Introducing Flexibility in an Engineering Curriculum Through Student Designed Elective Programs

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Abstract

Calls from industry, non-profits and government consistently encourage engineering programs to create a "well-rounded engineer." But what is meant by a well-rounded engineer? And how can university faculty meet these requests within the limitations of existing degree programs and the accreditation requirements of ABET?

Two years ago, the Industrial Engineering faculty at Montana State University undertook a major project to revamp and update their curriculum and attempt to answer these questions. The results of the project represented a major curriculum revision, with nearly 30% of the course credits in the curriculum undergoing some level of change. The cornerstone of these updates sought to increase flexibility in the program through introduction of cognate electives. Cognate is defined as of the same or similar nature. In that vein, this new program allows for students to build their own customized concentration using a free-form series of elective courses. The cognate system replaced a traditional set of professional electives focused on engineering topics.

The cognate enables students to develop a customized focus area based on their interests that is outside yet complementary to core industrial engineering topics. The electives are structured in a way that provides students a high degree of flexibility to explore other areas of education outside their field and requires them to acquire a certain level of expertise in their chosen cognate area. The change provides a higher level of flexibility than most traditional engineering programs allow. This article examines the creation and implementation of this program and explores how students are using this new-found flexibility.

The Need for Flexibility in Engineering Education

The world is changing and with it the skills needed by engineers to be successful in the workplace. The engineer of the future will work in an environment that is faster, more global, and requires greater levels of entrepreneurship and collaboration with everyone from designers to social scientists.[1,2] In order to be prepared for the continuous changes within the profession future engineers will need to become lifelong learners.[3,4] Unfortunately, the evidence continues to indicate that the engineering professorate is not doing enough to change the way engineers are educated to adequately respond to these changing market forces. As noted by participants at a recent National Academy of Engineering Forum, "If curricula was redesigned around the needs of the students, rather than the needs of faculty members, they would look quite different."[1] But what does this mean? What do the experts who are contributing to these reports tell us that the curriculum of the future should look like?

While opinions vary, a common theme is evident in many reports: the engineer of the future needs to be well-rounded and should be educated accordingly.[1,2] The meaning of a well-rounded engineer needs to be interpreted and has been in a variety of venues. These recommendations

vary somewhat in their format, but can be summarized to say that an effective curriculum to educate the engineer of the future should be:

- A broad education,[2,5,6] that is
- "well grounded in the basics of mathematics and science, [with an expanded view that includes] the humanities, social science, and economics",[7] while
- including flexibility to promote life-long learning,[6] with
- the end goal that graduates will be better prepared to work in a constantly changing global economy[2]

Given these calls, the IE faculty was highly motivated to find ways for the curriculum to be more flexible while performing the curriculum review and update.

Context and Process for Creation of the Cognate

This paper reviews the creation of a cognate elective system within the Industrial Engineering (IE) curriculum at Montana State University (MSU) and how students are using this new flexibility. Merriam-Webster defines cognate as "of the same or similar nature, or generically similar."[8] Thus, the cognate program allows students to select a set of related courses from across the university that support their interest area and augments their core IE education. In order to understand how the context of how the cognate came into being, it should be noted that this outcome was part of a much larger project to review and update the entire IE curriculum. The project resulted in a large scale change to the curriculum as it had existed for over a decade. The impetus for this change was a created by a variety of internal and external influences on the program simultaneously materializing. These influences can be categorized using the definition of Lattuca and Stark regarding the three origins origin of academic change: 1) those that result from the planning efforts of those within a program, college, or university; 2) response to external societal pressures; and 3) utilization of new educational ideas.[9]

Influences from inside the program included prior work to familiarize all members of the faculty with all curricular courses which set an expectation for change, changes in the make-up of the faculty, and flat to declining student enrollments within the program. Influences from outside the program included enrollment increases in other programs within the department creating resourcing pressures on the IE program, a department head mandate to reduce the costs of part time IE adjuncts in order to be permitted to proceed with filling an open tenurable position, and college and university level expectations related to the ongoing viability of smaller degree programs. External influences are numerous and included changes in the field from emerging topics,[3,11,12] direct employer feedback on the reasons the program's graduates are attractive, updates to ABET accreditation standards,[4] and general calls to improve engineering education.[1,2] Together these pressures created a mandate for the curriculum update to improve both the educational efficiency and attractiveness of the curriculum, while simultaneously ensuring that the program maintained its ABET accreditation and the implemented changes successfully modernized the curriculum in response to external influences.

At the conclusion of the process, nearly 30% of the credits in the curriculum experienced some change in status, and curriculum delivery became more efficient for the IE faculty with

substantial reduction in program level teaching loads. While the cognate and related changes were expected to address several aspects of recent calls for improving engineering education,[1,2] only through implementation has it become clear how students will make use of this new found flexibility.

Creating the Cognate – Adding Flexibility to a Degree Program

Changes over the fifteen years prior to this effort had attempted to increase the flexibility of the curriculum by raising the number of Professional Electives (PE) courses students could take in their degree program from one to four. However, due to the limited number of courses available as PE, these changes created only marginal increases in flexibility for students to explore subjects that might make them a more well-rounded engineer. Through the efforts of the larger update project, the curriculum changed to include as required courses several topics that had previously been elective offerings. Because of these and other changes, the updated core curriculum now meets the key ABET accreditation requirements of 32 semester hours of mathematics and basic sciences and 48 semester hours of engineering sciences and engineering design[4] without the use of any PE courses. This change enabled the faculty to consider eliminating the existing PE system and adding true flexibility to the curriculum through the cognate program.

The cognate program has its origin in the combination of two distinct ideas for curricular improvement. The motivation of the faculty member who created the initial concept for the cognate was to provide students the opportunity to develop a unique area of expertise that would support their chosen career aspiration. Since IE is a very broad field, practitioners can be successful in virtually limitless fields, from manufacturing to financial services and from healthcare to retail. By choosing an appropriate set of courses, students can gain some industry level expertise in one of these areas and differentiate themselves in the job search process. The second idea was born from the larger update project. During that process, the faculty performed an exercise to outline broad topics from outside core IE subjects that external recommendations and team knowledge indicated would be helpful to develop successful graduates. This list included such topics as organizational psychology, sales and marketing fundamentals , and data mining skills. While the team was in strong agreement that these topics would be valuable within the curriculum, the process of how to incorporate them as required courses in an already full program of study presented a rather large challenge. This challenge is substantively overcome for students who choose appropriate courses for their cognate.

In order to ensure that the cognate achieved the desired educational outcomes and is not merely seen by students as a way to find three easy courses to complete their degree, several basic requirements are provided to students through the published cognate policy.[10] Each of these requirements , and their rational are summarized as follows:

1. *Students will take a minimum of nine (9) credits outside the required curriculum coursework.* Although many of the faculty would have preferred a greater number of credits, state law limits the number of required credits in a degree program to the existing 128 hours and this was the space created by other changes.

2. *Any course that is taken to satisfy required courses or university core requirements for the Bachelor of Science degree in IE cannot be used to meet the cognate requirement.* This requirement simply ensures students do not attempt to double count credits and then fail to meet the overall degree credit requirements.
3. *At least six (6) credits of the cognate must be at the 300-level or above.* This requirement ensures that students move beyond superficial topics and obtain some depth in their chosen area of interest.
4. *The credits must represent a coherent area of study relevant to some aspect of IE as a discipline or practice.* This reflects the very definition of cognate and helps ensure that students achieve depth in the chosen area.
5. *Proposed cognates included in a student's program of study must be approved by the student's advisor and the IE Program Coordinator.* This requirement provides a final check on cognate quality and an early warning system with regard to any issues with the design of the program.

The first three of these requirements are straightforward and easily understood by students. However, the forth requirement of the cognate presents a potential challenge, since what constitutes a 'coherent area of study' can be interpreted in many ways. In order to support students as they work through what might be a critical area of uncertainty, the faculty took a number of steps to provide additional scaffolding for students considering how to meet these requirements. First, in the cognate policy, students are informed that they automatically meet the cognate requirements if they complete a university approved minor. In addition to providing clarification with regard to what a coherent area of study might look like, this example was expected to address the frustration of those students who had previously explored adding a minor only to find that it would require substantial additional time and expense at MSU to complete both the major and desired minor. Students were further informed that they can complete the cognate requirements by selecting a subset of courses from any approved minor, as long as those courses meet the credit and level minimums outlined above. Finally, the faculty provided a list of sample custom created cognates as examples to help students think through their options. Faculty built these sample cognates using knowledge of contemporary issues gained from industry and other sources, as well as prior student interest. The examples are shown in Table 1.

Since the cognate is designed to enable a multidisciplinary focus in a complementary subject area, it is expected to have many beneficial educational outcomes aligned with the student outcome expectations of ABET.[4] By pursuing the cognate, students will be enrolled in classes with many from outside engineering. This exposure to students from other disciplines in upper division courses is expected to enhance IE students' abilities to work in multidisciplinary environments (outcome d) and communicate effectively (outcome g). Since these interactions will expose them to different perspectives and expertise, the cognate should also improve student ability to assess the impact of their work in a larger context (outcome h). Finally, since students must take ownership of the development and execution of their cognate, the system should better prepared them to engage in life-long learning (outcome i).

Table 1 - Example Cognates Developed by Faculty

Manufacturing ETME 217 Manufacturing Process Laboratory (1 cr.) ETME 310 Machining and Industrial Safety (3 cr.) ETME 410 CNC & CAM Technology (3 cr.) ETME 415 Design for Mfg and Tooling (3 cr.)	**Design** ART 145RA Web Design (3 cr.) EMEC 403 CAE IV-Design Integration (3 cr.) EMEC 465 Bio-inspired Engineering (3 cr.) *Take ARCH 121IA to satisfy university core requirement.*
Human Factors PSYX 360 Social Psychology (3 cr.) PSYX 380 Memory & Cognition (3 cr.) PSYX 481 Judgment & Decision Making (3 cr.) *Take PSYX100IS to satisfy university core requirement.*	**Healthcare** CHTH 210 Foundations of Community Health (3 cr.) HADM 445 Managing Healthcare Orgs (3 cr.) EIND 506 Design of Healthcare Delivery Sys. (3 cr.)
Leadership UC 202 Leadership Foundations (3 cr.) BMGT 335 Management and Organization (3 cr.) BMGT 420 Leadership and Motivation (3 cr.)	**Ergonomics/Biomechanics** HDPE 221 Health Anatomy and Physiology (3 cr.) KIN 322 Anatomical Kinesiology (4 cr.) KIN 325R Biomechanics (4 cr.)
Optimization Techniques M 274 Intro to Differential Eq. (4 cr.) M 386 Software Applications in Mathematics (3 cr.) EIND 455 Design of Experiments for Engrs[1] (3 cr.) or EIND 457 Reg & Applied Multvar Analysis[1] (3 cr.)	**Sustainability** ECNS 132 Econ & the Environment (3 cr.) or ECNS 332 Econ of Natural Resources (3 cr.) MGMT 410 Sustainable Business Practices (3 cr) SOCI 470 Environmental Sociology (3 cr.) *Take ECNS 101IS or ECNS 251IS to satisfy university core requirement.*

1 – Students will take whichever second semester IE statistics course was not included in their core IE program of study.

Student Use of the Cognate

In order to understand how students are making use of their new found flexibility, a two part study was completed. In the first effort, the advising files of current students were reviewed to categorize the cognate plans of those students who already had a documented set of cognate courses in their program of study. The second effort included an assignment given to new IE students in the first semester introductory course. In this assignment they were given the cognate advising materials and asked to design their own draft cognate to include in their future program of study and explain why the cognate interested them. These efforts provided a list of 53 developed cognates. Of these 53 students, 50 developed a cognate that met the requirements outlined in the previous section. These data points are summarized below in Table 2. In order to better understand how students developed their programs the cognates were categorized in one of three ways:

- Example – The student utilized one of the example cognates provided by the faculty.
- Minor – The student designed a cognate that represented a sub-set of a university approved minor.
- Custom – The student designed their own custom cognate program.

Table 2 - Distribution of Student Proposed Cognates

	Students in Intro Course	Experienced IE Students	**Total**
Example	12	4	16
Minor	12	12	24
Custom	8	2	10
Total	32	18	50

Once collected, the selection of cognates were examined to understand the interests of students at different points in their academic careers. While the initial review seems to show key differences in the interests between the newer and more experienced students, none of these differences are statistically significant ($\alpha = 0.05$). Despite this lack of significant differences, the data does provide interesting insights. For example, a full 25% of students in the introductory course chose to create their own custom cognate, while only 11% of students further in their program of study did the same. Further investigation of these ten students found that both of the more experienced students built custom cognates that were either a minor modification of an example cognate or a subset of a different major where no minor is offered.

By comparison, newer students developed a variety of unique custom cognates including designing a multi-disciplinary set of courses in entrepreneurship when a minor exists in the university's College of Business and proposing the use of a unique course from a different university to accomplish a cognate in sabermetrics. Whether these choices reflect a true desire to move outside existing minor options, simply indicate a lack of understanding of existing programs, or that the interests of newer students are more easily swayed by the types of topics the students had recently been exposed to requires further investigation. However, this creativity was not evident in all members of the introductory class, as nearly 38% selected from the menu of sample cognates, a number which may be artificially inflated since these students are often still considering whether they have selected the correct major and may not be prepared to see how that major can be appropriately enhanced with electives. Again, these choices warrant further investigation.

For those students selecting a minor (or subset of a minor), as their cognate, the most common topics were business themes (e.g. management, finance, etc.) (n = 9), and languages (n=4). Additional topics that appeared multiple times included computer science, history, and economics.

Conclusion

A variety of external and internal forces created the impetus for the major redesign of the IE curriculum at Montana State. A key consideration of the faculty in this review was how to meet the calls for developing more well-rounded engineers so our graduates can better meet the demands expected of engineers in the future. By modifying the curriculum in key ways, the faculty were able to increase flexibility of the degree program while maintaining the courses needed to meet the requirements for continued ABET accreditation. The new curriculum incorporate a nine semester hour cognate elective program that allows students the flexibility to

explore additional educational areas and become more well-rounded engineers. During initial implementation, students have used the cognate to study areas ranging from foreign languages to healthcare and management to sustainability. Informal feedback gathered through student advising indicates students are pleased with the ability to explore additional educational areas without needing to spend additional time and money at MSU.

Initial data indicates that the redesign effort has meet its fundamental goals. The creation of the cognate has provided the IE program a differentiator in marketing itself against other programs within the college and current record freshman enrollments and increased overall enrollments indicate positive results from these efforts. By reviewing the curriculum, gaps in topical coverage were identified and addressed. These changes enhance the ability of IE graduates to make significant contributions to their employers and job placement rates at or near 100% for the past several years indicate employers are also seeing this value. The faculty will continue to monitor the success of these changes and look for additional enhancement opportunities for the curriculum and cognate program going forward.

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