Executive Summary: Michigan Engineering 2020

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

Joseph Bull, BME
Amy Cohn, IOE
Dale Karr, NAME
Michael Hartman, NERS
James Paul Holloway, ADUE & Commission Chair
Gregory Hulbert, ME
Susan Montgomery, CHE
Brian Noble, CSE
Kenneth Powell, AERO
Aaron Ridley, AOSS
Fred Terry, ECE
Steven Wright, CEE
Steven Yalisove, MSE

University of Michigan – College of Engineering

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Cover

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

Full Report

This is the executive summary of the report of the Commission on Undergraduate Engineering Education, a report on the state of the College of Engineering undergraduate curriculum as of 2009, and a set of design principles and recommendations for the future. The full report can be found at <<<url will go here>>>.

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 4th 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.