The Engineering Minor: Two Cases and an Analysis

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The structure of our colleges and universities has made it difficult for students not majoring in engineering to enroll in engineering courses on their own campus, no less to develop any *depth of understanding* about engineering and technology. The engineering major rests on a structured curriculum, requiring substantial prerequisite courses, and because of the number of credit hours required for the BSE, is difficult to combine with another field of study. Yet, there is an agreed-upon need for engineering literacy outside the field. Although the "E" in STEM was meant to incorporate engineering, the fact remains that students who do not major in science or mathematics and many who *do* have no exposure to engineering and are, as a result, unprepared to make informed decisions about such issues as the condition of the nation's infrastructure, fossil fuel alternatives, and appropriate regulation of nanotechnology.

It is for this reason that some college educators are coming to the conclusion that a college *minor in engineering* might provide the intellectually coherent program undergraduates not in engineering need to gain a practical and meaningful degree of technological literacy. Such minors would not develop design-level engineering skills, but rather the general competencies advocated by the National Academy of Engineering in such documents as *Technically Speaking* [1] and *Tech Tally* [2].

This review of efforts to develop minors in engineering will focus on Iowa State University's Minor in Engineering Studies (MES) and the Minor in Engineering Sciences at The Ohio State University. Although the program at Iowa State has been temporarily discontinued, faculty at the two institutions have begun to carve out the kinds of steps in stone that a movement to launch engineering minors on a larger scale can build on. The potential demand is, the authors believe, significant because in addition to advancing a student's technological literacy, a minor provides a transcript designation, which will count as a *credit* if not a *credential* for graduates entering an ever more technical job market.

While the development of a minor entails a considerable scope of effort, in 2006 Iowa State University established one possible model from which a number of Minors in Engineering Studies have graduated, who could with some effort be tracked and queried. Ohio State's Engineering Minor, which began in 2009, currently enrolls 60-70 students who start with the first two engineering courses required for the major, then a mid-level engineering course, a Technology and Society option, followed by a two-semester Capstone course (see *infra* for more details.)

Minor in Engineering Studies (MES) at Iowa State University

The Minor in Engineering Studies (MES) Program at Iowa State University (2006-2011) may have been the first engineering minor in the nation to be designed, implemented, and delivered by an engineering college. But until there are more adoptions, we will not know. What we do know is that the program was conceived in 2005 when the then Dean of Engineering, Mark Kushner, voiced his concern that leaders in the private and public sectors were making decisions, uninformed by the expertise of engineers, and the converse: too few trained engineers were in policy-

making positions. To contribute to a remedy, that same year Kushner proposed an Engineering Leadership Program that would provide a reciprocal give-and-take: engineers to be informed about policy issues; future government and business leaders to be informed about – as has been defined in this collection of case studies – what engineers do and how they think about what they do. Kushner's first effort was supported with a grant from the 3M company.

From 2005 to 2008, Dean Kushner worked in addition to establish and support a minor in Engineering Studies at ISU, enabled in part by two grants from the National Science Foundation, (see below) one for the training of future faculty, one to support the development of a conceptual framework for the MES. The lead team included Mani Mina, named director of Minors in Engineering Studies, together with Diane Rover, Associate Dean of Engineering and Mack Shelley from the Department of Statistics and Political Science. Developments at ISU were favored by an evolution of NSF's position on the subject of Minors.

The Role of the NSF

In 2007, the National Science Board in a directive to the National Science Foundation recommended that Colleges of Engineering should "…consider offering engineering courses to non-engineers." (*Moving Forward to Improve Engineering Education,* NSB-07-122). One year later, in 2008, the Foundation's Division of Undergraduate Education (DUE) made this goal operational, with the establishment of a specific funding program to support Course, Curriculum, and Laboratory Improvement (CCLI) "…to improve the quality of science, technology, engineering, and mathematics (STEM) education for *all* undergraduate students" (NSF 08-546).

Iowa State applied for and received two CCLI awards, both of which were applied to the MES program, the second in conjunction with faculty from other institutions also considering options for non-engineering students.

> Award 0837314 Creating Effective Future Faculty in Engineering, only to ISU
> Award 0920154 Expanding Technological Literacy through Engineering Minors jointly to Mani Mina at IU, Robert Gustafson at Ohio State, James Young, at Rice, and John Krupczak at Hope College

The second award expressly supported the development of a *conceptual framework* for an engineering minor including: *learning outcomes*, determining perceptions on the part of non-engineering students and industry of *the value of an engineering minor,* and *assessment of the potential on the part of non-engineers to acquire engineering skills***,** all essential to the foundation and eventual assessment of any Engineering Minor.

The Launch of the MES at Iowa State

By the time Dean Kushner left Iowa State for Michigan in 2008, there had been enough groundwork done for Mani Mina and a number of engineering faculty to launch a three-course Minor in Engineering Studies at Iowa State. The following courses were created and presented as a sequence.

Eng. 260 *From Thoughts to Things* in lecture form
Eng. 270 *How Things Work* in seminar form
Eng. 265 *Impact of Engineering Activities*

Course materials corresponded to the topics. Eng. 260, "From Thoughts to Things" assigned Henry Petroski's book with the same title as a text. Eng. 270 allowed participating students to choose their own topics to research and for class discussion. Meanwhile, students in Eng. 265 were introduced to historical writing about impacts of technological change. Some years, Eng. 265 would focus on the political/technical impact of the shift from incandescent to fluorescent lights; other years, nuclear waste. In one course, several seminar members weighed in on a local case, having to do with a drainage emergency on their own campus. Students discovered on their own the truth that had originally launched Dean Kushner's Engineering Leadership Seminar, namely that if they were to have an impact on policy they would have to educate a broader public than is usually engaged,to counter lobbying from vested interests. Graduates of the program were not formally tracked, but one is known to have gone on to a graduate program in energy policy. Class size ranged between 5 and 10; by 2009-2010, there were 17-21 registered in the courses, some effectively taking the minor even when undeclared.

To complete the minor, MES students were required to take an *additional six* credits of junior- or senior-level classes from an approved course list. The approved classes, offered by different faculty, had to do with understanding technology, technological development, and social, ethical, and environmental aspects of technology. The remainder of the twenty-one credits required to complete the minor, could be filled from an approved course list.

A possible recruitment arena for the Iowa State's MES, as will be occurring elsewhere once engineering minors are launched, might have been science majors. Without especially targeting science majors, the program did attract some who intended to enroll in graduate programs in engineering-related areas. But, instead of fashioning the minor to appeal to science majors, the MES faculty focused on an overall commitment to attract and engage *non majors*. This was accomplished by requiring (as ISU does for all its minor programs), that the courses have *no prerequisites* other than a high school degree (including basic college algebra). To complete the minor, however, students had to meet a 21-semester credit requirement, of which nine were the three introductory classes.

By 2011, Eng. 260 and Eng. 270 were regularly enrolling 35 students. But while the new Dean may have agreed on the *principle* of an engineering minor, he had different priorities. There followed an energetic debate that year as to the future of the MES. While many in the Engineering College continued to support it, the program was given a year to wrap up. Rather than lose the students or the courses, already on the books, the Department voted to convert the Engineering Studies Minor to an Engineering College-wide offering, even though half the enrollees would not be engineers.

One ancillary benefit from the four years that MES had been on the books, was that for the first time engineering and non-engineering students were sharing classes and the faculty members who taught them were surprised to discover how little they had to modify these classes to serve non-majors. Simply by assessing non-engineering

students by means of separate tests and not requiring them to do the more advanced assignments, non-engineers were being accommodated. The faculty then persuaded other colleagues as well to assign tasks that tested concepts over technical rigor. Graduate students helping to design learning modules, presentations and activities at a nontechnical level, were converted as well. A contributing factor might have been a growing awareness by the College of Engineering that teaching non engineering students, who might be future decision makers is essential to engineering as a profession. But this can only be inferred. ,

In time, two of the MES classes, ENG 260 *From Thoughts to Things* and ENG 270 *How Things Work* found another home. They were integrated into a newly constituted program in ISU's Design College, named Industrial Design. The courses are highly subscribed and the Industrial Design Program, which was new in 2011, today enrolls 60-80 students (2015-16). The success of this single integration leaves some of the initial MES faculty wondering whether the MES might have survived had more faculty *outside* Engineering known about and recommended the minor to their own undergraduate majors.

Finally, one is tempted to assess the likelihood of reinstating a Minor in Engineering Studies program at ISU. There is no question that a need on the part of students and demand on the part of employers is growing. Some believe the next iteration of a minor in engineering studies should be initiated by collaboration of departments within and outside of the College of Engineering. Timing might be right. ISU currently has courses and programs in the arena of computer security. With the 2015 Paris agreement on the need to deal with climate change, and increasing geopolitical conflict over resources, the problems and the issues are becoming the fabric of the everyday lives of a new generation of students. There is already a faculty-wide collaboration on climate change.

The Engineering Science Minor at Ohio State University

Two wide-ranging reviews of general education at The Ohio State University over the past decade brought forth an agreed-upon need for technological literacy as an "insight area" within general education. In December 2006, within the College of Engineering, three College committees (the Core Curriculum, the College Services Committee, and the College Committee on Academic Affairs) established a joint six-member task force to consider what the College of Engineering could offer in terms of *one or more minors*, with particular focus on the area of technological literacy. The task force members consulted several of the other OSU colleges with potential student interest (Business; Food, Agriculture and Environmental Sciences, Education and Human Ecology; and Colleges of Arts and Sciences), primarily through College advisers and administrative representatives. Feedback was positive overall especially as regards to minors leading in March of 2007 to the recommendation that two new minors be developed, one in Engineering Studies, the other in Technology Studies.

The Technology Studies Minor was launched but didn't seem to attract any interest from the students. The Engineering Sciences Minor, however, flourishes as an offering of the Department of Engineering Education. Lisa Abrams, a long-time member of the Engineering faculty and Associate Chair of the new Department, is involved both in managing the Engineering Sciences Minor, and in advising students who are or who

might want to enroll. Thus, she is well positioned to describe the Minor and, since she talks regularly to students about the minor, to account for increasing student interest.

Construct for Engineering Sciences Minor at Ohio State.

	Engineering Sciences Minor
Key Audience	Students who have an interest in working with technology experts/engineers and in technology based industry/environments. *Examples:* Business, Economics, Science, and Math majors *Assumptions:* Competence in mathematics through beginning concepts of calculus
Learning Goals—At the completion of the minor, students will be able to:	1—demonstrate a basic understanding of the engineering design process
	2—perform simple analysis and estimation using engineering methodology
	3—understand the capabilities and limitations of basic manufacturing processes and engineered systems
	4—make informed decisions about the desirability of engineering activities by weighing the benefits of those activities against the risks
	5—work effectively as a member of a team including technological experts
Key curriculum components—Model Curriculum	Understand fundamentals of engineering science and design (beginning calculus prerequisite)

	• Introduction to Engineering
	  o Design process
	  o Communication with graphics tools
	• Science base and complimentary engineering science base
	• Appreciation of interaction of technology and society
	• Capstone interdisciplinary teamwork experience

Contents, Pedagogy, and Outcomes

As presently designed, the Engineering Sciences Minor requires students, whatever their major, to begin with the first two courses all engineering students take followed by a mid-level engineering course from any/all of the engineering fields. Rounding out a total of six semester courses is a required Technology and Society option and a two-semester Capstone course designed to enable engineering majors and engineering sciences minors to work together. The Capstone (see Appendix for more details about the Capstone) enables students to work on a specific project with an outside client. The tasks include: defining the scope of the project; modeling the decision process, and, in the second semester, implementing or building the project.

One key to its relevance and popularity, according to Lisa Abrams, is that students in the Engineering Minor are studying together with seniors working toward their BSE's. The argument for joint enrollment is that graduate engineers *often* have to work with clients who do not have a full engineering background.

Students who select the Engineering Minor include the following majors: economics, psychology, zoology, business, journalism, sports management. But since the courses they take are in the College of Engineering, Lisa Abrams' challenge and that of the faculty is to give them projects to match their interest. The Capstone course (see Appendix) is especially popular with both populations and with the faculty who teach it. The faculty, Lisa Abrams reports, especially like the diversity and multi-disciplinarity of their students in the Capstone courses.

The Engineering Minor is not widely advertised and was expected to be and to remain small in number of applicants. But even without advertising (beyond the program's web site), 60-70 students regularly find the program on their own. On the record, Lisa Abrams says, "We could push our engineering science minor if we had the bandwidth. The minor is already bursting at the seams." But untila new PhD in Engineering Education is thoroughly launched which will take a few more years, she doesn't see room for significant expansion for the Engineering Minor at Ohio State, in spite of steady demand.

Other Opportunities at OSU

In addition to the Engineering Sciences Minor, OSU offers an Integrated Business and Engineering (IBE) Honors Program, run by Peter Rogers, a professor of practice in the Engineering Education Center who arrived at OSU eight years ago from a long career in industry. Modeled on a program at Lehigh, IBE is a hotly competitive all-Honors program that enrolls 2/3 engineering, 1/3 business students. Business majors earn a minor degree in engineering science. Engineering majors earn a minor degree in business..

At any one time, there are 120 students enrolled in the IBE program, two-thirds from engineering, one-third from business. But unlike the capstone experience for the engineering studies minors, IBE students study together for all four years and conclude their program with an Honors Capstone Course with company-sponsored projects involving product and marketing development. The program introduces students to business protocols early. They get business cards upon arrival freshman year and early in the program experience internship opportunities in their areas of interest. The program

is oversubscribed by high-achieving students in the top 5% of their high school classes having multiple AP credits. Notable is that there is higher than expected interest from women students, currently, 25% but growing, if Peter Rogers has his way, to 33% or higher.

Professor Rogers also runs the Social innovation and Commercialization (SIAC) program, which pulls together engineers, business students, designers, occupational therapists, and speech and hearing students, to create commercial products for people with disabilities.

In addition to these formal programs, Ohio State University has three general Education courses open to non engineering students.

> History of Ancient Engineering, taught by Fabian Tan, a faculty member in civil engineering, which counts as fulfilling a general education requirement for all students .Yet, as a rule, 70% of the enrollees are from engineering; 30% other..
>
> History of American Technology, taught by Ed McCaul, who holds a dual PhD in engineering and history. This course attracts approximately 60% engineering, 40% other.
>
> American Attitudes about Technology, taught by multiple faculty out of Engineering Education and featuring instruction in technical writing. The course attracts the largest number of enrollees in 20 sections of 36 students each. Coordinator is Mary Faure.

"Weaving liberal arts and engineering together," concludes Lisa Abrams, "makes good business sense." From her perspective,

> Engineering problem solving provides tools that are useful no matter what you do; important everywhere. A minor with the engineering spin on it will enable graduates to *lead* their community in an engineering environment. Technical writing, by itself, has value in a range of environments.

Assessing the Engineering Minor: Checking in with Employers

Supported by a 2009 NSF Award 0920154 Expanding Technological Literacy through Engineering Minors, two of the authors of this Case Study, Mina and Krupczak, conducted a survey in 2010-2012 of a selected group of employers to measure their perception of the desirability of an engineering minor. Results were illuminating.

Employers rated the following engineering-related skills as most useful for non-engineers working in technological industries:

- Function effectively on teams with varying technological expertise.
- Communicate effectively, both orally and in writing, regarding technological issues.
- Define basic engineering concepts and terms, such as systems, constraints, and trade-offs.

- Discriminate the role of problem-solving for troubleshooting, invention, innovation, research and development.
- Think critically and creatively regarding technological issues including an ability to assess, rank, or to compare proposed designs on the basis of the desired outcomes, consequences, and constraints.
- Describe the development and use of technology and evaluate trade-offs including a balance of costs and benefits--both economic and social.

The employer survey also exposed concerns on the part of employers. While most employers valued the engineering-savvy non-engineer, others voiced concern about having a "half-trained" non-engineer assuming engineering duties.

> A typical Endorsement:
> *"Non-engineers with the ability to understand a discussion of a technical nature and have a sense of the relative advantages, disadvantages, benefits, and risks would be extremely useful to any organization that does any amount of engineering work."*
>
> A typical Concern:
> *"…a minor in engineering would be similar to being a 1/2 engineer. It can be very dangerous to an organization if someone has a little engineering background and the organization is using their limited knowledge to make decisions."*

Conclusion

Engineering minors represents one of several approaches to achieving engineering-enhanced liberal education. Minors make possible some depth of understanding of the complex socio-technical issues with which we all grapple. As we have documented in the review of Iowa State's and Ohio State's efforts in this direction, there is flexibility in the structure and format of a minor which enables adaptation to local institutional circumstances and individual faculty expertise and interests. Key course archetypes exists in the form of survey courses, courses focused on specific technological topics, technology and society courses, and design courses open to non-engineers. Joint programs such as the IBE at Ohio State, as well as minors in engineering studies, provide a credential that accommodates today's and tomorrow's students, and at the same time, provides them with a competitive edge in the job market. Engineering minors may be (as engineers are wont to say), "the optimal solution meeting the needs of diverse customers, using the resources available, under existing constraints.

References

1. Pearson, Greg, and A. Thomas Young, eds. *Technically Speaking: Why All Americans Need to Know More About Technology*. National Academies Press, 2002.
2. Gamire, Elsa, and Greg Pearson. *Tech Tally: Approaches to Assessing Technological Literacy*. National Academies Press, 2006.
3. Mani Mina, Diane T. Rover and Mack Shelley "Work In Progress - Preparation Creating Effective Faculty Of Engineering: A Technological Literacy Approach," *Proceedings of the 41st IEEE Frontiers in Education Conference*, Rapid City, SD, October, 2011.

Appendix

OSU's Capstone Course for Majors/Minors

A two-semester Capstone course for senior engineering students has become very popular in the last two decades. Because the typical Capstone is project oriented, students often have to work at the boundaries of two or more disciplines, which means that they – the projects and in some cases the students – tend to be multidisciplinary. Also students are "working for" a wide variety of for-profit and non-profit ventures.

The OSU Capstone, managed by Professor Robert Rhoads with participation of other engineering faculty, is more interdisciplinary than most, given that 1/3 of any Capstone class are from business, communication, neuroscience and other bio specialties, even psychology. Thus, students are somewhat harder to match up than when Capstone courses (in other universities) are only for engineering majors. An engineering student in an OSU Capstone class has to justify his or her recommended solution not only to his/her peers but to a food-science major or a psychologist.

As with the more typical Capstone courses, project topics are scoped out with a participating company prior to the students coming into the course. Since the "problem" is often not well defined, problem definition is Phase 1 and delivery of findings and eventually of a solution, to the sponsoring company, ongoing. At OSU, student teams stay in close contact with the project sponsor – by means of weekly teleconferences . Also students are required to make two team-prepared presentations per semester.

The OSU Capstone course typically enrolls 100-120 students in multiple sections. Following is a sample of 2015-16 Capstone Projects for the teams.

- Elastomers for HTHP Applications Phase III
- In-Home Patient Monitor
- Friction Tester for (Winter) Traction Model Development Phase II
- Tabletop Room Cooler Modular Components for a Dormitory Refrigerator
- Bumper Painting Electrical Grounding
- Specifications of Fuel Cell System for VOC Reclamation Onsite
- Torque Vectoring Project
- Tractor Speed Sensor
- Tube Feeding Infusion Pump
- Golf Driver
- SpaceX Hyperloop Competition
- Offshore Subsea Piping Experiment & Test Module Phase II
- Toy Adoption