

AC 2010-1980: CURRICULAR DESIGN FOR 21ST CENTURY ENGINEERING MANAGEMENT: NEED, DESIGN CONSIDERATIONS, AND IMPLEMENTATION

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Abstract

The **Journal of Engineering Education**, in a special 2005 issue subtitled *The art and science of engineering education research*, emphasized a recommendation drawn from the National Academy of Engineering report **The Engineer of 2020**: “engineering education should be revitalized to anticipate changes in technology and society, rather than lagging behind them.” Structural change does not come easily even to a profession that sees new technologies displace old ones on an ongoing basis. To maintain the historically competitive advantage of the engineering workforce in the United States, our undergraduate engineering programs must have the ability to *change* to meet societal need.

In the College of Engineering, Michigan State University we are developing an agile engineering education program that builds on the foundations of physical and social sciences, business and the humanities. Building on these pillars, a student develops career-oriented knowledge and skills in a student-selected satellite cognate. Our program design balances between technical depth and breadth. Further, it allows rapid evolution of the set of topics for advanced studies to complete the undergraduate degree.

In this report we discuss the general background leading to our approach, the current state of our program, and the specifics of our new program. Although not a traditional “engineering management” program, we believe our approach will lead to an academic program that will develop productive engineering managers. The emphasis in this paper is on the *need* for the type of program we have designed, and on the *specifics of our implementation* for meeting the perceived need. In subsequent papers we will report on results from our experience with our new program. We will describe in a forthcoming paper on the process we followed in developing our design for curricular program changes.

Our program is not a traditional Engineering Management (EM) program. Nor do we intend to seek accreditation as an EM program. As described in more detail below, our program consists of a core of standard engineering mathematics and science, a carefully selected, interdisciplinary cross section of engineering courses, a core of business courses, and a finishing depth area that is student selected from four AES concentrations. Our program model may not be the norm in EM programs today. We believe however that our design may be a viable alternative to developing effective managers in engineering firms. This distinction - between conforming to current models is the EM area and developing a alternative model to develop managers for the technical/ engineering workplace - is important to keep in mind as the reader puts our approach into the broader context of engineering programs, and specifically into the context of Engineering Management programs.

Introduction: Importance of Ability to Change in Engineering Education

The global environment is changing rapidly. The pace of change is causing dislocations in some arenas, and a growing awareness that change is now the norm. And the pace of change will likely quicken. The importance of adaptability in the face of increasingly rapid change is no where more evident than in the widening mismatch between the methods and goals of the nation's colleges of engineering and the societal and corporate needs for graduates of those institutions.

In 2005, the guest editors of a special issue of the **Journal of Engineering Education (JEE)**, subtitled *The art and science of engineering education research*, opened their foreword with the statement "The engineering profession is currently facing an unprecedented array of pressures to change." [1, p. 7] The editors emphasized a recommendation from the National Academy of Engineering (NAE) report *The Engineer of 2020* [2]: "... engineering education should be revitalized to anticipate changes in technology and society, rather than lagging behind them" This may be taken as both a call for engineering educators to try to anticipate changes in technology and society, and prepare our students for anticipated change. But it is also a call for engineering education as a societal institution to become *rapidly reactive* when necessary as well as anticipatory when possible. Sometimes changes in technology cannot be seen coming until they are on us; e.g., few anticipated the current importance and influence of the world wide web 15 years ago. Yet the profound effect of the web now on how engineers do their daily business is undeniable. The structures of engineering education need to be flexible enough and nimble enough to rapidly respond to change.

The NAE followed *The Engineering of 2020* in rapid succession with *Educating the Engineer of 2020*. [3] In the section "Getting to 2020: Guiding Strategies," a discussion is framed around the issue of how engineering students can effectively learn the specific skill set required for the *practice* of engineering in the modern world. In a more recent special issue of **JEE**, subtitled **Educating future engineers: who, what, and how** [4], the guest editors ask: "How can we help students better learn in and about engineering?" This can be rephrased as: *How can engineering students be exposed to authentic problems that require exercise of the tools that they will need after the degree is conferred?* As the engineering student graduates and goes into the world to become a working engineer there is a need for that engineer to be competent not only with concepts but also competent with manipulating the concepts in service of solving a real problem, and competent in using appropriate tools in appropriate ways to get to a solution. Repeated and increasingly more real world use of tools is necessary to blend problem analysis, solution methods with well chosen tools, and solution analysis.

The insistence on *authentic problems* being part of the educational experience for engineering students applies broadly. But it also applies specifically to students whose career path targets management. The core expectations of a manager in an engineering firm are that (a) the manager will be an effective communicator broadly across technical and in particular engineering disciplines, (b) the manager will be an effective agent in human relations, (c) the manager will have coursework in her background that includes an appropriate mix of mathematics, science,

broad engineering exposure, and key business areas, and (d) the manager will above all else be an effective, team oriented problem solver. Each of these key attributes should be exercised in the context of solving authentic problems portrayed via extensive case studies in academic programs developing managers for engineering areas.

Bottom line - two of the necessary areas of study to transform an apprentice engineer into a working engineer are (a) content (e.g., understanding of mass balance systems) and (b) tools and methods to manipulate the concepts (e.g., simulation tools to model mass balance systems to determine steady state conditions). As shown in Figure 1, there is a third dimension/third area of concentration that is necessary to complete the picture: the *learning environment* (e.g., is the learning environment focused on lecture only for content delivery versus is active learning emphasized in the program).

By learning environment we mean both *why* a student should learn something and *how* the student might learn it. Typically an engineering faculty member focuses most of their time and attention on content, some of it on developing a professional skill set, and little time and effort on the learning environment. The result is an overstuffed curriculum based on “necessary” content, some significant fraction of which will be outdated within five years - a curriculum often described as “a mile wide, and an inch deep.” Engineering educators seem to pay mostly lip service to the need for engineers’ life-long learning but we debate curriculum changes as if once we get the curriculum “right” we will never need to change it again.

To be explicit, we take *content* to mean the concepts and relations among the concepts that a professional engineer needs to know. We understand *skills* to be the methods and tools a professional engineer uses to *do* engineering. And we understand the *learning environment* to encompass *why* an apprentice engineer would need to learn a new topic and the *methods* by which the engineer would learn the new topic.

Figure 1 provides an abstract foundation to focus attention in a balanced manner across all areas that must be considered in building a undergraduate professional program in engineering. Starting with that foundation, a curricular program architecture can be designed that recognizes *change is the norm*, that prepares the undergraduate engineer for evolving professional practice.

We do not start from a blank slate. In the College of Engineering at Michigan State University, one of our nine undergraduate academic programs is the Applied Engineering Sciences (AES) major. In the next section we will describe the current AES program.

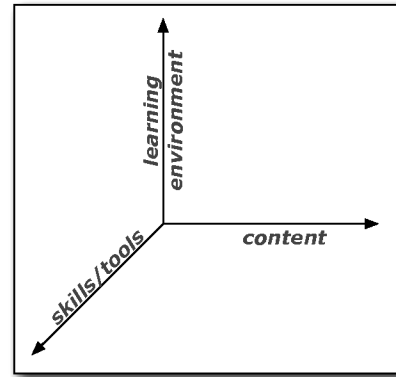


Figure 1: Understanding engineering education in three dimensions

Description of the Current AES Program

Figure 2 depicts the current AES curriculum from a structural perspective. Examination of Figure 2 shows that there are six major intellectual components to the AES program. The three foundation blocks include the basic sciences and mathematics, the humanities and social sciences, and a business/psychology/organizations component. The business component provides a basis for later specialization, as well as placing many issues that arise in engineering in their broader socioeconomic context and preparing students along one key recommendation of The Engineer of 2020 - understanding business and commerce.

Two engineering core blocks build on the basics. The Multidisciplinary Engineering core extends the content knowledge base of the basic sciences to application in engineering contexts. We believe that it is necessary for our students to have a degree of familiarity with concepts, tools, and applications that are typically found in the traditional discipline majors – mechanical, materials, electrical, chemical, civil, and bio-environmental engineering. This engineering core plays a key role in enabling our graduates to function effectively on multidisciplinary teams in industry, since they are familiar with the underlying concepts and the associated jargon across core engineering disciplines. A block of two courses specific to AES completes the view of the AES program that all students take - no matter which specialization area selected.

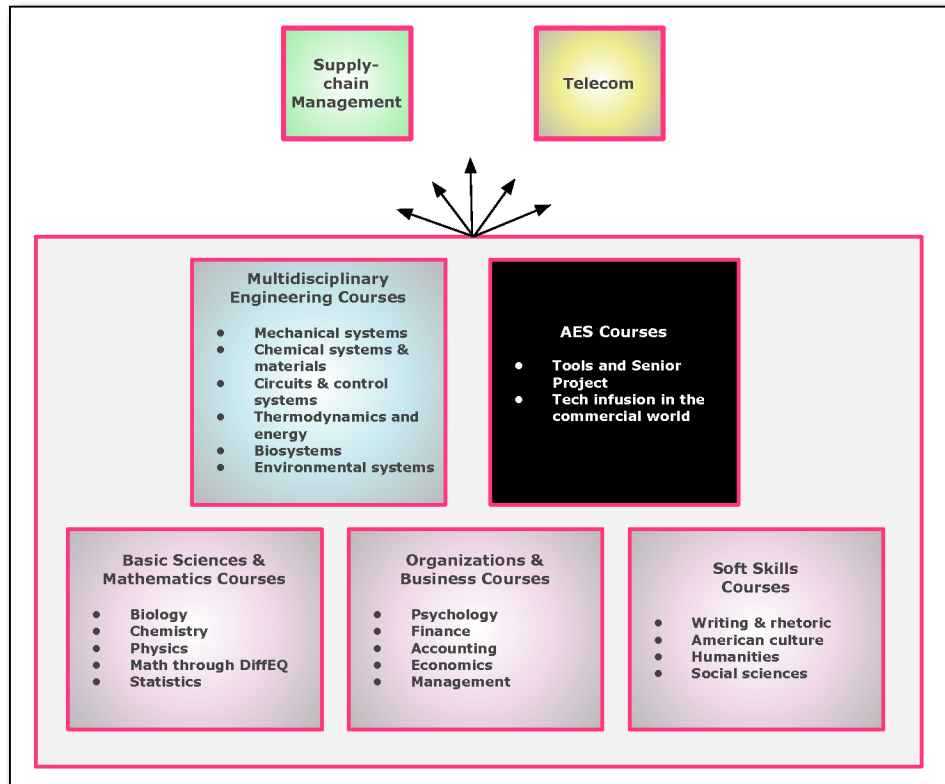


Figure 2: Current Structure of the the Applied Engineering Sciences Major

A specialization block extends the student's knowledge in a career-oriented direction and at an advanced level of undergraduate study. An AES student selects her specialization based on student interest, career opportunity, and strengths in collaborating units on campus. Supply-chain management and telecommunications are the two existing specializations.

The supply chain management program is currently selected by approximately 95% of AES students and constitutes 27 semester hours of work. Courses are taken in our Management and Supply Chain Department, a top-five ranked program on a national basis. The selection by a very large majority of AES students is prompted by the stature of the supply chain program at MSU, and by strong prospects of employment following graduation. In the very difficult economic environment of Spring 2009, of all AES graduates, approximately 85% secured positions in industry. The graduating class for Spring 2009 was made up of 42 graduating seniors.

Strengths of the current AES Architecture

Unlike traditionally organized undergraduate programs in engineering including traditional EM programs, most AES faculty are distributed across other disciplines. The foundational tier of courses in AES is taught by faculty in basic science and mathematics areas and in business. This is not in concept different than most other engineering programs. The uniqueness of the existing AES architecture lies above the foundation. While traditional programs in ME, ChE, Civil, ... have dedicated faculty to teach disciplinary courses, in AES the focus is on an *Engineering Commons* that is a cross section of core engineering disciplines. Above that, and leading directly to industrial careers or to further professional studies, there are specialization areas that build on the broad background of both the AES foundational courses and on the *Engineering Commons*.

Current AES Program Shortcomings

There are two program weaknesses in the current AES program, and in the AES program architecture as shown in Figure 2. Referring to the three-dimensional view of engineering education in Figure 1, the *content* of the program should be fully reviewed and updated. The last major updating of the AES program was approximately five years ago. There are two areas of concern about content: (a) the selection of foundational and Engineering Commons courses/content and (b) the selection of advanced study specialization areas.

As an example of the first area of content concern, technical foundation and Engineering Commons courses, we are confident that more coursework in biology and/or biosystems engineering is required to adequately prepare AES students as broadly educated, 21st century engineers. Such additions or substitutions cannot be made in isolation; to simply add new course after new course eventually results in a bloated and disjoint curriculum. The need for additional background in biological sciences is an exemplar. The entire core program has been reviewed, recommendations for improvement developed and acted on, and assessment conducted to determine the effect of implemented curricular changes.

The second area of content concern lies in the current specialization options of the AES program. Because 95% of students select the supply chain management program, AES is effectively a more technically grounded variation on the Michigan State University supply chain major. AES graduates are increasingly finding excellent professional employment opportunities as more and more employers understand and seek out graduates with multidisciplinary engineering credentials coupled with expertise in supply chain logistics. However, the program is not functioning to its potential with only one area of specialization. The AES core program prepares students for more opportunities.

Deeper concerns about the AES program are in the second and third dimensions of Figure 1: (a) skills and tools and (b) learning environment. Referring to Figure 2, part of the AES program now is in AES specific courses, but there are only two such courses. Isolating the AES courses black box of Figure 2, the two current AES courses are content-focused on (a) infusion of technology into the commercial world and (b) tools/methods for AES and a senior project course. A top level issue for the current AES program lies in its strongest asset - the distributed nature of the bulk of AES coursework. The issue is that students perceive the AES educational experience as a set of courses/silos until they reach the specialization. They then largely identify with the specialization (currently supply chain/logistics predominately) and not with AES (engineering).

The root cause of the difficulty does not lie with the distributed coursework, but rather with the breadth, reach, and integrative nature of the AES-specific courses. Explicitly, a weakness of the AES program is that the AES specific course work should play an integrating role that weaves the program into an integrated AES educational experience but that top level goal is not met.

The New AES Program

The AES program architecture is capable of rapid change where rapid change is most likely - in the areas of specialization. The foundational science/mathematics/business and the multidisciplinary Engineering Commons evolve more slowly; the AES architecture can accommodate slow change in these areas through a standard if laborious faculty process of curricular review and modification. But for AES to mature and to more fully reach its potential, the concerns pointed out in the preceding section must be addressed. Once addressed, the AES program and its underlying program architecture may act as an exemplary engineering program architecture that could be generalized and implemented in other engineering programs.

We envision the AES program structure to be modified as shown below in Figure 3. The areas of specialization are grouped into larger content domains purposefully to enable stronger interaction between large segments of the AES student population. The three specialization domains that are shown are (a) in business specializations, (b) in pre-professional specialization, and (c) in information technology oriented areas. The specific cognate areas that are part of our new curriculum are show with bold red box borders. Others remain for future AES expansion consideration.

Not apparent in Figure 3 are changes in specific course requirements in the foundational science and mathematics block, the organizations and business courses block, the soft skills block, and the multidisciplinary engineering courses block.

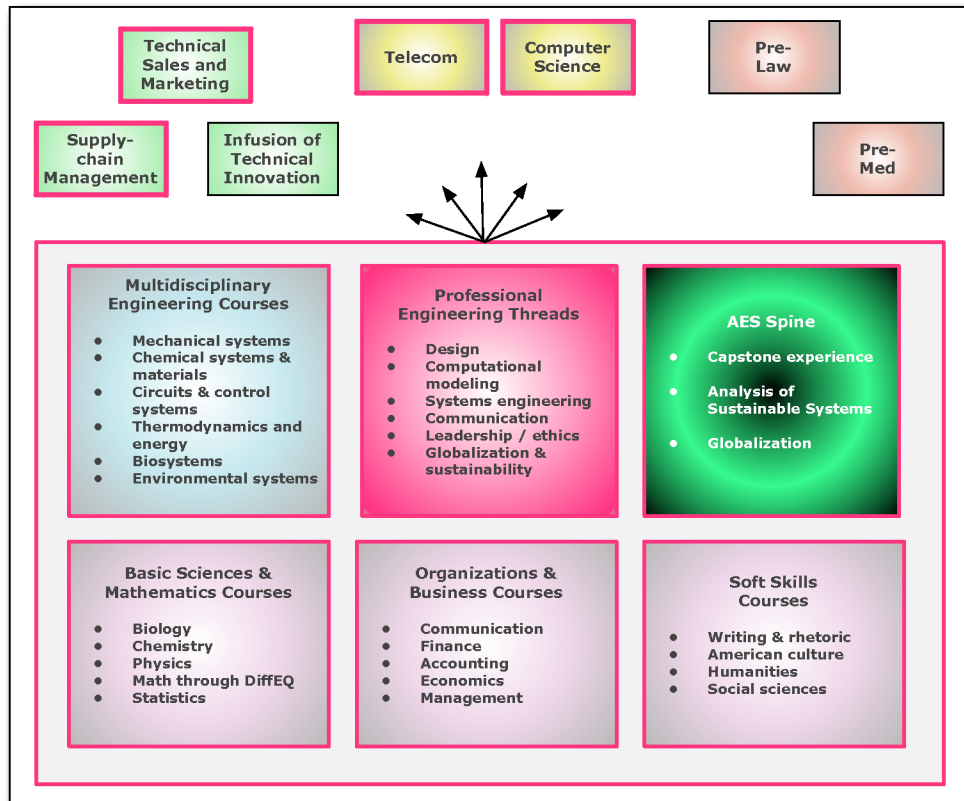


Figure 3: Vision of AES Program. Changes include an enhanced AES-specific course set (the AES Spine), a threaded set of topics, professional methods and tools, and an expanded set of areas of specialization.

The most profound changes in the structural view of Figure 3 lies in the changes to the “AES Spine” block and in the new block labeled “Professional Engineering Threads.” The AES Spine block contains three courses, one each at sophomore, junior, and senior levels. The purpose of the AES Spine is figuratively to bind together the entire AES program and to address issues in professional skills and tools, and in the learning environment of the program.

The AES Spine starts with a sophomore level course on globalization. This course is aimed at introducing the key concepts and problems in globalization in the context of engineering. The course includes 50% time in active student engagement in discussion of the concepts introduced. This course has the meta level goal of beginning the discussion of WHY the AES program includes the topics/courses it does - part of the “learning environment” of Figure 1. The second level meta goal for the first AES Spine course is to begin the discussion of the professional thread topics - listed in the “Professional Engineering Threads” box in Figure 3.

The “Professional Engineering Threads” are not linked to individual specific courses - as in one course for systems engineering. Rather these threads will weave through the AES Spine courses in a recurrent, spiral curriculum sense. The goal of the threaded spiral curriculum on the identified professional topics is to for the student to become facile with tools, methods, and professional mindset appropriate for any AES graduate.

The AES Spine continues at the junior level and will invert the discussions that had taken place in the sophomore level spine course on globalization. In the sophomore level course, the progression was talking about concepts in the abstract, then discussing case studies in small groups with introduction and description of appropriate methods and tools that would be applied to given problems. In the junior level spine course, students will learn how to use tools for selected types of problems. An example would be an off the shelf method/tool for life cycle analysis (LCA). Then using the tool, the student will attack a real world problem, but one that is somewhat idealized to simplify the solution.

Having dealt with professional topics like LCA in the abstract in the sophomore level course, and having used matching tools in the junior level course, in the senior AES Spine course, the student will develop (in teams) a solution for an authentic problem such as the student will find after graduation. The same threads will again appear at the senior level, completing the spiral curriculum for the professional threads embedded in the AES Spine.

Pedagogy to be Used to Develop the AES Spine

The pedagogical approach we will follow in principled development of the AES Spine courses will be a “spiral curriculum approach.” Jerome Bruner’s theory of cognitive growth and curriculum development emphasizes the idea that students need to be exposed to difficult concepts early in their learning. Students will be able to grasp and assimilate these concepts if concepts are repeatedly revisited in increasingly complex forms as the student’s understanding and cognition grows. [5] This notion of what is now commonly called a spiral curriculum has been applied in several instances, notably in programs at Virginia Polytechnic Institute and State University [6] and at the Worcester Polytechnic Institute [7-9].

Cognitive science emphasizes that repetition is important for learning. Traditional modes of instruction in which a topic is taught and is assumed to have been “learned” lead to segmented learning and the lack of student ability to integrate material across courses. Spiral and integrated curricula are not new and have been applied in elementary and secondary education as well as at the college level. For example, Clark, DiBiasio, and Dixon [7-9] describe a project-based spiral curriculum developed for second year chemical engineering courses. Their approach was to construct a four-course spiral sequence based on prioritization of specific skills and content from the traditional sophomore year material. The prioritized skills and content were then arranged into instructional components of the spiral courses and a “just-in-time” basis for the required fundamentals. A combination of traditional lecture, group work and cooperative learning, and hands-on projects were used in the courses. Their spiral encompasses the sophomore year only

with project-based relationships extending into the traditional junior and senior year.

A graphic depiction of a spiral curriculum is shown in Figure 4. Students start their engineering education at the core of the spiral and start a journey outward. For example, in the AES Spine, the tool/method for life cycle analysis will be encountered in the sophomore spine course. But as the student progresses around the spiral, again and again the same concept (LCA) is encountered in varying contexts, and in increasingly more sophisticated applications. By the time the student engineer reaches the terminus of the spiral (graduation) the newly minted, full fledged AES engineer has (a) internalized the concept of LCA, (b) developed an understanding of how to apply the concept in different problem solving contexts, and what is perhaps most important (c) is not going to be shocked when she sees a novel (to her) application of life cycle analysis and has to extend her “school knowledge” to the new situation.

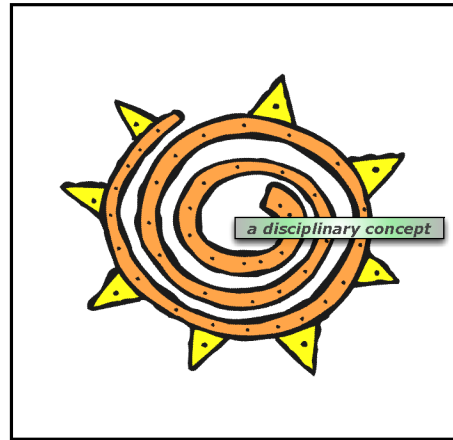


Figure 4: General idea of a “spiral curriculum”

We do not claim that a spiral curriculum approach is novel to our program. We do intend to emphasize the spiral approach to learning within especially the AES backbone courses as described above.

Current Status and Future Plans

After a year of study, and iterative conversations with all stakeholder groups (current students, faculty, program alumni, and employers of recent graduates), we developed a curriculum that is both well balanced across technical areas (math, science, engineering, AES spine) and business, and affords a significant investment in a “cognate” that allows the student to do in depth studies in a selected area. The balance of our new program is shown in Table 1, below. The program is now before our academic governance system and we expect approval by the end of Spring Term, 2010. Approval by our College of Engineering was won in February, 2010. We anticipate final university level approval by May, 2010.

Our key motivation for our realignment and expansion of AES is to capitalize on the need for broad engineers who have a business background. From a program architecture focus, the “engineering commons” approach we are taking provides the grounding that all AES students will have. The agility of our curricular architecture comes *via* the cognates. As new and important areas open for broad based engineers, our cognate set can change, and change rapidly.

As our new AES program comes online in Fall, 2010, we intend to study student outcomes from the new AES curriculum intensively. The dimensions of our study will be (a) learning outcomes

at the programmatic level, (b) attitudinal outcomes at the graduating senior level, and (c) employment outcomes for our students. We do not expect our program to remain static; we anticipate periodic updates as we learning from our outcomes-based studies. But we do believe we have a good starting point that will over time provide a viable alternative for education of technically based engineers who will pursue management opportunities.

Table 1: Balance of new AES Program

AES PROGRAM TOTALS			
	(hrs)	(%)	
Humanities Core	12	10%	19%
Social Science Core	11	9%	
Science Core	17	14%	26%
Math & Stats	14	12%	
Engineering Core	21	18%	25%
AES Major Core	9	8%	
Business Core	15	13%	13%
Total Core Programs	99	83%	83%
Cognate & Electives	21	18%	18%
TOTAL AES PROGRAM	120	100%	100%

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