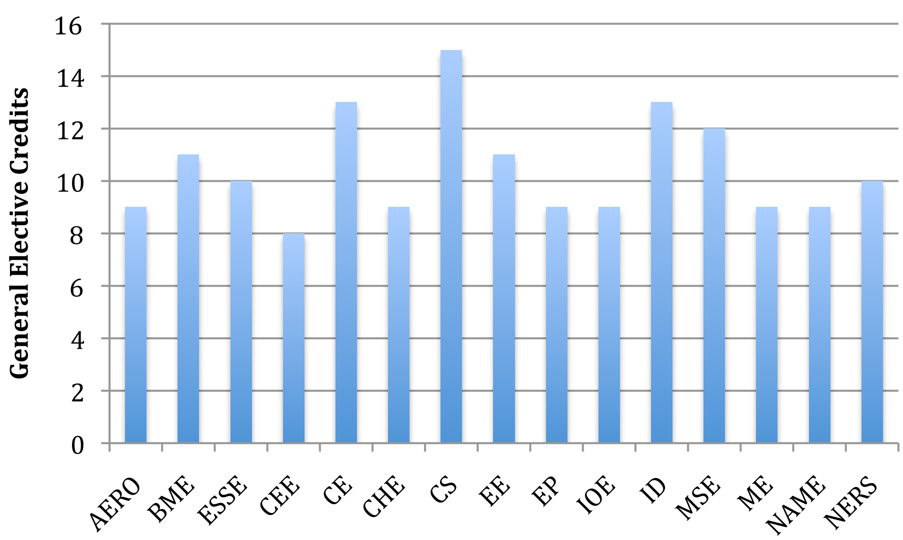

Figure 5. Minimum number of general electives built into departmental program curricula.

General Electives

Recommendation 2 of Curriculum 2000 was that all undergraduate programs have at least 12 credit hours of general electives. This recommendation was never achieved. It was approached by many programs, surpassed by a few, and recently has been reduced by some. Figure 5 shows the minimum number of general elective credits advertised by each degree program in the college. Only 4 programs currently achieve the goal of having a minimum of 12 credits of general electives (and one of these, the Interdisciplinary Engineering program is a non-accredited program taken by very few students).

Advising

The Curriculum 2000 report recommended (Recommendation 6) that advising be strengthened throughout the college, including a requirement that students meet with their advisor at least once per term before registering for classes. This recommendation has not been generally implemented. Some departments receive high marks in alumni survey data while others receive significant criticism. Advising has been raised as an issue in ABET reviews for some programs since Curriculum 2000. Recent external departmental reviews of some departments have identified advising as being in an "unhealthy" state. In many departments many hundreds of students are the responsibility of an advising team consisting of a single faculty and staff member. No mechanism has been put in place to require students to meet an advisor before registering for classes, and the online registration system has allowed many students to register without speaking to any staff or faculty advisors, sometimes to their harm.

Our undeclared first year provides our students with a great opportunity for self-exploration and it provides us with a significant recruiting tool, but it also provides us with a significant advising challenge. We currently have no requirement or even strong inducements for a student to declare a major; we simply raise GPA barriers when the student gets beyond 55 credit hours. Those barriers, as often as not, trap the student because they suddenly find themselves unable to meet the increased departmental admission requirements. Equally, very advanced students can bring in so many AP credits that they reach 55 credit hours within one semester, an event apparently not envisioned when barriers based on credit hours were created.

Since 2001 the largest undergraduate department in the College has been Mechanical Engineering, with a peak Fall term enrollment of 666 students in Fall 2006; but that same term the number of undeclared students was 1894. In March 2009 there were 310 out of 1242 students (September 2007 admits) who had still not declared a major 18 months after starting at the College of Engineering, and there were 59 out of 1095 students (September 2006 admits) fully 30 months after entering the College. In March 2009 there were over 1500 students who were still the primary responsibility of the Engineering Advising Center.

The lack of direction that some of our students experience represents a failure to engage them with the intellectual community of the departmental disciplines, and research has shown the engagement with the community and with faculty is a significant predictor of success for students. The current system allows students to remain the responsibility of the Engineering Advising Center for too long. While the EAC is an excellent advising service, it is not sized to support large numbers of sophomores (let alone juniors). Some students naturally want to remain connected to the EAC because they have adopted it as their "home-away-from-home," but for their own intellectual growth they need to be required to declare a major.

Curriculum 2000 recommended strengthening advising across the college. However, subsequent ABET visits, departmental external reviews, and senior surveys have time-and-again raised concerns about our advising of students. Because we want students to have flexibility, we need good advising, both to navigate the rules of the curriculum and to navigate the intellectual content of the curriculum. In addition, alumni and employer feedback highlight the need for students to hear about career possibilities, the broad nature of engineering work from the highly technical to the non-technical, and about the realities of the real world and the culture shock that an arise when students become employees.

Recent Curricular Innovations

Since the renovations of the Curriculum 2000 experience, several other large-scale curricular changes have occurred. The first was the approval of LSA minors for engineering students, starting in 2002. This gave our students an improved mechanism to organize their humanities and social science studies, as well as their mathematics and science courses. Mathematics, Economics, Physics, Spanish, and Music have been consistently popular minors in recent years (see Figure 6). Since 2002, over 300 students have completed a minor in Math, 93 in Economics, 59 in Physics, 57 in German, and 23 in Spanish Language and Literature.

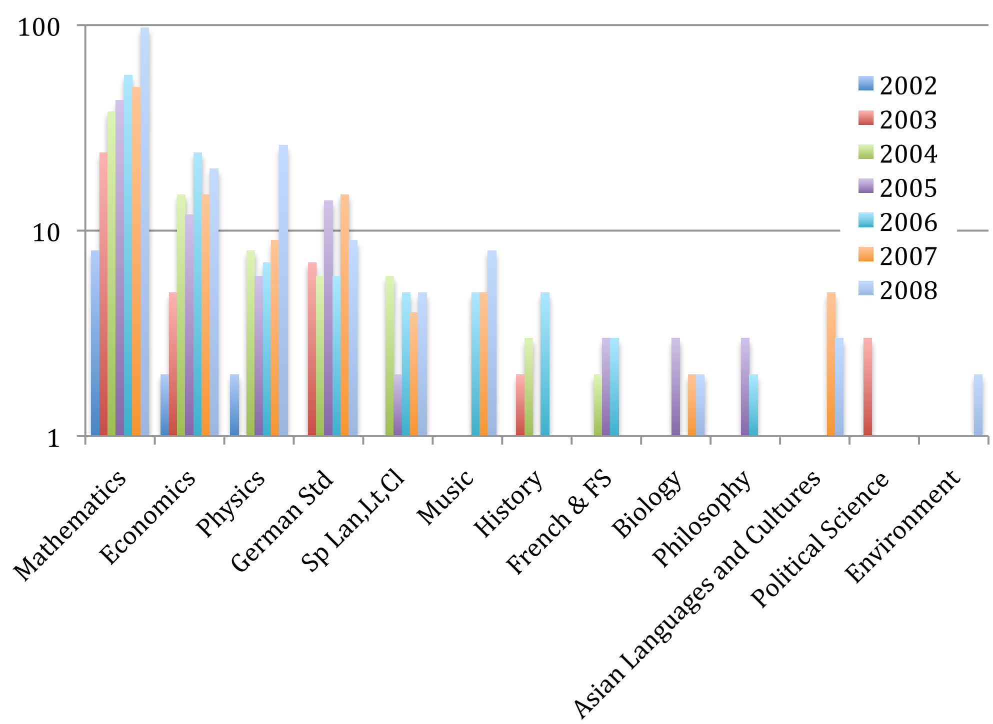

Figure 6. LSA Minors completed by CoE graduates by AY of graduation; only those minors completed by 5 or more CoE students are shown.

It should be noted that many of our students are pursuing the minors (Mathematics and Physics) that are easiest to complete based on the foundation of mathematics and physics that we require. Economics is also somewhat easier for our students, as a few of our departments require an economics course. It is difficult for our students to fit LSA minors into their degree, as most LSA minors require 17 – 24 credit hours in LSA, which necessitates the use of all our currently require humanities and social science credits and additional general elective credits as well. When a department requires economics and only allows 8 general elective credits, there are only 20 credits available (through the combination of remaining humanities and social science credits and general electives) for a student to complete a minor within the nominal 128 credits for a degree. This makes it quite difficult for our students to complete minors that would be of great relevance to their engineering education, such as the minor in Science, Technology & Society.

More recently the College of Engineering has created its own minors. The first was the International Minor for Engineers. Created in Fall 2007, the International Minor has quickly become one of the most popular minors for engineering students. Over 110 students are currently pursuing the International Minor, and over a dozen graduates have already completed it.

The second CoE minor was the Multidisciplinary Design Minor, a flexible template for students to pursue design-build-test activities that is the centerpiece of a Multidisciplinary Design Program which seeks to increase professional practice activities for our students. This was followed in April 2009 with a minor in Electrical Engineering.

Finally, in Winter 2009 the College approved a Minor in Art for our students. This minor, administered by the School of Art & Design, complements the Minor in Music and provides our students with a complete suite of curricular programs in the arts. Both of these minors require significant numbers of courses that do not count within the humanities and social science requirements; with as few as 8 credits of general electives in some of our curricula it is difficult for our students to complete these minors within their 128 credit hour program. Given that these minors (especially the Minor in Art) are explicitly supporting the increasingly important development of creative capabilities, this is unfortunate.

Another new experimental program is the Program in Entrepreneurship; this program is not officially a minor because it requires fewer credits than the 15 required for a minor. The program is the academic arm of a set of programs sponsored by the College of Engineering's Center for Entrepreneurship, which has as it's mission to foster an entrepreneurial ecosystem to teach the skills needed to allow students and faculty to bring their technical ideas into the marketplace. The Program in Entrepreneurship was also recently expanded to a credential for graduate students as well.

Several of our recent curricular innovations seek to directly provide the experiential learning that our students, alumni, and business partners call for. A challenge for students, however, is in finding the space within their curriculum to complete these programs. It would be more efficient if the best elements of these programs became more widely available within all our departmental curricula. As Ray Almgren, Vice President at National Instruments has recently written (Almgren 2008), an ideal engineering education in today's world requires the "integration of hands-on, experiential learning with classroom-taught theory."

Recommendations for the Coming Decade: Design Principles

We begin our recommendations with some discussion of curricular design principles that we have developed based on our reading of national studies including *Engineering for a Changing World* (J. Duderstadt 2008), *Creating a Culture for Systematic and Scholarly Engineering Educational Innovation* (Jamieson and Lohmann 2009), *Educating the Engineer of 2020* (National Academy of Engineering 2005), *Educating Engineers: Designing for the Future of the Field* (Sheppard, et al. 2009). We have also based these principles on our examination of senior and alumni survey data and interviews with employers of CoE graduates, and interviews with CoE alumni. Finally, we have also asked the College's Engineering Advisory Board to reflect on a draft set of these principles. Based on all these inputs, we have developed this set of curricular design ideas.

We believe that departmental faculty and students, curriculum committees, and the college leadership should reflect on these principles as they make decisions about curriculum and resources over the coming years.

Design principles for our curriculum

We have identified the following general areas of knowledge and skills that our graduates need, and we believe that the College must make curriculum design decisions around these core needs. When our students graduate they must have developed:

- Theoretical tools: Mathematical modeling; analysis; science; engineering science; suitability of tools/ideas to a task
- Design & Reasoning concepts: problem recognition & definition; specification; solution generation; systems thinking; solution evaluation; creative application of ideas & experience to new problems; troubleshooting
- Practical knowledge and Wisdom: tools for working with quantitative data; estimation skills; measurement science; statistics; rules of thumb; heuristics; practicality of design; usability; respect for reality
- Collaboration skills: teamwork; project management, task definition and implementation; communication (including technical, cross cultural, non-technical)
- Contextual knowledge: Human, social and global understanding; human needs, human differences, human attitudes; social norms and human values; business knowledge; ethical reasoning; environmental dimension of engineering practice

- Important personal characteristics: Persistence; healthy skepticism and self-criticism tempered by optimism; an ability for decision-making; high self-expectations

Our curriculum needs to be organized to revisit these key skills and areas of knowledge repeatedly during a student's time here, with increasing levels of sophistication at each visit, and with an increasing shift of responsibility for learning and accomplishment to the students. Our curriculum also must be organized to create excitement for students so that the enthusiasm they bring to college can be built on and enlarged. Finally, we must teach our students to become expert learners; we must explicitly model learning processes for them, give them opportunities to practice and demonstrate self-learning, and demand that they do so.

The overall curricular structure presented here is designed with the goal of increasing flexibility for the student, both in her technical course elections and in the election of broader course experiences. Our students need flexibility to pursue their varied aspirations and to support the varied careers that they will have.

Curricula should be designed around a few core courses with key material, and electives that provide learning experiences partially redundant with the core, and with pre-requisite chains as short as possible (and no shorter). We must expect students to learn on their own, both in their undergraduate career and after; we must therefore ask them to do so, and hold them accountable for such self-learning. We should make the connections between courses explicit so that we can build on concepts from class to class, and so that students explicitly know the connections. Content in core classes should be there because there is a high probability that the student or graduate will build on it. Content that does not meet this criterion should be in an elective class.

Curricular Structure

Our curriculum should be built around a common structure into which individual degree programs can flexibly plug discipline specific learning experiences. The structural elements that we recommend include:

Flexible Foundation: A foundation of knowledge and skills developed in all our graduates through completion of a flexible menu of courses spanning 1st – 2nd years, taken by all students. The foundation includes:

- Introductory engineering design with an experiential, hands-on component
- Teamwork development
- Technical communications skills development
- Quantitative modeling and problem solving (mathematics, programming)
- Theoretical knowledge foundations (physics and chemistry)
- Knowledge of measurement and data
- Development of contextual knowledge of human cultures, societies, other modes of thought and communication

Undeclared first year: First year students should still enter the College undeclared to afford them the time to explore their interest in engineering without being bound to a particular major. Simultaneously, students should be supported to find their departmental home quickly, and should not be allowed to drift as undeclared students. There should be benefits to declaring a specific degree program early, as soon as each student understands her own future goals.

Intermediate Development: Increasingly discipline-oriented education spanning 2nd through 3rd years, characterized by requirements for our students to address increasingly ill-defined problems, in the presence of incomplete knowledge and uncertainty, and including experiential, hands-on, learning. Elements of this development include:

- Theoretical knowledge development: Engineering science within a discipline.
- Problem solving: increasing development of students' ability to recognize what concepts and tools are needed to address an unfamiliar problem, and to discover what they need to learn, and learn it without an instructor delivering it.
- An intermediate engineering design experience (perhaps within the context of a discipline).
- Experience of engineering practice through hands-on opportunities such as prototyping or laboratories.
- Increasing knowledge of measurement processes.
- Continued teamwork and communication skills development, including team strength through diversity and cross-cultural communication.
- Continued development of contextual knowledge including social impact (sustainability, ethical reasoning) and understanding of the world with a trans-national perspective, and business and finance.

Advanced Development: more specialized disciplinary development, but also increasing inter-disciplinarity and development of skills to understand and impact the world, spanning the 3rd and 4th years.

- Engineering design in teams and individually, more open-ended work, and the development of project management skills, and opportunities for multidisciplinary design.
- Continuing experience of engineering practice through hands on opportunities.
- Increased use of case studies and project centered learning so students can practice applying theoretical constructs in the identification and solution of ill-defined problems, and practice self-directed learning in service of a goal.
- Development of increased knowledge of the world, including societal and global problems
- Development of practical engineering knowledge within a discipline
- Experience at accepting and managing risk, finding resources, and self-reliance

- Experience with measurement and data collection for the purpose of furthering a project
- Further teamwork and communication development and practice on complex projects requiring problem definition, potential solution generation, technical analysis and down-selection, and ideally prototyping and testing (real or virtual).

Breadth: Provision for the formal development of personal interests and time to pursue additional learning, spanning 1st – 4th years, including space to pursue courses in business, minors in Engineering, LSA, or the arts. There needs to be space within the curriculum for this personal development, and opportunities outside of formal learning environments as well (e.g. in student organizations and volunteer activities).

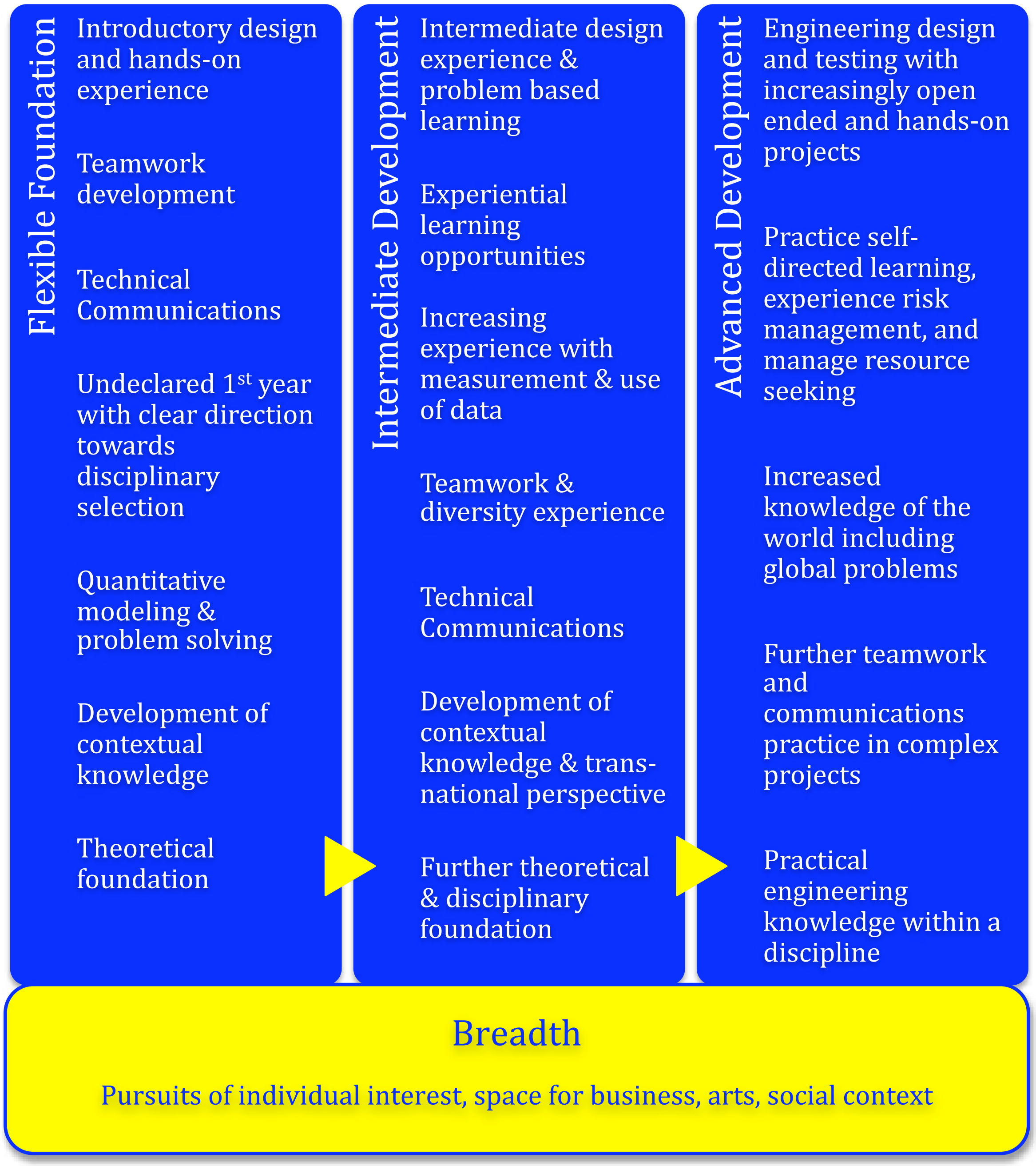

Figure 7. Our recommended curriculum design elements.

Recommendations for the Coming Decade: Action Items

Recommendation 1: Increase Experiential and Open-Ended Content Throughout the Curriculum

From alumni, employers, and students we have consistently heard that students need opportunities to use the foundational knowledge that they gain in our classes within the context of engineering practice, involving problem identification and definition, ambiguity, the search for required knowledge, the use of quantitative data, and hands-on experiences that connect the student's work to the physical world. That is, our students need to *experience* the process of *doing engineering* and our curriculum must support this. Our curriculum should first train our students to welcome open-ended problems, and then challenge our students with problems that grow in sophistication as students progress through their education. There should be constant reinforcement between their development of theoretical tools and their engagement with experiential activity wherein students must synthesize their knowledge and use their creativity to attack an unrehearsed, even undefined, problem relevant to engineering practice, where they must create a solution, and assess it against reality. This approach engages students more fully in their own learning, which is known to lead to better learning of fundamental ideas, and to reinforce the motivation of students to be engineers by giving them context for their education (Prince 2004)(Smith, et al. 2005). In order to ensure that this happens, the College Curriculum committee should be proactive and require information from bachelors degree programs in order to ensure that program objectives concerning the use of open-ended and experiential work are being met. This call for a curriculum that pays due attention to engineering practice is also found in the recent literature from both academics (Sheppard, et al. 2009) and industry (Fouger, et al. 2008).

Recommendation 1.1: Introductory Experiences

All Engineering 100 and 101 classes should include hands-on project-based learning experiences in which students deal with ambiguity, design, and have many opportunities to analyze identifiably relevant engineering problems. Some of these sections could include projects inspired by societal needs, by industrial sponsors, by student teams or by more advanced student design groups. Laboratory/fabrication facilities to support this must be identified and developed, as must appropriate instructional and technical staffing.

Recommendation 1.2: Increasingly Challenging Open-Ended Experiences Throughout the Curriculum

Departmental curricula should each year engage students in the analysis of increasingly ambiguous problems, and with problems that require them to work on projects (as teams or individuals) that demand research, discovery of information, and surmounting barriers of insufficient knowledge and resources. Departmental curricula should provide students with experiences that involve increasing exposure to design, prototyping and testing. Once again, some of these problems and projects should be inspired by social and global needs, by industry, by student entrepreneurs, by student teams, by College of Engineering researchers, and by more advanced student design groups. Laboratory and fabrication facilities to support this must be identified and developed, as must appropriate instructional and technical staffing.

Recommendation 1.3: Curriculum Committee Oversight

The College Curriculum Committee should exercise proactive oversight of all undergraduate programs, and require regular reports on how students engage in experiential learning with departmental programs and in the required college curriculum. For example, the Curriculum Committee could request and review a short assessment from 3 different programs per term on a rolling schedule to review all programs every 5 terms. Program reviews should become a standing Curriculum Committee agenda item.

Recommendation 1.4: Resource Needs

Resources to support this educational goal are needed, and the College leadership, including Deans, the Executive Committee, and Department Chairs, must take steps to make these resources available. Therefore:

1. The College should institute a College-wide educational incentive fund to which faculty can apply with proposals to increase design and hands-on class content, improve laboratory classes to require student design of experiments, and to increase opened ended problem solving in classes from first- through senior year. Applications to this fund by faculty (or departments) should be competitive and selection based on alignment of the proposed use with this recommendation. Applications should also include clear plans to disseminate any new techniques and tools to other faculty so that the investment has a broad impact. The fund could provide direct monetary support, and could also have a set number of GSI positions to be awarded based on project merit.
2. The yearly planning and budget process for departments should include questions on how they are implementing open-ended and experiential exercises in their programs.
3. Faculty should be recognized in annual reviews, promotion and tenure processes for undertaking critical, demonstrated effective, and curricular development.
4. The College should also begin a re-examination of budgetary processes for supporting GSIs and Instructional Aides, and should also seek gifts and endowments to support exceptional GSIs. Note that this is complementary with the recommendations of the Grad Task Force on full funding of Ph.D. students.
5. The College should support the development of necessary spaces and facilities to support hands-on work, including flexible classroom space and instructional labs. This should be accompanied by development metrics for efficient use and of best practices on the efficient and flexible

use of lab space, which should by default support multiple classes and co-curricular activities rather than single courses.

6. The College should seek additional external partnerships with business, community, and industrial partners from Michigan and the world to provide students with clients for in-class projects. Information technology tools to support the matchmaking and interaction between students and sponsored should be provided.

Besides the steps that we should take within our formal curriculum, we must recognize that valuable educational experiences are available to our students in internships, international experiences, and cooperative education (co-op) programs. The College departments should explore steps that might make these experiences easier for students to pursue, including: making co-op less onerous by increasing the flexibility of the curriculum (see Recommendation 6: Curricular Changes to Support Flexibility); providing courses online when possible so that students on co-op assignment can complete courses; offering required courses every term; and providing more spring or summer term courses where demand warrants in order to allow students more opportunity to complete in 4 years even if they pursue a co-op or international programs.

Recommendation 2: Curricular and Pedagogical Innovation

The College leadership must send a consistent message over a period of several years that the changes we wish to see occur are in fact important. These messages must set expectations for faculty action to improve education using evidence and sound theory. We therefore recommend that the College enhance, encourage and extend opportunities for faculty development in pedagogy so that we can learn from what is shown to be effective, and to encourage faculty research on effective learning in engineering education so that we can discover when teaching ideas work and when they don't. This idea, that we base our own educational programs on solid research about what works in teaching and learning, has been supported by a number of recent reports (National Academy of Engineering 2005) and is now backed by significant NSF funding programs (National Science Board 2007).

Recommendation 2.1: Enhance faculty Development Programs

The College, as part of faculty development, should expect faculty to engage in their own development as educators. This development might take the form of learning effective teaching techniques through Center for Research on Learning and Teaching – North (CRLT-North) programs, through learning at conferences on teaching, or through the study of existing monographs and literature on engineering education pedagogy and on how students learn. Programs are especially needed to help faculty efficiently learn to teach the use of open-ended problems in engineering classes, and to integrate ethics, sustainability, and technical communications into their classes. Enhanced support for CRLT-North in the form of additional staffing and for additional programs should be provided, and support for faculty travel to appropriate conferences should be developed.

Recommendation 2.2: Enhance Student Instructor Development

The development recommendations in Recommendation 2.1 also apply to GSIs and undergraduate Instructional Aides. In addition, and consistent with the recommendations of the Grad Task Force, we should encourage GSI positions for students with academic ambitions, and develop additional budgetary structures and funding to support this, including endowed GSI positions, as suggested in Recommendation 1.4. We should equally encourage GSIs to pursue the CRLT teacher certificate and the new Rackham Certificate in Engineering Education Research, and make sure that we are supporting students with aspirations to do so.

Recommendation 2.3: Establish the Culture Needed to be Innovators in Engineering Education and Support Engineering Education Research

The College should be an innovator in engineering education. This will both enhance our reputation as a leader in engineering and education, and provide us with the talent needed to create the changes in curriculum and educational practice that we know are necessary to keep the college at the forefront of education for the future. The College's Faculty, Department Heads, Curriculum Committees, Advisors, and Administrators need to make strategic investments in change, and must be able to make these changes based on data and evidence of effectiveness. The College should therefore foster research into engineering education on the University of Michigan Campus, and we should widely publicize our accomplishments in this area. Where appropriate, individual faculty should consider adding engineering education to their research portfolios, and the impact of such work should be considered along with other work in annual reviews, promotion and tenure decisions. Such work should be considered for matching funds by the ADR, on an equal footing with other engineering and science research. In addition the college should support an increase in the research portfolio of CRLT-North supported by external funds.

Recommendation 3: Honors Program

The College should develop an honors program to structure and provide community to our highest achieving undergraduate students. The College's EGL honors program is very successful but it draws students into the business world through its focus on Tauber projects. We have no program to structure the work of high achieving students with other interests, and some students join EGL for the honor's experience rather than an interest in the business leadership focus at the heart of the EGL experience; EGL is not a good program for students whose interest runs to engineering research and the Ph.D. (Van Oyen 2009). A more traditional honors program for our students, centered on a significant engineering research activity, can provide students with the experiential practice that we argue for throughout this report. Such an honors program is also a powerful tool for recruiting new students into our undergraduate programs and for recruiting our undergraduates into graduate study.

Recommendation 3.1: First Year Honors Program

The College should establish a first year Honors Program. Students would apply during their senior year in high school, in parallel with their UM application. Acceptance would be based on high school academics and an essay. The first year Honors Program would require students to take some number of accelerated or honors classes (e.g. the applied math honors sequence, honors physics sequence, or accelerated computing class). This program would be a useful recruiting tool to draw the best students to the CoE, and would encourage high achieving students to take the more advanced courses that, for lack of any clear incentive, they all too often avoid at present.

Recommendation 3.2: Upper Class Honors Program

The College should create an Honors Program for second year and upper division students. Application to the program would be for declared students and rely on high UM GPA, and possibly other criteria (e.g. an essay). Continued membership in the program would rely on a high GPA. Students in the program would be advised by a distributed set of departmental Honors advisors who would help students develop Honors Plans that could flexibly include research, project team activities, or completion of appropriate minors, all with high GPA. Other deliverables for the student could include a senior thesis, a published paper or professional conference presentation, or similar milestone. Another possible program element would be to require students to identify a focus field outside their major and do a project/paper that connects it to their major and their career goals. The Office of the Associate Dean for Undergraduate Education could approve these Honors Plans to provide appropriate College-wide uniformity; the James Scholars program at the University of Illinois Urbana-Champaign provides a model for this program (http://jamesscholar.cen.uiuc.edu/).

Recommendation 3.3: Honors Program Office

To support the first year and upper division honors programs, an Honors Program Office must be created, and an honors coordinator must be charged with creating a community of honors students. Building on the EGL Honor Society as a model, and ideally drawing together the disciplinary honors societies across the college, the office will help forge the honors societies into a more unified community. The Honors Program Office can help sponsor seminars, professional development events, social events, community service activities (including coordination of tutoring services provided by honors societies), and coordinate occasional joint events with the LSA Honors Program.

Recommendation 4: Sustainability and Ethics Education

Sustainability has clearly become a core issue for the 21st century engineer, and anyone with a background in quantitative and scientific reasoning must be able to add the systems thinking and value judgments required to assess the impact of an engineered technology. Considerations of sustainability and life-cycle analysis are no longer optional for engineers, and the College needs to provide a rich set of opportunities to students to learn how engineering integrates into broader economic, social and environmental concerns regarding the impacts of technologies. This should include specific outcomes in all undergraduate curricula, and a widely available course that can satisfy those outcomes. Similarly, since at least 1997 the faculty of the college has held that ethics education is important for our students (Undergraduate Curriculum Taskforce 1996), and recent societal issues reinforce this need. We must strengthen this requirement with specific outcomes across all curricula, and with educational opportunities for students to display those outcomes. It is also worth considering how these three themes: professional ethics, the impact of engineering on society, and sustainability can be tied together.

Recommendation 4.1: Sustainability and Connections of Engineering to Society

Each department curriculum should develop substantial specific milestones in sustainability that all students must meet for graduation. These milestones should be reviewed and approved by the College Curriculum Committee. Such milestones could take advantage of a College-wide course, be based on outcomes embedded in departmental courses, or based on courses in other units. Our curricula should also be flexible enough that students can also take courses in Public Policy or SNRE to learn more about environmental considerations.

Objectives for the sustainability requirement could include students gaining understanding of:

- Drivers for sustainability issues: population, water, energy
- Lifecycle analysis
- Systems thinking in the context of technology-environment interaction
- Systems thinking for system energy efficiency
- Economic/energy analysis tools
- The impact of engineering on the world

Recommendation 4.2: Professional Ethics Education

Each department curriculum should develop substantial specific milestones in engineering ethics that all students must meet for graduation. Such milestones could take advantage of stand-alone courses or be based on outcomes embedded in departmental courses. In addition, we should provide students with opportunities outside of class to engage in ethical reasoning: for example Dean's Seminar lectures addressing engineering ethics cases, or student activities with an ethical element and structured discussion. Various student groups, including the College of Engineering Honor Council, could be engaged in elements of these activities.

Objectives in the ethics requirement could include students gaining an understanding of:

- The nature and value of engineering ethics
- Tools of ethical reasoning (identification of stakeholders, ethical conflict, professional, legal and personal codes, risk assessment)

- Case studies of student motivated ethical issues
- Case studies of professionally motivated ethical issues
- The impact of engineering on society, and of society on engineering

Recommendation 4.3: College Ethics and Sustainability Courses

The College should support the development of an elective course in Sustainability for Engineers, perhaps in CEE or the ENGR division, which can be used to meet these sustainability milestones. The College should similarly develop an elective course in Ethics Case Studies for Engineers that introduces ethical case studies in a range of disciplines, provides students the opportunity to discuss the interface of engineering with society, and study important engineering failures and successes from a societal perspective.

Recommendation 4.4: Provision of Teaching Resources

The College should establish a small group of faculty and students to collect materials for distribution on the web to assist departmental implementation of engineering ethics and sustainability education in existing courses. The website would include links to case studies, PowerPoint slides for download, engineering ethics problem bank, suggested exam questions that could be used or modified for ABET outcome direct assessment, etc. Much of this material exists at similar sites throughout the country, and the proposed site could be a gateway to some of these remote sites. This effort might provide an opportunity for student projects. This could also be combined with the online elements of the ETeCC (see 5.1 Engineering Technical Communications Center) and help support a broader set of curricular threads via a College of Engineering Teaching Resources website.

Recommendation 4.5: Curriculum Committee Oversight

The College Curriculum Committee should exercise proactive oversight of all undergraduate programs, and require regular reports on how students engage with ethics and sustainability objectives. For example, the Curriculum Committee could request and review a short assessment from 3 different programs per term on a rolling schedule to review all programs every 5 terms. Program reviews should become a standing Curriculum Committee agenda item.

Recommendation 5: Technical Communications

The College must provide students with improved mechanisms to support technical communications development. Our present Communications Across the Curriculum system has been largely effective but there are significant inconsistencies across departments in the mechanisms used, inconsistencies in the level of support provided, and some of our current practices are difficult to sustain in the face of changing needs. Improvements should include creating an Engineering Technical Communications Center that supports both students and faculty in their work to provide effective technical communications learning for our students.

5.1 Engineering Technical Communications Center

The College should establish an Engineering Technical Communications Center (ETeCC). This center, which should incorporate both physical space and virtual online elements, can house the Program in Technical Communications and support Communications Across the Curriculum efforts by:

1. Providing professional and peer consulting to students, referred by faculty or self-referred, to understand technical communications needs that arise in class assignments or project team activities, develop ideas and support arguments and claims using data, cite sources, revise work at the paragraph and sentence level, develop meaningful visuals to support a claim, and present effectively.
2. Providing student-focused workshops on technical communications, especially for students whose departments do not use fully integrated Communications across the Curriculum courses.
3. Providing faculty with help in incorporating technical communications seamlessly into their courses, and helping them develop techniques for effectively and efficiently providing students with feedback on technical communications.
4. Providing departments with consulting on how to integrate technical communications instruction into their programs.
5. Training departmental instructors (including IAs, GSIs and faculty members) in technical communications instruction and grading through workshops or courses.
6. Providing funding for departments to hire GSIs and IAs to grade the technical communications aspects of reports.
7. Supporting a comprehensive online resource, a Virtual Communications Resource Center for students and faculty to provide instruction on report, poster, and presentation preparation.
8. Providing technical communications instruction for first year engineering courses.
9. Providing a base level technical communications instruction for the Communications Across the Curriculum Program.

To move forward on this recommendation we must define appropriate staffing expertise and staffing level, as well as determine the necessary office and meeting space. The Sweetland Writing Center can provide a comparative model. Through the Center, the Program in Technical Communications should continue to provide a base level of technical communications instruction in departmental curricula, but the appropriate base level must be examined and rationalized. The model of technical communications supported by the ETeCC is meant to provide some capacity building in technical communication education across the college. It will leverage our technical communications faculty move effectively by moving away from the expectation that they must do all technical communications instruction, while providing training for others—faculty, GSIs and even student peers—to provide communications instruction and feedback.

5.2 Departmental Feedback on Technical Communications

For departments with integrated Communications Across the Curriculum, we must develop an annual review system by which departments can provide feedback on both the overall program and on specific technical communications faculty. This feedback should include an annual report and discussion on the success of the program between a technical communications faculty member assigned as the primary liaison to each department and departmental faculty appointed for the purpose of this review (curriculum committee chairs, or undergraduate program advisors are obvious departmental representatives). In addition, the hiring of technical communications faculty should be undertaken in open searches with departmental representatives on search committees.

5.3 Introductory Course for Transfer Students

The College, through the ETeCC, should develop an elective course for transfer students to learn technical communications. This course was identified as a need by the Technical Communications internal review. In addition, transfer student groups, especially international students, have specifically requested this course. Objectives for such a course might touch on teamwork and introductory professional ethics.

Recommendation 6: Curricular Changes to Support Flexibility

Our students deserve time in their curricula to explore their own interests and to find connections that we perhaps cannot even imagine of other fields to their engineering studies. Our students grow greatly through their non-engineering work, be it from Marching Band or Habitat for Humanity, from Piano Performance or Project SERVE. Our curriculum must leave space for these important educational opportunities. At the same time, we must provide incentives and help for our students to make good choices within their formal curriculum. We make the following set of recommendations to serve these goals.

Recommendation 6.1: Flexible Common Math and Science Core

All College of Engineering students should master core material in calculus, linear algebra, and differential equations, physics, and chemistry. The core material should be defined by its educational objectives and outcomes, not by a specific number of credit hours or specific set of courses. Sets of courses can then be identified that meet the core requirements, and all programs must accept a Curriculum Committee approved standard set of courses that provide the common math and science core. However, the standard sequence can be made more flexible by allowing those students who have declared a major degree program to substitute for standard core classes other appropriate mathematics and science classes, subject to Curriculum Committee approval. This will give students an opportunity to optimize their basic core selections, and provide an incentive for students to declare a program. Because all programs must accept the standard sequence, following the standard sequence will never disadvantage a student. A declared student who has taken approved non-standard selections but wishes to switch to a different major, can take either the standard core course selections or the specific alternatives appropriate for their new major (or their new major department can allow the non-standard selections they may have already completed).

At present, these core requirements can be met by a standard sequence for all programs, comprising Math 115, 116, 215, 216, Chemistry 125/126 and 130, and Physics 140, 141, 240, 241, a total of 31 credits, or approved substitutes (e.g. applied Math sequence). Math 214 already constitutes an example of a flexible alternative to Math 216 for IOE students.

Recommendation 6.2: Intellectual Breadth

It is important that our students learn about modes of thought and areas of human accomplishment beyond the technical. This breadth can be designed by the student to provide context to their engineering work by learning about human modes of thought, the structure and history of the human societies that they serve as engineers, how humans think, and what human aspirations are in the arts, literature and music. This breadth makes our students more flexible and better able to work with diverse groups and has been endorsed by our alumni and the employers of our students. Students also need the opportunity to develop breadth in understanding of business, or in knowledge of public policy, or in natural resources. We cannot precisely define all of these possibilities for every student so we should create the opportunity for students to pursue their own interests, both beyond and within engineering.

Our curriculum should contain a Flexible Block of electives designed to allow students to have some freedom in selecting both non-technical and technical classes that address their own interests, independent of the specific demands of their undergraduate degree. These classes must in part be from outside the College of Engineering (including cross listing), and must in part be from Humanities and Social Science subjects. Minimum numbers of classes meeting certain criteria are required, however, precise numbers of classes are not specified.

All CoE undergraduate Bachelors curricula should contain a block of 28 credit hours of electives with the following characteristics:

1. *At least 12 credits must be taken from LSA units, excepting courses in mathematics or physical science. At least 3 of these credits must be from upper division LSA courses. At least 6 of the 12 LSA credit hours must be taken from classes that satisfy the LSA HU/SS distribution requirement.*
2. *At least 4 additional credit hours must be from courses outside the College of Engineering (Art & Design, Business, LSA, Public Policy, SNRE, etc.)*
3. *The remaining 12 credit hours may be from any field, subject to the General Electives restrictions set by the College Curriculum Committee.*

This block of electives would replace the existing HU/SS requirement (16 credit hours) and the existing General Electives requirement (set at 12 credits hours in Curriculum 2000). The purpose for requiring classes from outside the College of Engineering is to ensure that our students learn something about the modes of thought of those in other disciplines, and learn the ways in which those in other fields approach the definition and understanding of problems. The purpose for requiring classes in LSA that include HU/SS distribution courses is to ensure that engineers learn something of the modes of human social organization, human communication, how humans think and the ways in which we communicate. However, we avoid the current practice of trying to classify all LSA courses into HU or SS.

With this structure our students would have room to complete most minors in LSA as well as the International Engineering Minor. Supported with strong advising, this could help our students find focus to their non-technical education. In addition, with 12 credits of general electives most of our students could complete the Multidisciplinary Design minor using only one of their technical electives (to meet the 15 required credits), or to complete the Entrepreneurship Program (9 hours) using courses in business. With 12 general electives and 4 additional non-CoE courses students can complete a Minor in Art & Design.

Recommendation 6.3: Modifications to the Undeclared First Year

Undergraduate students entering the College as first year students should continue to enter the college without declaring a specific engineering major. A student should have at least one full-time term (12 credit hours) at Michigan and be in good standing in order to declare a major. This should be augmented by a program that urges all students to declare a major by the end of their second term in the College, and a ***requirement*** that a student cannot register for a 4^{th} term in the College unless they have declared a department or a waiver has been granted by the Associate Dean for Undergraduate Education; such waivers will require a plan on the part of the student to select and be admitted to a major within a reasonable time. This requirement is defined by the number of terms a student has been at Michigan, not by a number of credit hours; the current 55 credit hour barrier will be eliminated. Transfer students should continue to enter specific departmental programs as they do now.

Recommendation 6.4: Retire the 4x4x8 Model

The 4x4x8 model was never fully implemented and has already been abandoned in practice. We recommend that the departmental and College Curriculum Committees not use this model in devising curricula but rather design the credit hour content of classes as merited by the content and workload of the course. However, programs must give appropriate attention to the time required for their students to complete their degrees. One effect of the 4x4x8 model was the recognition that some courses were too packed with content for the credit hours awarded, and expanding those courses to 4 credits without increasing content was warranted. This gain should not be lost. Workloads of courses should be carefully considered in designing departmental and college curriculum requirements. Generally speaking, averaged over the classes of a students' program, one hour of class credit should imply 3 hours of work for a typical student outside class contact time. We expect our students to be very active outside the classroom, and we cannot over-structure or over-pack their curricula without endangering this important extracurricular development.

Recommendation 6.5: Advising

Flexibility in our undergraduate curriculum requires good undergraduate advising. The College should undertake a systematic improvement in advising, involving both faculty and staff in the process. Our current advising system focuses too much on helping students navigate rules and not enough on helping students develop as future professionals. We have artificially separated advising from education by making it the province of staff and a few faculty members. On average each of our 340 faculty members would only need mentor 15 students each to provide students with more meaningful contact with engineering professionals outside the classroom. Systematic improvements should include workshops to better inform faculty and staff advisors about student development, the curriculum, and the engineering profession. There should also be a commitment from departments to engage more of their faculty time in advising (either more faculty doing advising or greater time commitments by a few dedicated faculty), and this commitment should include frequent reviews of effectiveness and student satisfaction so that advisors can learn to improve their approaches. Departments should include the quality (or lack of quality) of a faculty member's advising of undergraduate students in annual faculty reviews.

Recommendation 7: Interdisciplinary Programs

The interdisciplinary BS program currently lacks faculty direction, and students pursuing this program sometimes have difficulty getting the classes they need because of barriers erected by departments (for example, against non-majors taking a design class). However, the program does provide an important pathway to an engineering degree for a handful of students who find they cannot follow the existing pathways. In addition, because of the great flexibility of the program it provides a place in which to try innovative new curricula; this seems to be an underdeveloped potential for the program. The College should ensure that there is faculty leadership of the Interdisciplinary Engineering program.

Recommendation 8: Undergraduate Educational Objectives

The current educational mission and objectives of the college appear online at http://www.engin.umich.edu/students/bulletin/uged/index.html. These should be augmented, to read:

A UM undergraduate engineering graduate will be prepared to generate value for society through a lifetime of technical and professional creativity. Our graduates will display reasoning skills developed through problem definition, problem solving, quantitative expertise, a respect for measurement and data, and the wisdom of experience. Our graduates will use these reasoning skills to:

- *Contribute in entry-level technical engineering practice*
- *Pursue graduate education in engineering, either following a path towards a professional masters degree and practice, or a doctoral degree*
- *Pursue careers in law, medicine, education, or other fields, bringing engineering problem solving skills—honed through practice in problem definition and quantitative problem solving—to bear in those disciplines*

Michigan Engineers will grow into leaders in all of these areas of endeavor and will be able to develop into successful managers, leaders, entrepreneurs, and philanthropists.

Additional Resources Needed for the Michigan Engineer of 2020

In addition to the resources identified with each actionable recommendation above, the Commission identified a few general areas in College planning, resources and infrastructure that need attention:

1. Develop more meaningful metrics for evaluation of teaching effectiveness, and use these metrics in annual evaluation, and promotion and tenure decisions.
2. Encourage greater openness in sharing of class materials, including making Ctools sites open to all faculty across the college.
3. Update existing classrooms to support active learning by providing movable furniture, arrangements for small group interactions, and copious whiteboard space for brainstorming.
4. Ensure that all new classrooms are designed with flexibility in mind, and that a wide group of faculty with different teaching styles review new classroom plans.
5. Explore the balance and placement of projection and whiteboards (or blackboards) in classrooms.
6. Make laboratory and fabrication facilities more accessible for wider student use.

Conclusion and Implementation

The key to the future of our undergraduate engineering educational programs is the increased used of authentic experiences in which students can practice the skills of creative and critical thinking, problem identification and definition, dealing with ambiguity and scarce resources, and understanding the impacts of their work on society. Hands-on work, design with prototyping, and the use of open-ended and project based learning can all provide these experiences. Through such experiences they can experience working with a client, and they can learn what it means to make a difference. Likewise they must come to understand the interaction between engineering and society, and how engineering can creates both value and unintended impacts. Through all of this, our will become better motivated to continue their engineering academics and to pursue professional practice.

The College should start a wider conversation with all our faculty members to engage them in identifying the most important next steps to achieve this end. Our 8 actionable recommendations should receive attention from the college faculty, the college executive committee, and the college leadership to identify necessary resources and devise changes in resource priorities. The commitment will require focus for several years to bring about the change in culture that is required to increase the focus on professional practice within our curriculum and to drive pedagogy by scholarship and data.

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Appendix

Charge to the Commission on Undergraduate Engineering Education: Curriculum for the 21st Century

As the College of Engineering moves forward we must re-examine our core and disciplinary curricula with an eye towards preparing our students for the challenges of the new century. As we do so, we must be cognizant of their aspirations – be it as future engineers, lawyers, entrepreneurs, business persons, social activists, graduate researchers, or one of a host of other career paths. We should contemplate our commitment to curricular and pedagogical innovation, and to providing our students with a multidisciplinary education suited to the flat-world in which they will live and to which they will contribute.

Within this context, the Commission on Undergraduate Engineering Education is charged to study and make recommendations on the future of our undergraduate curriculum. While the recommendations should be forward-looking, they should, where appropriate, reflect on previous curricular initiatives (e.g. Curriculum 2000) and also on the practical realities of resources and university structure.

The committee will have a draft report by April 2009, to be presented to the College External Advisory Committee at the April 17th 2009 meeting.

Specific Charge:

The Commission report should address the following questions:

1. What is the central goal of an undergraduate engineering education in the early 21st century?
    a. What will distinguish a Michigan engineering graduate in the 21st century from her fellows from other universities, or from the graduates of the past?
    b. What are the design characteristics of the curricula that will prepare our students for the industries and jobs of the future?
        i. What is the appropriate balance between discipline specific engineering career preparation and the construction of a foundation for multiple career paths involving quantitative problem solving and life-long learning?
        ii. What is the proper balance between undergraduate breadth and flexibility, undergraduate specialization, and masters degree specialization?
2. To support the central goal defined in Question 1, what should be the common core curriculum for our programs, and how can the core be

structured to support flexibility for our students and their varied aspirations?

a. What should the key elements of this core curriculum be?

    i. Can the core be structured to allow flexibility as students declare their programs at the end of their first year, and how can curricular structure encourage this declaration to happen?

    ii. Can biology be required or at least available in a flexible core?

    iii. Should we require or encourage the applied math calculus sequence to strengthen the math component of the core?

b. Should we develop our students' opportunities to learn about the interaction of engineering and society, including issues of:

    i. Sustainability and life-cycle analysis.

    ii. How global change impacts engineering & engineering impacts global change.

    iii. Globalization of engineering services

    iv. The role of multidisciplinary teams and multicultural communications.

c. The current core includes Math (16 credits), Physics (10), Chemistry (3-5), Engineering (8) , HU/SS (16), and general electives (8-18). What is the proper breakdown of credit hours in a college core between science, math and engineering, general electives, HU/SS, and specific disciplinary (departmental) requirements?

d. How can technical communication best be learned?

    i. What are the best practices across the college, and can these best practices be shared across departments?

    ii. Should we develop separate courses, or encourage integrated technical communication instruction in disciplinary courses?

    iii. Are there structural issues that should be addressed, including accountability, financial structures, or program organization?

    iv. What is the future of the Program in Technical Communication?

e. How should opportunities to learn professional ethics be structured in our curricula?

   i. Should this be done through a cross-departmental course (perhaps with LSA)?

   ii. Should we develop case-study modules for use in disciplinary courses?

   iii. Should professional ethics be tied with our students' learning about the interaction of engineering with society?

3. What is the role of interdisciplinary learning experiences for our students' education, and how should these be supported?

   a. Can or should the disciplinary curricula be structured to allow flexibility for students to more easily pursue cross-disciplinary programs?

   b. What is the future of the existing B.S. in Interdisciplinary Engineering?

   c. How should we support, intellectually and in the provision of resources, cross-disciplinary programs such as the International Minor or Multidisciplinary Design Minor? What is the proper role for the College departments in supporting such programs?

4. Should the college develop a research-focused honors program, perhaps culminating in a senior thesis or research project, to support and recruit future graduate students?

5. How should the College ensure the creation of further curricular and pedagogical innovations to support our educational goals?

   a. Are there new course formats with which we should experiment or support, such as short courses, online courses, project based courses, and self-paced courses?

   b. What do we know about how our students learn, and how should this reflect in our curricular design and in our pedagogy?

   c. With what new technologies for learning should we provision our facilities?

6. What are the structural, cultural, personnel and resource issues that must be addressed to make real the vision that the commission develops?

Data Sources: The commission should make use of existing data and literature wherever possible. The commission will have access to College accessible databases, and to senior and alumni survey data. Departmental data already collected for curricular review should also be reviewed when appropriate. Existing reports from NAE, ASEE and other sources on the future of engineering education should be reviewed. The commission should consult with or survey students, staff from the Office of Recruiting and Admissions, Engineering Advising Center, International Programs in Engineering, Center for Entrepreneurship, and other appropriate departmental, college and university offices. The commission should consult with industrial advisory boards and others who hire our students, including the ECRC industrial advisory board. Appropriate benchmarking of other schools might also be undertaken.

Commission Approach: The commission members should quickly draft "strawman" answers to the questions above as a means to generate discussion and identify necessary data to support recommendations. Through a series of in-person and virtual discussions, and through review of appropriate data focused on these initial ideas, the commission should move towards consensus on the answers and the recommendations that the answers imply.

We anticipate 10 meetings of 90 minutes duration spanning October 2008 – April 2009.