AC 2008-416: BUILDING A NEW KIND OF ENGINEERING DEGREE AT JAMES MADISON UNIVERSITY

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Building a New Kind of Engineering Degree at James Madison University

Abstract

In December of 2005, James Madison University set out on a mission to develop a new kind of engineering degree program. A task force of faculty from the College of Integrated Science and Technology, the College of Science and Mathematics, and the College of Business envisioned a new degree program that combined the best elements from a strong Liberal Arts education with a strong science, technology, engineering, math, and business curriculum.

Recommendations from the National Academy of Engineering and ideas from faculty, industry representatives, and the popular literature were combined with ABET accreditation standards and requirements from the Fundamentals of Engineering (FE) examination to develop a different kind of engineering curriculum which will, in turn, produce a different kind of engineering graduate. The task force developed a list of desired learning objectives and educational outcomes for the new degree program. Using the ABET accreditation criteria and the FE licensure exam as guidelines, more than 200 detailed learning objectives were developed and mapped to the individual courses in the new curriculum.

The result of this work is a new School of Engineering at James Madison University which will accept its inaugural freshman class in August 2008. The new school will offer a single, interdisciplinary engineering bachelor's degree that is designed to meet ABET accreditation standards and prepare graduates for the FE examination. The 4-year, 120-credit curriculum will focus on sustainability, engineering design, and integrated systems analysis.

History of Program Development

In December of 2005, a collaborative team of faculty and administrators was assembled from across campus. The task force represented the College of Integrated Science and Technology, the College of Science and Mathematics, the College of Business, the Center for Assessment and Research Studies, and the Science and Technology branch of the University Library. This task force was charged by the Provost to examine the feasibility of James Madison University offering an engineering program and, if feasible, to propose a type of program that will meet current and future workplace needs for more qualified engineers, contribute to the overall academic offerings of the university and the state, and attract additional qualified students interested in science, technology, engineering, and math to the university.

The task force established an aggressive timeline (Table 1) that took the group from concept to implementation in little more than two years. In that time period, many external and internal sources of information were reviewed and considered in the design of the new program.

Table 1: Program Planning and Implementation Timeline

EVENT	DATE
Planning Task Force Formed	December 2005
Board of Visitors Approval	May 2006
State Education Council Approval	January 2007
Faculty Hiring & Website Development	February 2007
First Faculty Hires	August 2007
First Freshman Class	August 2008
First Community College Transfers	August 2010
First Program Graduates	May 2012
Anticipated ABET Accreditation	July 2013

For example, two reports from the National Academy of Engineering (NAE), "The Engineer of 2020" (1) and "Educating the Engineer of 2020" (2), were important resources. These reports, prepared by industry and academic leaders in engineering, are the result of an NAE initiative that attempts to prepare for the future of engineering education by addressing questions such as: (1)

- What will or should engineering be like in 2020?
- Will it be a reflection of the engineering of today and its past growth patterns or will it be fundamentally different?
- Can the engineering profession play a role in shaping its own future?
- Can a future be created where engineering has a broadly recognized image that celebrates the exciting roles that engineering and engineers play in addressing societal and technical challenges?
- How can engineers best be educated to be leaders, able to balance the gains afforded by new technologies with the vulnerabilities created by their byproducts without compromising the well-being of society and humanity?
- Will engineering be viewed as a foundation that prepares citizens for a broad range of creative career opportunities?
- Will engineering reflect and celebrate the diversity of all the citizens in our society?

To quote from the NAE report: "To maintain the nation's economic competitiveness and improve the quality of life for people around the world, engineering educators and curriculum developers must anticipate dramatic changes in engineering practice and adapt their programs accordingly. This report from the National Academy of Engineering, written by a group of distinguished educators and practicing engineers from diverse backgrounds, includes various scenarios for the future based on current scientific and technological trends. In addition to identifying the ideal attributes of the engineer of 2020, the report recommends ways to improve the training of engineers to prepare them for addressing the complex technical, social, and ethical questions raised by emerging technologies." (1)

Another example of a more recent report is from the Millennium Project at the University of Michigan entitled "Engineering for a Changing World". (3) Among other conclusions, this report recommends the following:

- "… the key to producing world-class engineers is to take advantage of the fact that the comprehensive nature of American universities provide the opportunity for significantly broadening the educational experience of engineering students, provided that engineering schools, accreditation agencies such as ABET, the profession, and the marketplace are willing to embrace such an objective." [3]

- "Undergraduate engineering should be reconfigured as an academic discipline, similar to other liberal arts disciplines in the sciences, arts, and humanities, thereby providing students with more flexibility to benefit from the broader educational opportunities offered by the comprehensive American university with the goal of preparing them for a lifetime of further learning…" [3]

Indeed "reinventing undergraduate education" (not just in engineering) was the theme of the Ernest L. Boyer Project of the Carnegie Foundation for the Advancement of Teaching. [4] [5] [6] [7] These reports were also considered by members of the task force as we considered "reinventing" undergraduate engineering education. The following recommendations were considered from among the broad conclusions in these reports: [6]

- Make research-based learning the standard
- Construct an inquiry-based freshman year
- Build on the freshman experience
- Remove barriers to interdisciplinary education
- Link communication skills and course work
- Culminate with a capstone experience
- Cultivate a sense of community

Popular literature describing the future of science and technology in our society was also considered. For example, in Thomas Friedman's landmark book entitled "The World is Flat" [8] he describes how technical education of the future must adapt to compete in a more global economy. "Enterprises that focus on technical aptitude alone will fail to align workforce performance with business value… Instead, they need to build a team of <u>versatilists</u> who build a rich portfolio of knowledge and competencies to fuel multiple business objectives." [8] He goes on to further define "versatilists" with respect to our traditional understanding of "specialists" and "generalists". "<u>Specialists</u> generally have deep skills and narrow scope, giving them expertise that is recognized by peers but seldom valued outside their immediate domain. <u>Generalists</u> have broad scope and shallow skills, enabling them to respond or act reasonably quickly but often without gaining or demonstrating the confidence of their partners or customers. <u>Versatilists</u>, in contrast, apply depth of skill to a progressively widening scope of situations and experiences, gaining new competencies, building relationships, and assuming new roles." [8]

These are but a few examples of the literature reviewed by the task force. These insights, along with perceptions from industry and academic experts who were consulted to review the progress and products of the task force, were synthesized along with on-campus discussions with faculty, staff, and administrators to develop design parameters for a new type of engineering degree that seamlessly integrates science, technology, engineering, and math subjects together with one another and with the appropriate economic, social, political, ethical, and legal concerns (exemplified in a strong liberal arts education) to prepare the "engineering versatilists" of the 21st century.

Program Design Parameters

The task force quickly developed a set of six basic design parameters for the new engineering degree program. Namely, the new Engineering program at James Madison University will:

- provide a single Engineering Bachelor's degree spanning the traditional engineering sub-disciplines
- matriculate approximately 50 students per graduating class
- meet ABET EAC accreditation standards [9]
- prepare students to pass the Fundamentals of Engineering (FE) pre-licensure exam [10]
- be designed to be completed as a 4-year, 120-credit curriculum
- have a program focus on sustainability, engineering design, and systems analysis

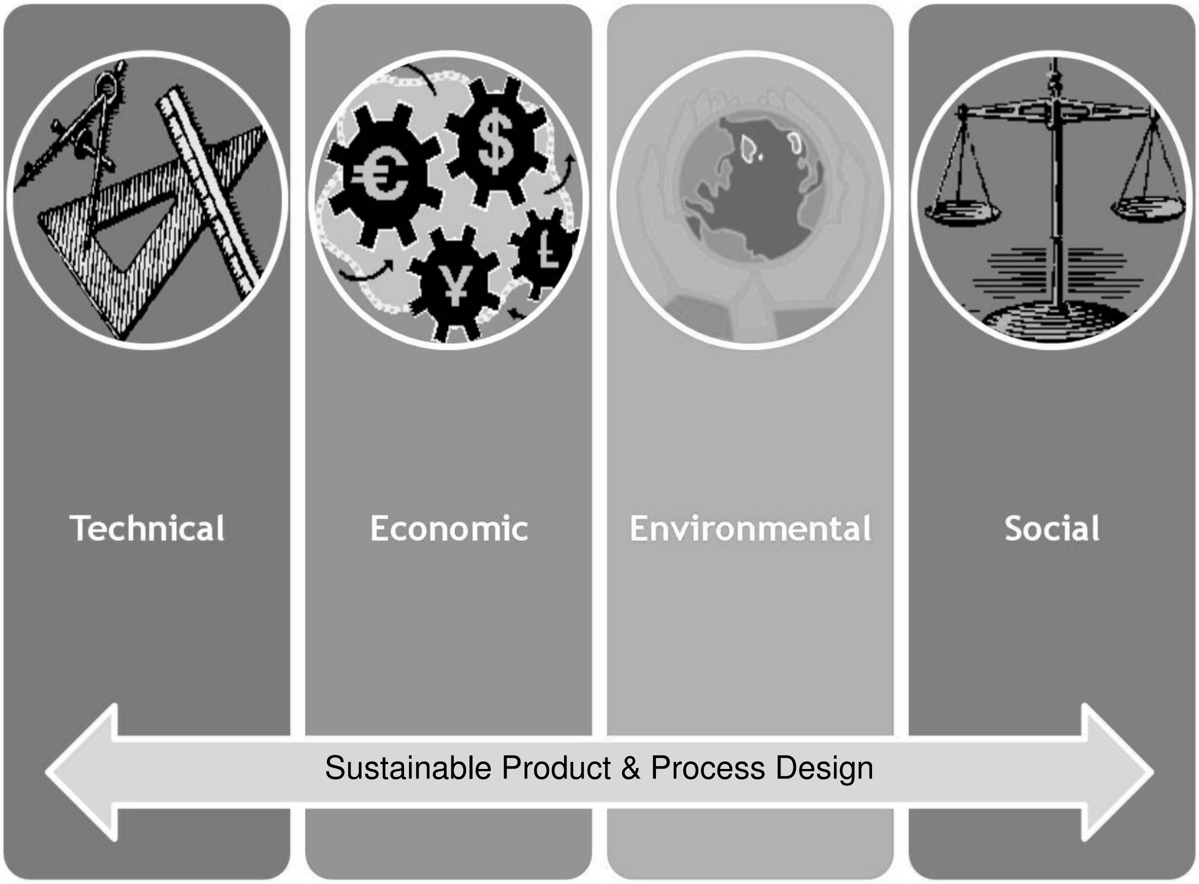
The focus of the new program on sustainability and engineering design was amplified and further defined as additional literature was reviewed, discussions were held with on-campus and external experts, and new engineering faculty were hired to begin implementation of the program. Sustainability resources reviewed ranged from the oft-cited 1987 Brundtland Commission Report [11] to more recent general, sustainability-focused publications [12] [13] [14] [15] [16] to contemporary NSF-sponsored workshops focusing specifically on the incorporation of sustainability objectives into engineering curricula [17].

Gro Harlem Brundtland once stated that "while industry used to be a main reason for environmental degradation, it is increasingly becoming part of the solution to environmental problems". [11] This sentiment is, if anything, increasing as we move into the 21st century. Tomorrow's engineers will be looked to more than ever to exhibit "sustainable engineering" practices as they execute their assigned product and process design duties. In fact, one could claim that the engineer of the future will be asked to transcend traditional engineering design in order to participate in the design of sustainable societies. With that image in mind, the Center for Sustainable Engineering defines "sustainable engineering" as "engineering for <u>human development</u> that meets the needs of the present without compromising the ability of future generations to meet their own needs." [17]

With these thoughts in mind, and a defined focus on sustainability and engineering design in our new curriculum, we defined the "sustainable design process" in our curriculum to be the integration of four distinct elements into teaching the engineering design process. These elements are the: <u>technical</u> requirements, <u>economic</u> requirements, <u>environmental</u> requirements, and <u>social</u> requirements of engineering product and process design.

Figure 1 illustrates how these four key elements of design come together to synergistically reinforce the design of truly sustainable products and processes. Unless and until these four elements are equally incorporated into the learning objectives of engineering design curricula, engineers will not truly be answering the call to participate in the design of sustainable societies.

Figure 1: Key Elements in Sustainable Product and Process Design



Together, consideration of these program elements led the task force to develop the following vision for the new engineering degree program: *James Madison University engineering graduates will improve the sustainability of Virginia and our world by participating in projects in which they analyze problems and design solutions in the context of environmental, energy, financial, security, and social impacts.*

Curriculum Design and Development

Next, the vision was used in conjunction with the six program design parameters to develop a comprehensive list of learning objectives for the new degree program. Using the ABET accreditation criteria and the FE pre-licensure exam as guidelines; more than 200 detailed learning objectives were developed and divided into the categories listed in Table 2.

Table 2: Learning Objective Categories

• Cognitive, Affective, & Communication Processes
  ○ Personal Development
  ○ Professional Development
  ○ Oral Communication: Interpersonal Behavior
  ○ Oral Communication: Group Processes
  ○ Written Communication
  ○ Decision Making
  ○ Allocentrism
	• Engineering Skills
	  ○ Transport Properties: Heat/Mass Transfer & Fluid Dynamics
	  ○ Equilibrium Properties: Thermodynamics
	  ○ Electricity and Magnetism
	  ○ Material Science: Process, Structure, Property Relationships
	  ○ Mechanics of Materials: Statics, Dynamics, & Deformable Bodies
	  ○ Engineering Design
	  ○ Systems Analysis
	  ○ Sustainability: Life-Cycle Design & Analysis

• Foundational Skills
  ○ Mathematics: Calculus & Statistics
  ○ Physics
  ○ Chemistry
  ○ Biology
  ○ Technical Problem Solving
  ○ Technical Reasoning & Problem Analysis
  ○ Instrumentation, Measurement, & Data Analysis
	• Business Skills
	  ○ New Product Development
	  ○ Business Functions
	  ○ Professional Values & Ethics
	  ○ Management of Technology
	  ○ Project Management
	  ○ Business Process Management

Next, learning objectives were mapped onto courses in six basic areas of the curriculum:

- General Education
- Science & Math
- Engineering Science
- Engineering Design
- Sustainability
- Business & Management

This curriculum design process led to the development of proposed courses, outlined in Tables 3 and 4. Table 3 organizes the proposed courses as a typical student would progress through the 4-year, 120-credit curriculum. In order to better compare the proposed curriculum with the vision and design elements described earlier, the credit hours in Table 3 are broken down and organized by curriculum area in Table 4.

Table 3: Proposed Courses for New Engineering Degree
(L) indicates courses with one or more integrated laboratory credits

Freshman Fall		Freshman Spring	
Calculus I	4	Calculus II	4
Physics I (L)	4	Physics II (L)	4
General Education	3	Introduction to Engineering (L)	3
General Education	3	General Education	3
SEMESTER TOTAL	*14*	*SEMESTER TOTAL*	*14*
Sophomore Fall		**Sophomore Spring**	
Calculus III	4	Differential Equations	4
General Chemistry (L)	5	General Biology or Geology	3
Management of Technology I	3	Statics & Dynamics (L)	4
General Education	3	General Education	3
Engineering Design I (L)	1	Engineering Design II (L)	1
SEMESTER TOTAL	*16*	*SEMESTER TOTAL*	*15*
Junior Fall		**Junior Spring**	
Fluids & Transport (L)	4	Thermo & Heat Transfer (L)	4
Instruments & Circuits (L)	4	Strength of Materials (L)	4
Technical Elective	3	Management of Technology II	3
General Education	3	General Education	3
Engineering Design III (L)	2	Engineering Design IV (L)	2
SEMESTER TOTAL	*16*	*SEMESTER TOTAL*	*16*
Senior Fall		**Senior Spring**	
Sustainability I	3	Sustainability II	3
Systems Analysis	3	Technical Elective	3
Technical Elective	3	General Education	3
General Education	4	General Education	3
Engineering Design V (L)	2	Engineering Design VI (L)	2
SEMESTER TOTAL	*15*	*SEMESTER TOTAL*	*14*

Table 4: Breakdown of Credit Hours by Curriculum Area

Curriculum Area	Further Breakdown	Total Credits	Laboratory Credits
Foundational Science & Math	Math	16	0
	Physics	8	2
	Chemistry	5	1
	Biology/Geology	3	0
Engineering	Engineering Science	32	7
	Engineering Design	10	10
Business		6	0
General Education	(non-STEM/Business)	31	0
Technical Electives		9	---
TOTALS		*120*	*20*

Critical review of Tables 3 and 4, as compared with traditional engineering curricula, identifies several differentiating features of the proposed curriculum. Namely, the proposed engineering degree program:

- *spans the traditional engineering sub-disciplines.*
  The new School of Engineering will offer a single Engineering Bachelor's degree as opposed to building separate degree programs in engineering sub-disciplines.

- *provides an in-depth, hands-on, 4-year engineering design experience.*
  The focus on engineering design spans the entire four years of the curriculum, beginning with the freshman "Introduction to Engineering" course and continuing through six semesters of a longitudinally integrated design curriculum.

- *contains integrated business courses designed specifically for engineers.*
  Two required business/management courses have been designed exclusively by the College of Business (COB) for the School of Engineering. COB representatives are also involved in the design and delivery of the "Introduction to Engineering" course, the "Systems Analysis" course, and the entire "Engineering Design" sequence.

- *provides an integrated focus on sustainability and sustainable design processes.*
  Sustainability and sustainable design concepts are not limited to the two capstone "Sustainability" courses, but rather are incorporated throughout most of the classroom, laboratory, and design studio experiences. In fact, the COB is working collaboratively with the School of Engineering to offer a "Business Sustainability" certificate to students in COB and Engineering that encourages and recognizes integrated project and course work beyond the required sustainability curriculum in both programs.

- *contains 20 credits of hands-on laboratory experiences.*
  In order to encourage and develop the "practical ingenuity" that is so desperately required (and often lacking) in today's engineering workforce [1] [2], the curriculum contains 20 credits of hands-on laboratory experiences. These include laboratories in the traditional sciences, the engineering sciences, engineering technology, and the integrated design studio.

- *is rooted to a strong, traditional liberal arts core curriculum.*
  In order to create the global engineering versatilists that will be a critical part of the 21st century economy [8], the political, cultural, and social aspects of a strong liberal arts education are incorporated throughout the curriculum. In fact, a strong engineering degree on a campus that is known for producing broadly educated and enlightened global citizens is one of the most unique attributes of the new program.

- *prepares students to pass the Fundamentals of Engineering pre-licensure exam.*
  In order to ensure that our alumni are well prepared to perform as practicing engineers, all students will be required to take the Fundamentals of Engineering pre-licensure exam before graduation. In fact, the learning objectives of the new curriculum were developed, in part, with the FE exam in mind. This will not only demonstrate each student's knowledge and

skills upon graduation, but, taken as an aggregate, will serve as a nationally normed assessment instrument in our integrated ABET program assessment strategy.

- *exists on a campus with a strong undergraduate teaching, research, and service focus.* According to the 2008 U.S. News & World Report rankings, James Madison University is the South's top public, master's-level university for the 14th consecutive year. The university was also one of 12 public colleges (and 35 institutions overall) from across the nation spotlighted by the same publication for excellence in undergraduate research opportunities. Furthermore, the university also earned national recognition for its outstanding first-year experiences, learning communities and service learning environment.

- *provides an engineering bachelor's degree within a relatively flexible 4-year, 120-credit curriculum.*
  The proposed curriculum will allow a student to graduate with an engineering degree in 120 credits. This credit count, combined with relatively short "prerequisite chains" will allow appropriately prepared students to complete the curriculum in four years, while still having an opportunity to pursue a related minor or concentration. Furthermore, appropriately prepared community college transfer students will be able to transfer into the program with an associate's degree in engineering and complete their bachelor's degree in two additional years.

Integrated Assessment Plan

During curriculum development, an integrated assessment plan was also developed that incorporated a wide range of assessment instruments, while remaining cognizant of the need to make the assessment process sustainable and well-aligned with accepted ABET standards. While not the focus of this paper, it is important to outline the assessment instruments that will be deployed in this curriculum, and to emphasize the importance of incorporating an integrated assessment plan into the design of any new curriculum. Assessment instruments that will be used in this program include:

- Personal Reflective Journals
- Learning Style Indices
- Student Portfolios
- Concept Inventories
- FE Exam Scores & Sub-Scores
- Student Focus Groups
- Senior Exit Interviews
- Alumni Surveys
- Employer Surveys
- Exam/Course Grades

Details of the assessment plan and challenges associated with assessing the effectiveness of a new, non-traditional engineering curriculum will be addressed in more detail in subsequent papers.

Opportunities after Graduation

Upon graduation from this program, we anticipate that alumni will be prepared for a wide range of opportunities in three primary areas, as outlined in Table 5.

Table 5: Anticipated Opportunities After Graduation

Engineering Workforce	Engineering Graduate School	Other Opportunities
Applications Engineering	Civil Engineering	Business School
Process Design	Environmental Engineering	Law School
Product Design	Industrial Engineering	AmeriCorps
Process Engineering	Materials Engineering	Peace Corps
Project Engineering	Mechanical Engineering	Military Service
Systems Engineering	Systems Engineering	Entrepreneurship
Other Options: • Product Service • Technical Sales • Management Training • Technical Marketing • Etceteras	Other Options: • Aeronautical Engineering • Agricultural Engineering • Biological Engineering • Chemical Engineering • Etceteras	Other Options: • Applied Science Fields • International Experiences • Medical School • Politics/Policy Careers • Etceteras

As you can see from Table 5, there are a wide range of opportunities available for a well-prepared "versatilist engineer" with a well-balanced liberal arts/technical education and the "practical ingenuity" associated with strong hands-on experiential laboratory and engineering design experiences. Furthermore, the focus on sustainability, engineering design, and systems analysis will empower and motivate graduates to engineer systems for sustainable societies by:

- analyzing and solving real-world human problems
- modeling, simulating, and testing complex interdependent socio-technical systems
- integrating business, social, and ethical aspects into engineering solutions
- working effectively in interdisciplinary teams & international environments
- managing engineering projects in a timely and cost-effective manner
- communicating solutions effectively to diverse audiences
- striving toward lifelong learning & creative critical thinking

In short, engineers graduating from this program will be, as the mission statement of James Madison University states, *"educated and enlightened citizens who will lead productive and meaningful lives."*

Industry, Student, and Faculty Response

Ultimately, the success in building a new program depends, in large part, on the response of prospective employers, prospective students, and prospective faculty.

In the process of preparing the curriculum for the new School of Engineering, the task force had the opportunity to share our work with several engineering industry representatives who provided suggestions and comments on our work. Following are representative quotes taken directly from their reviews and letters of support.

- "Certainly the rising global awareness of environmental and energy conservation issues emphasizes the need for engineers who understand and appreciate sustainable systems design." *Michael Stoltzfus, President and COO, Dynamic Aviation, Bridgewater, VA.*

- "A graduate from the proposed Engineering Program at JMU would provide just the kind of engineer we need, with a focus on engineering design and analysis, project management skills and a background in engineering business practice." *David Maccarelli, President, nTelos Wireline, Waynesboro, VA.*

- "… it is evident to me that the graduates of this program will possess the requisite skills to enroll in graduate programs or enter the engineering workforce." *Kent Murphy, Founder and CEO, Luna Innovations Incorporated, Blacksburg, VA.*

- "… I see a demand for engineers with the skill sets described in your proposal at our Ecomagination infrastructure businesses, where we are making concerted efforts to meet customers' demands for more energy-efficient, less emissive products." *Jim Berlin, VP, HW Technology, GE Fanuc Automation, Charlottesville, VA.*

- "… [the] multiple discipline approach will provide students with the in-depth knowledge to meet the needs of those companies which are seeking professional employees who will integrate knowledge from different fields in order to create marketplace solutions." *Catherine Glordano, President and CEO, Knowledge Information Solutions Incorporated, Virginia Beach, VA.*

- "It is our belief that the new curriculum proposed by JMU will produce the traditional engineering talent combined with new skills required in this conceptual age." *Jose Travez, CEO, Prototype Productions Incorporated, Ashburn, VA.*

In terms of student response to our new program, recall that the program was designed for an average of 50 students per class, for a total student body of approximately 200 students. The first class is scheduled to enter the program in August of 2008. As of February 2008 there were more than 700 applications at the university admissions office indicating the new School of Engineering as their anticipated major. Given our university's typical selectivity ratios, one would anticipate that this number of applications would translate into an entering freshman class of approximately 80-90 students. This is well within our design parameters and indicates strong student interest in the new program.

As for faculty interest, we have successfully recruited two new faculty members into the program over the last year. One is a male mechanical engineer and the other is a female biomedical engineer. Both enter the university as Assistant Professors, but with some teaching and curriculum development/assessment experience. Combined with my 20-year industry/academic experience in chemical engineering and materials science, we have quickly developed the core of a very diverse, interdisciplinary faculty. We are currently searching for a fourth faculty member and have received more than 170 applications from faculty candidates with a wide range of technical backgrounds and experiences.

Program Administration

The formation of the new School of Engineering at James Madison University occurred in conjunction with other administrative changes at the institution that were designed to synergistically coordinate campus activities in science, technology, engineering, and mathematics (STEM). Specifically, a Vice-Provost was named to coordinate the university's STEM initiatives. The Director of the School of Engineering reports directly to the STEM Vice-Provost and, along with the Dean of the College of Science and Mathematics and the Dean of the College of Integrated Science and Technology, makes up the university's STEM leadership team (see Figure 2). This streamlined organizational structure allows the School of Engineering to have extraordinary access to, and opportunity to coordinate with, the entire spectrum of STEM departments and programs on campus (see Figure 3). Furthermore, this "compact" administrative structure facilitates demonstrable university support for the new School of Engineering in terms of consideration for resource allocation and curriculum approval processes.

This structure also allows the School of Engineering to easily tap into the knowledge and expertise of faculty across the entire spectrum of STEM programs in developing new engineering courses and identifying existing courses that will complement and support the engineering curriculum. For example, faculty in the Department of Integrated Science and Technology and the Department of Geology and Environmental Science will contribute significantly to the sustainability content of engineering courses, while faculty in the College of Business will design and offer the two Management of Technology courses in the curriculum. Furthermore, all of the departments in the College of Science and Mathematics are working with the Engineering faculty to coordinate the science and mathematics course offerings to support the new engineering curriculum. To encourage and facilitate these types of interactions, an Internal Advisory Committee has been formed with representatives from the following academic units:

- Biology
- Chemistry & Biochemistry
- Geology & Environmental Science
- Integrated Science & Technology
- Management (College of Business)
- Mathematics & Statistics
- Physics & Astronomy
- School of Engineering

This advisory group currently meets with the Director of the School of Engineering every two weeks to insure that good lines of communication are kept open and that a wide range of knowledge and expertise is used in the design and implementation of the new Engineering curriculum. It is anticipated that this very effective group will continue to meet (on a less frequent basis) once the new program is completely implemented to further assist the Director.

Figure 2: Administrative Structure of STEM Areas at JMU

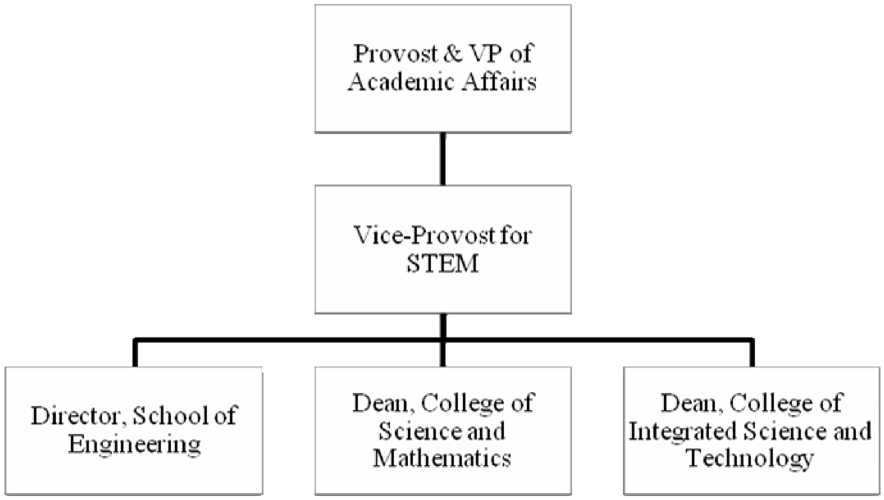
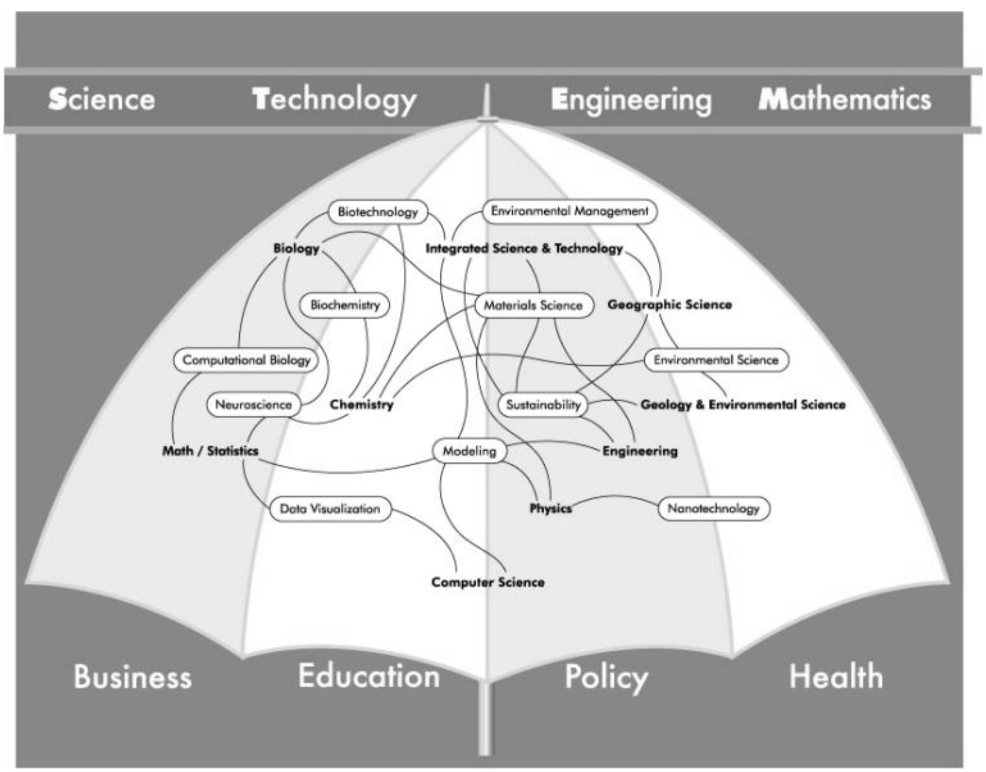


Figure 3: STEM Departments and Programs at JMU



Summary & Conclusion

A new type of engineering degree program has been developed at James Madison University that synergistically combines the strengths of a traditional engineering curriculum with many of the attributes that industry and academic experts have identified as desirable in the engineer of the 21st century. The new curriculum spans the traditional engineering sub-disciplines; focuses on sustainability, engineering design, and systems analysis; provides extensive hands-on laboratory and design studio experiences; and integrates business, management, and social aspects of sustainable engineering design into the curriculum. The 4-year, 120-credit curriculum is designed to meet all ABET accreditation standards and to prepare students to pass the Fundamentals of Engineering pre-licensure examination. Graduates will be prepared to succeed in the engineering workforce or in advanced engineering degree programs by exhibiting the "practical ingenuity" of an "engineering versatilist". Initial indications show a strong positive response to the new degree program by students, faculty, and industry alike. We look forward to welcoming the inaugural freshman class into the new School of Engineering in August of 2008 with excitement and enthusiasm.

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