Quality Approaches in Higher Education

Adding curricular flexibility to develop well-rounded engineers.

Educating Tomorrow's Engineer: Adding Flexibility Through Student-Defined Electives

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Abstract

Industry and political leaders continue to call for change in the way that engineers are educated. Future engineers need to be more than just technically competent. They must be able to refresh their skills continually to remain relevant in an ever-changing world while simultaneously being able to work effectively with diverse groups of people from a wide variety of backgrounds and expertise. This article examines the process utilized at Montana State University to redesign the curriculum of an industrial engineering program to be more attractive to prospective students while adding the flexibility needed to develop more well-rounded engineers. The project resulted in major curriculum change, with changes to nearly 30% of program credits. The cornerstone of these updates increased program flexibility through a student-defined elective program. Results are discussed including student enrollments, ABET accreditation, and student use of the new flexibility.

Keywords

Higher Education, Accreditation, Student Satisfaction, STEM, 21st Century Skills

Introduction

Consistent calls for additional science, technology, engineering, and math (STEM) graduates in the United States over the past decade have led to an increasing demand for engineering education and climbing enrollments for many existing engineering programs (The White House, 2014; Yoder, 2014). This increased demand has also motivated the creation of many new engineering programs (Meixell, Buyurgan, & Kiassat, 2015; Muggli & Tande, 2011). With these changes in the marketplace, ensuring that a program is ABET accredited is one of the most effective ways for students (consumers) to ensure that the program they are investigating is of sufficient quality that its graduates are ready to enter the workplace in an engineering role (ABET, 2015).

Simultaneous to these rising enrollments, there is a growing call for changing the ways that engineers are educated (American Society for Engineering Education, 2013; National Academy of Engineering, 2013). There is an increasing movement toward the incorporation of curricular materials that promote developing engineers who meet the broad needs of today's industry for a number of reasons. This includes changes in engineering accreditation criteria (ABET, 2012), calls from seminal reports such as the *Engineer of 2020* (National Research Council, 2004), and evidence from engineering graduates that indicate professional skills are often what engineers find most important in the workplace (Passow, 2012). These needs include engineers who are not only technically competent, but also what Atman (2009) defines as well-rounded. In this context, the well-rounded engineer is both broadly educated and holds the skills of a lifelong learner necessary to be prepared for the continuous changes expected in the profession. Unfortunately, the evidence continues to indicate that the engineering professorate is not doing enough to change the way engineers are educated and adequately respond to these changing societal needs (Atman, 2009; National Research Council, 2005; National Science Board, 2007).

In response to these needs, the faculty of an industrial engineering (IE) program at Montana State University (MSU) undertook a multi-year effort to revise the curriculum.

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A key desired outcome of the new curriculum was to create program flexibility that enabled students to study additional areas and graduate more well-rounded engineers, while maintaining the program's ABET accreditation. This flexibility was largely accomplished through the creation of a unique elective system within the curriculum. This article examines the path to the development of this system, how ABET and other key stakeholders view the revised curriculum, how the revised curriculum has performed on key metrics, and how students are putting the flexibility to use.

Curricular Reform in the Literature

Given the broad pressures to improve engineering education, it is not surprising that a number of engineering programs have studied ways to improve their curriculum over the past decade. Often these efforts look to bring in new topics to existing curriculum such as green engineering (Christ et al., 2015), sustainability (Price & Robinson, 2015), innovation and entrepreneurship (Oswald Beiler, 2015), and Total Quality Management (Chowdhury, 2014). In addition to these specific topic efforts, programs have also implemented more wide-reaching changes to better attract and retain diverse students (Busch-Vishniac et al., 2011), modernize their curriculum (Hamidreza et al., 2007), and respond to the needs of external stakeholders (Sari, 2013).

A great deal of the literature regarding IE programs focuses on developing an appropriate topic list, or body of knowledge, to include in the curriculum (Elsayed, 1999; Hamidreza, et al. 2007; Kuo & Deuermeyer, 1998; Sari, 2013). This focus seems to be largely due to the breadth of the discipline and corresponding needs to balance the depth of education in any one area versus covering all of the potential topics that could be considered core (Elsayed, 1999). In what appears to be the most complete work in this area, Hamidreza et al., (2007) performed a three-round Delphi study involving both faculty and industry professionals to define the desired characteristics of an IE with an undergraduate degree. Their work involved several hundred survey respondents and developed a prioritized list of 17 desired characteristics and 45 emerging skills. The researchers then utilized these lists to define priorities for curricular changes in their program.

Context and Motivation for Curricular Reform at Montana State

The effort to add flexibility to the existing curriculum was part of a larger effort to perform a substantive curricular reform. The project resulted in a large-scale change to the curriculum as it had existed for more than a decade. The impetus for this change was created by a variety of internal and external influences on the program that materialized simultaneously. These influences can be categorized using Lattuca and Stark's (2009) three origins of academic change:

1. Response to external societal pressures.
2. Response to internal pressures from within a program, college, or university.
3. Utilization of new educational ideas.

In this case, new educational ideas fall into two categories. The first are those coming from external societal pressure, while the second are new technologies and techniques implemented in support of classroom instruction. Since this article examines program-level changes, only the first category of new educational ideas are discussed. How these influences affected the program at MSU are summarized in Figure 1.

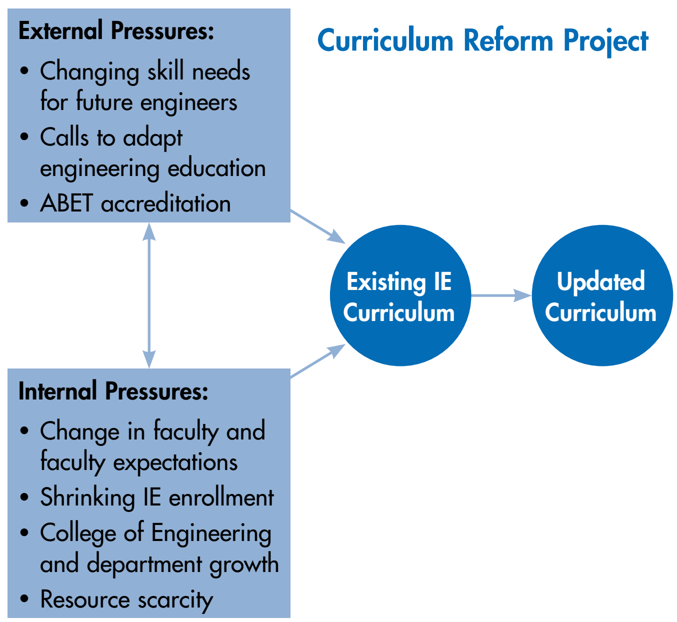

Figure 1: Summary of Academic Change Influences at Montana State

External Pressures for Engineering Curriculum Reform

The world is changing and with it so are the skills that engineers need to be successful in the workplace. The engineer of the future will work in an environment that is changing faster, is more global, and requires greater levels of entrepreneurship and collaboration with everyone from designers to social scientists (National Academy of Engineering, 2013; National Research Council, 2005). The types of expertise that engineers need for success in the workplace is constantly changing. For example, the hot skills or knowledge areas of just a few years ago, such as integrated design or Lean Six Sigma, are today's sustainable design and big data analytics. To prepare graduates for successful careers and ensure the continued competitiveness of our nation, engineering curriculum must provide students "a knowledge of contemporary issues" and "an ability to engage in life-long learning" (ABET, 2012). Despite this importance, evidence shows that the engineering professorate is slow to adopt new content and that engineering curriculum remains rather rigid. As noted by participants at a 2013 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" (National Academy of Engineering, 2013).

These changes and pressures point to the need for education to develop a different engineer for the future than the one who is trained for today. But how should the future engineer be different? 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 (National Academy of Engineering, 2013; National Research Council, 2005). Well-rounded engineers are more than just technically competent, they must also grasp the bigger-picture needs of their organizations. They must understand what is possible and what is useful. They must then possess the skills needed to effectively communicate the difference to a variety of audiences. How education should be changed to develop a well-rounded engineer has been interpreted in a number of venues. While these recommendations vary, they can be summarized to say that an effective curriculum to educate the engineer of the future should be:

- A broad education (Duderstadt, 2008; National Research Council, 2005; National Science Board, 2007).
- "Well grounded in the basics of mathematics and science, [with an expanded view that includes] the humanities, social science, and economics" (National Research Council, 2004).
- Flexible to promote life-long learning (Duderstadt, 2008), with the end goal that graduates will be better prepared for a constantly changing global economy (National Research Council, 2005).

Internal Pressures for Curricular Reform

In addition to the societal pressure to change the way tomorrow's engineers are educated, the IE program was under a variety of pressures internal to the program, department, and university. Influences from inside the program included prior work to familiarize all members of the faculty with all courses, substantial changes in the makeup of the faculty, and declining student enrollments. Influences from the department and college included enrollment increases in other programs, which created resource pressures on the IE program and a department-head mandate to reduce the costs of part-time, non-tenurable instructors before being permitted to fill an open tenurable IE position. At the university level, there were also expectations related to the ongoing viability of smaller degree programs, which put additional pressure on the IE program as the smallest in the college.

Together, these internal pressures created a mandate for the curriculum update to improve both the educational efficiency and attractiveness of the curriculum. At the same time, the external environment provided motivation to use the curriculum review to find ways to introduce additional flexibility to support the development of well-rounded engineers, while maintaining ABET accreditation.

The Process of Curricular Reform at Montana State

With these influences in mind, as the faculty began the process to update the curriculum, the team agreed on a fundamental goal of the effort: *The goal of the undergraduate Industrial Engineering curriculum rebuild effort is to develop a supremely marketable and compelling degree program that prepares students to make significant contributions to the economic well-being of their employers and to pursue graduate studies at institutions of their choosing.*

Based on the overall goal and the needs of internal and external stakeholders, the team agreed on a number of key objectives that should be met with the final curriculum, chief among these were:

1. To maintain ABET accreditation.
2. To ensure an integrated and coherent, yet flexible structure.
3. To maintain strong foundations in engineering and IE fundamentals.
4. To introduce emerging topics deemed important by employers, along with flexibility to add/change topics as market demands shift.

Before detailing the process the team utilized to modify the curriculum in line with this goal and objectives, it is important to discuss the constraints on the development of the new curriculum.

Constraints on Curricular Reform

Any effort to modify an existing curriculum is constrained by a number of factors. In this case study, these factors included compliance with state and university policies, the need for existing students to complete their degree requirements successfully during the transition with limited or no impact on faculty workloads, and the need to maintain ABET accreditation. Together these form a complex set of interlocking constraints that require systems-thinking approaches be applied to quality improvement in higher education (Furst-Bowe, 2011).

Perhaps the most challenging of these constraints dealt with the inherent conflict regarding credit requirements between state and university policies and ABET requirements. Per Criterion 5 (ABET, 2012), to achieve or maintain accreditation, an engineering program must include:

- 32 semester hours of a combination of college-level math and basic sciences,
- 48 semester hours of engineering topics including engineering sciences and design, and
- a general education component that complements the technical content of the curriculum.

Through these requirements, ABET prescribes the type of curricular content for 80 semester hours, plus the general education requirement. This general education requirement is also prescribed at MSU in the form of Core 2.0 (Montana State University, 2015). Core 2.0 requires that students take at least one course in each of ten different areas including diversity, contemporary issues in science, arts, and others, representing an additional 30 semester hours of courses. This total of 110 prescribed credits leaves little room for additional flexibility before a program of study runs into conflict with the Montana Board of Regents policy, which limits programs to a maximum of 120 semester credits (Montana State University, 1999). Even with the exception granted to engineering programs at MSU allowing a maximum of 128 semester credit hours, without combining multiple objectives into a single course, only 18 credit hours remain to meet both program-specific goals and implement flexibility of topics.

Modifying the Curriculum

With these constraints guiding the types of options that could be considered, the team engaged in a multi-step process to identify and finalize potential changes to the curriculum and then have those changes approved and implemented. Figure 2 presents an overview of this process.

A year before the formal project to update the curriculum began, the faculty started work to prepare for the project. This work involved a series of faculty meetings to review all courses in the current curriculum. This provided a knowledge base for all faculty in the program, similar to the update efforts of Busch-Vishniac et al. (2011). The formal project began with brainstorming to identify knowledge areas that should be included in the future IE program. The structure sought to elicit faculty knowledge gained from the literature, published reports, student and other stakeholder input, time in industry, and knowledge of other programs. This information was then utilized to identify key subjects central to an IE curriculum, subjects from outside IE which should be included in an IE curriculum, key professional skills that need to be developed through the curriculum, and existing subjects that might not be essential to the curriculum of the future. This resulted in a list of topics to potentially eliminate from the program and an even longer list for possible inclusion that would be helpful in developing graduates who will be successful in their chosen careers. The key areas from outside the discipline identified through this process were:

- organizational psychology and human motivation,
- financial analysis and accounting from a business perspective,
- sales and marketing fundamentals, and
- data-mining skills, including programming and database applications.

While the team was in strong agreement that these topics would be valuable within the curriculum, the process of how to

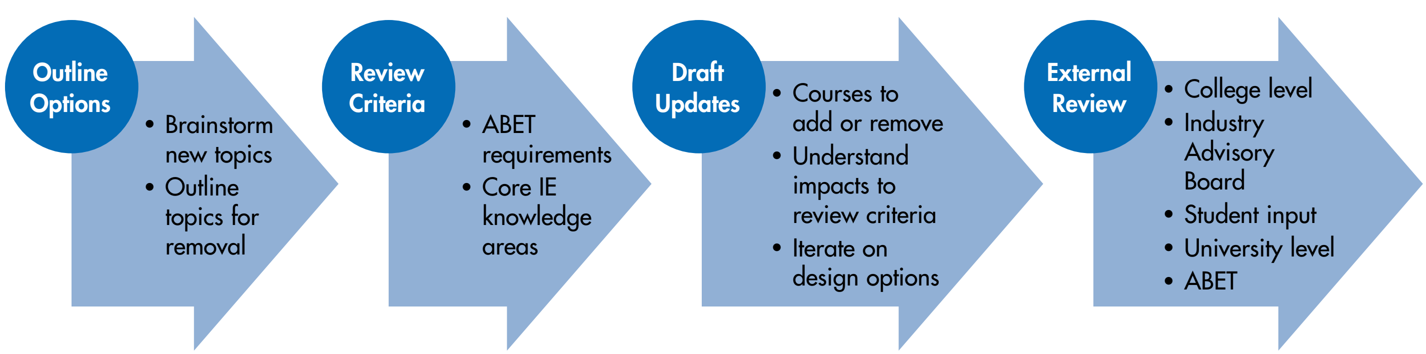

Figure 2: Overview of the Curricular Review Process

incorporate them into an already full program of study presented a large challenge. The prospect of beginning with a white sheet of paper and building an ideal curriculum from the ground up was considered neither efficient nor practical. This was due to a variety of reasons, including constraints associated with existing university courses outside the influence of the IE faculty, the need for existing IE courses to continue to support other majors within the college, and the need to accommodate existing IE students as the curriculum transitioned into its final state. As an initial step to create space for new topics, while considering the practical issues of implementation, all courses in the existing curriculum were reviewed to consider which might be removed or modified. This step created an initial list of potential changes for consideration, including several courses for potential removal or substantial revision.

This list was then reviewed against the existing curriculum considering ABET credit-hour requirements. These requirements, along with Objective 1 (maintain accreditation) of the process proved a substantial constraint on any potential changes. These constraints were reinforced by the team's desire to maintain a strong emphasis in IE fundamentals (Objective 3).

To understand the impacts of any proposed change on Objective 3, the team used existing bodies of knowledge, published guidance on the future direction of the profession, and personal knowledge to create a list of core knowledge areas thought to be crucial for future engineering graduates and which should be represented in the degree. These included:

- Systems modelling and optimization techniques
- Management systems
- Engineering economic analysis
- Sustainable system design and analysis
- Human factors
- Quality assurance

The faculty then reviewed course content and mapped the curriculum to this list. These efforts enabled the team to identify areas of perceived strength and deficiencies using a quality scoring matrix approach (Sower, 2011). The perceived deficiencies in the required course work were in two areas: management systems and human factors. These topics combined with the objectives of the reform provided the final framework to evaluate each potential change to the curriculum considered by the team and enabled the final curriculum to take shape. Figure 3 shows an evaluation matrix with examples of the changes considered and the expected impact on the evaluation criteria. While the team modified the listing of required courses to address the perceived deficiency in human factors and designed a new course to address the gap in management systems (Schell, 2013), it became clear that adding many topics from the list of areas outside the discipline would not be easily accomplished. This led the team to search for other ways to utilize the curriculum to develop more well-rounded engineers. This was done by adding more flexibility to the program through the student-defined electives.

Once the faculty had agreed to a complete draft of a revised curriculum, the process of internal and external review as well as approval and implementation began in earnest. This process included focus group meetings with junior and senior students from the Alpha Pi Mu honor society and members of the department's Industrial Advisory Board (IAB). These two groups provided the type of counterbalance of student and industry desires that Hall, Swart, & Duncan, (2012) argued is important to utilize to avoid some of the overly customer-centric approaches happening today in higher education. Consistent with published reports of industry direction to curriculum design (Sari, 2013), feedback from the IAB was universally positive. Board members were excited about specific updates to sequences in operations research and human factors as well as the improved coverage of management systems and increased flexibility. The student review also generated almost universally positive feedback. Students were pleased to see the amount of thought that had gone into updating the experience for future IE majors and were excited about the majority of the changes, including the increased flexibility. Subsequent reviews by the college-level curriculum committee, university-level faculty senate review, and the Office of the Provost went smoothly with several members making positive comments regarding the new electives policy and substantial praise from the long-standing chair of the college committee. At the conclusion of the process, nearly 30% of the credits in the curriculum had some change in status, and curriculum delivery became more efficient for the IE faculty with substantial reduction in program-level teaching loads.

Adding Flexibility—Origin of the Cognate

A key aspect of creating flexibility in the curriculum was the development of the cognate elective program. Merriam-Webster defines cognate as "of the same or similar nature, or generically similar" ("Cognate," n.d.). Thus, the cognate program enables students to select a set of related courses from across the university, and beyond, that supports their interest area and augments their classic IE education. In addition, the cognate is designed to promote more meaningful use of MSU's Core 2.0 general education requirement, since students often build upon designated core courses as they select courses for their desired cognate.

The cognate program has its origin in the combination of two distinct ideas for curricular improvement. The first was to

● = Strong positive influence expected
◐ = Slight positive influence expected
◑ = Slight negative influence expected
◉ = Strong negative influence expected

	Key Outcomes				Core Topic Areas					
	1. To maintain ABET accreditation.	2. To ensure an integrated and coherent, yet flexible structure.	3. To maintain strong foundations in engineering and ID fundamentals.	4. To introduce emerging topics deemed important by employers, along with flexibility to add/change topics as market demands shift.	Systems modelling and optimization techniques	Management systems	Engineering economic analysis	Sustainable system design and analysis	Human factors	Quality assurance
Replace professional electives with flexible system	◑	●		●		◐		●	◐	◐
Develop new management course	◐		◐	◐		●			◐	◐
Eliminate differential equations requirement	◑				◑					
Condense operations research sequence to two semesters		●			◉					
Move elective human factors courses to required	◐		◐			◐			●	
Eliminate management focused professional elective courses	◐					◑				

Figure 3: Evaluation Matrix With Example Changes Considered

provide students the opportunity to develop a unique area of expertise that would support their chosen career aspirations. Because IE is a very broad field, practitioners can be successful in virtually any industry, from manufacturing to financial services and 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 view of skills that would be valuable to IE students in their later careers, but there was a challenge of how to fit them into an already full program of study. This challenge was substantively overcome by enabling students to add complementary depth to their education with the cognate.

Broadening Education With the Cognate

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 through the published cognate policy (Montana State University Industrial Engineering Program, 2013). These requirements, and their rationale are summarized as follows:

1. *Students will take a minimum of nine (9) credits from outside the required curriculum coursework.* Although many of the faculty would have preferred a greater number of credits, Montana law limits the number of required credits in a degree program.

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 that students do not attempt to double count credits and then fail to meet the credit requirements for the degree.
3. *At least six (6) credits 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.
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 unforeseen issues with the program.

The first three of these requirements are straightforward and easily understood by students. However, the fourth requirement of the cognate presents a challenge, since what constitutes a "coherent area of study" can be interpreted in many ways. 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. 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 customer-centric approach was expected to address the frustration of those students who had looked to add 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. 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 input and the literature, as well as prior student interest. The examples are shown in Table 1.

Results From Program Implementation

In many ways the results from the curriculum update have met and exceeded the expectations of the faculty members involved in its execution. Given the nature of the multiple objectives of the work, we will examine these results in two distinct discussions. First, we examine the impact of the program on areas outside of increasing curricular flexibility and the ability to educate more well-rounded engineers.

Enrollment Growth, Retention, Student Performance, and ABET Evaluation

In the five years prior to the curriculum review, the IE program at MSU had experienced multiple years of declining enrollments from a high of more than 100 undergraduate majors to only 73 majors, a trend that continued during the redesign effort. While IE shrank nearly 30% during this period, the college experienced a 25% enrollment growth. The redesign of the IE curriculum has had a major positive impact on enrollment numbers. Beginning one year after implementation, IE enrollment grew from less than 70 majors in fall 2012 to nearly 120 in fall 2015, a growth rate that has outpaced the college's own record enrollments. At the same time, a two-sample t-test of enrollment numbers for the four years prior to and following the change shows the program has

Table 1: Faculty-Designed Cognates Provided to Students as Examples

Healthcare	Design
• CHTH 210 Foundations of Community Health (3 cr.) • HADM 445 Managing Healthcare Orgs (3 cr.) • EIND 506 Design of Healthcare Delivery Sys. (3 cr.)	• CS 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.*
Sustainability	**Inventory Management**
• ECNS 132 Econ & the Environment (3 cr.) or • ECNS 332 Econ of Natural Resources (3 cr.) • BMGT 410 Sustainable Business Practices (3 cr.) • SOCI 470 Environmental Sociology (3 cr.) *Take ECNS 101IS or ECNS 251IS to satisfy university core requirement.*	• BMGT 405 Supply Chain Analytics (3 cr.) • EIND 373 Prod Inventory Cost Analysis (3 cr.) • EIND 468 Mgr Forecast & Decision Analysis (3 cr.)

Montana University System Course Codes
ARCH: Architecture, BMGT: Business: Management, CS: Computer Science, CHTH: Community Health, ECNS: Economics, EIND: Industrial Engineering, EMEC: Mechanical Engineering, HADM: Health Administration, SOCI: Sociology.

attracted significant (p = 0.019) increases in freshman enrollments. It has also continued to attract meaningful transfers. This performance is evident in freshmen-sophomore retention rates that average 132% in the past three years and sophomore-junior rates of 110% during that same period. Student performance remains high with students averaging over a 90% pass rate on the Fundamentals of Engineering (FE) examination since the curricular changes were implemented, including three of the last four semesters achieving 100% pass rates. As all students are required to take the FE as part of their degree requirements, this is a meaningful measure of program outcomes. In addition, graduates from the program have enjoyed job or graduate school placement rates of 100% each of the past five years.

Unlike some other programs that have sought to develop flexibility in an undergraduate engineering program without seeking ABET accreditation (Sticklen & Rosenberg, 2010), maintaining accreditation was a key requirement of this update. This requirement was made more difficult due to the level of change. In addition to modifying nearly 30% of program credits, the curriculum review resulted in the adoption of a program name that more accurately reflects the updated curricular content and broad applicability of the degree. The new name became Industrial and Management Systems Engineering (IMSE). As expected, this change led to the program being evaluated on both the Industrial Engineering and Management Engineering criteria on its recent ABET evaluation visit. This review went very well. While official results will not be available until summer 2016, the feedback provided by the evaluator was positive and noted the cognate elective policy as both a strength and differentiator.

How Students Benefit From Educational Flexibility

One of the reasons that the ABET evaluator noted the cognate as a strength is due to the many beneficial educational outcomes aligned with the student outcome expectations of ABET (ABET, 2012). By pursuing the cognate, students will be enrolled in classes with many students from outside the engineering program. This exposure to students from other disciplines in upper-division courses appears to enhance IE student's abilities to work in multi-disciplinary environments (outcome d) and communicate effectively (outcome g). Because these interactions will expose them to different perspectives and expertise, the cognate also appears to improve student ability to assess the impact of their work in a larger context (outcome h). Finally, because students must take ownership of the development and execution of their cognate, the system better prepares them to engage in lifelong learning (outcome i). Since 2010, two of these outcomes (g, h) have been evaluated each year by the program's IAB through review and scoring of capstone project reports written by graduating seniors. On both measures, the average rating has climbed from near 3 prior to the change, to in excess of 3.5 following the change. These measures are on a scale where 3 = achieved and 4 = strongly achieved the outcome being evaluated. In addition, senior exit surveys measuring their perception of how well the program has prepared them to demonstrate each of the standard 11 ABET student outcomes (ABET, 2012) shows each outcome achieving the benchmark measure of 80% strongly agreeing or agreeing, and the average of all measures increasing since the changes were implemented.

While the cognate provides a number of program-level outcome benefits, only through implementation has it become clear how students are making use of this newfound flexibility and developing a more well-rounded skill set and perspective. To better understand the utilization of this newfound flexibility, a two-part study was completed one year after the implementation of the program and again three years into the implementation. Each year, the first part of the study reviewed the advising files of current students to categorize the cognate plans of any student who already had a documented set of cognate courses in his or her program of study. The second part used an assignment given to new IE students in the first-semester, introductory course. In this assignment the students 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.

One year following the implementation, these efforts provided a list of 50 cognates for review, while the most recent effort provided 74. 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 or intends to complete a minor.
- Custom: The student designed his or her own custom cognate program.

Table 2 summarizes this data for the each cohort for both of the years the data was collected.

The information presented in Table 2 begins to show the diversity of uses that students are finding for their cognates. In fact, only six of the 51 cognates found in student advising files are from areas that might typically be considered part of the electives offered in a more traditional IE program, such as inventory management, supply chain, or human factors. The remaining nearly 90% of cognates are from areas as wide ranging as community health, sociology, foreign languages, and business or entrepreneurship. Of these, by far the most popular are business topics, representing nearly 20% of the data set.

Table 2: Distribution of Developed Cognates

	Fall 2013 Data Set			Fall 2015 Data Set		
	Students in Intro Course	Experienced IE Students	Total	Students in Intro Course	Experienced IE Students	Total
Example	12	4	16	8	11	19
Minor	12	12	24	12	32	44
Custom	8	2	10	3	8	11
Total	32	18	50	23	51	74

Perhaps even more informative than the summary data are specific examples of how students are putting their cognate programs to use to achieve their near-term career goals. In one of the first cognates developed, a student who desired to work in healthcare developed a custom healthcare cognate combining a graduate course in healthcare engineering with courses in nursing and public health administration to deepen her understanding of the industry. Following graduation, this student was hired as a project manager and healthcare engineer for a leading medical research hospital in the Midwest. In another case, a recent graduate used study-abroad courses to build a focus in supply chain management since adequate courses did not exist at MSU at that time. This student is now working as a supply chain engineer in the oil and gas exploration industry. This dramatic use of courses from outside MSU is not an isolated case. Additional examples include a junior student currently studying sustainability topics in Sweden as part of his cognate, while another prepares to study in Japan as part of his language cognate, and another is exploring online courses in sports management for a cognate in Sabermetrics. A final example is a student with an interest in improving engineering education, who has developed a cognate around engineering writing research by combining course credit from an undergraduate research experience with advanced technical writing work. These are but a few of many cases where the flexibility provided by the cognate is making a real difference for students. In each of these cases, the cognate program enables students to pursue their passion while broadening their educational experiences.

Conclusion

A variety of external and internal forces created the impetus for transforming the IE curriculum into the IMSE curriculum at MSU. A key consideration of the faculty in this change was how to add flexibility to the curriculum to address calls for developing more well-rounded engineers who are prepared to meet the demands expected of engineers in the future. At the end of the update 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. By modifying the curriculum in key ways, the faculty were able to increase the flexibility of the degree program while maintaining ABET accreditation.

The new curriculum incorporates 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 a broad range of areas. Results indicate that the effort has met its fundamental goals on each dimension, including increased enrollments, high student performance in IE fundamentals, and increased student interest in studying a broad range of topics outside IE that will further their career goals. In the spirit of continuous improvement, the faculty continues to monitor the success of these changes and look for additional enhancement opportunities for the curriculum and cognate program.

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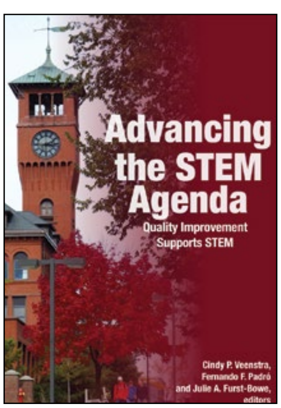

This publication is full of collaborative models, best practices, and advice for teachers, higher education faculty, and human resources personnel on improving the student retention (and thereby increasing the supply of STEM workers). Ideas that will work for both STEM and non-STEM fields are presented. The introduction maps out the current landscape of STEM education and compares the United States to other countries. The last chapter is the conference chairs' summary of what was learned from the conference and working with 36 authors to develop this book. This effort is part of a grassroots effort among educators to help more students be successful in STEM majors and careers.

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