Transformational Engineering Education

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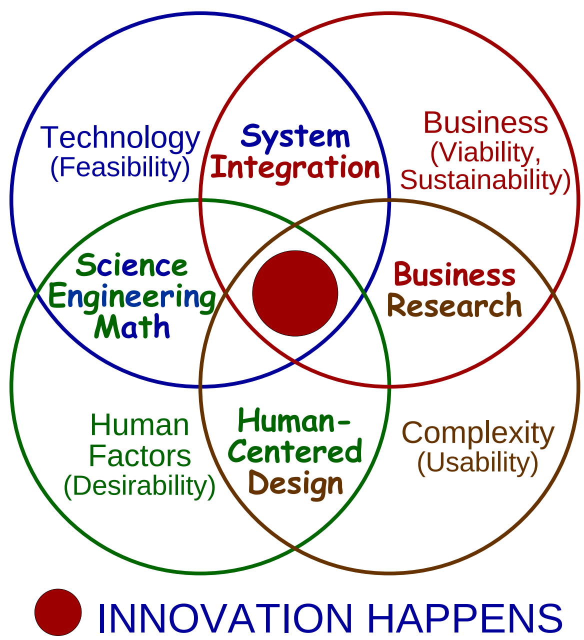
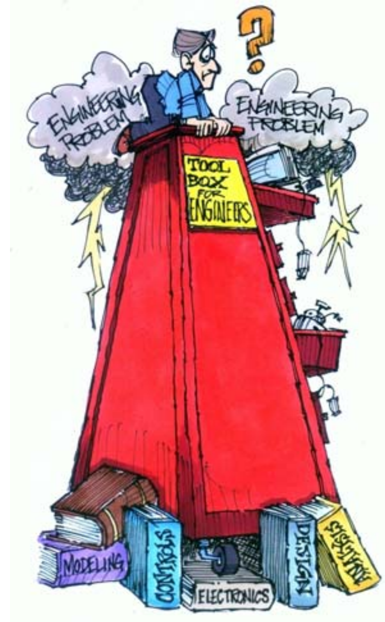
Current Situation

It is widely recognized that the future of the U.S. and indeed our everyday lives are increasingly dependent on scientific and technical innovation. However, the United States is in an innovation crisis fueled by a crisis in engineering education. The innovation shortfall of the past decade is real and there have been far too few commercial innovations that can transform lives and solve urgent human problems. Society's problems are getting harder, broader, and deeper and are multidisciplinary in nature. They require a multidisciplinary systems approach to solve them and present-day engineering education is not adequately preparing young engineers for the challenge. Basic engineering skills have become commodities worldwide. To be competitive, U.S. engineers must provide high value by being immediate, innovative, integrative, conceptual, and multidisciplinary. In addition, innovation is local – you don't import it and you don't export it! You create it! It is a way of thinking, communicating, and doing.



Innovation, the process of inventing something new, desirable, useful, and sustainable, happens at the intersection of technology, business, human factors, and complexity (see diagram, right). In addition to addressing the nation's needs for economic growth and defense, engineers, scientists, and mathematicians must identify and solve societal problems that benefit people, their health and quality of life, and the environment. The STEM (science, technology, engineering, and mathematics) disciplines must embrace a renewed human-centered focus and along with that a face that attracts a diversity of students interested in serving people at home and worldwide. Ninety percent of the engineering in the world today addresses the needs of the richest ten percent of the population. What about the other 90%? STEM students, as well as students from the humanities, arts, social sciences, and business, must all realize they are partners in solving the innovation crisis. They each play a vital role and must be able to identify the needs of people, to critically think and solve problems, to generate human-centered ideas and rapidly prototype concepts, to integrate human values and business into concepts, to manage complexity, to work in multidisciplinary teams, and to effectively communicate results. The quality of STEM education in innovation, both in K-12 and at universities, has a direct impact on our ability as a nation to compete in the increasingly competitive global arena.

Engineering, science, and mathematics educators face daunting challenges to prepare this next wave of STEM professionals. In general, the current preparation of students is inadequate for the challenge. Students focus on facts, tests, and grades and fail to understand concepts and processes. They are unable to integrate knowledge, processes, techniques, and tools, both hardware and software, to solve a multidisciplinary problem. Students need first, and foremost, to become critical-thinking problem solvers. Indeed, one of the great failures in STEM education has been the inability of graduating students to integrate all they have learned in the solution of a real-world problem, as the cartoon (right) suggests.



Students need to be shown the difference between studying engineering and becoming an engineer. They need to experience in a hands-on, minds-on way what it is to be an engineer – and this must happen early and often during their four-year academic career. The exclusive use of straight lecturing and the posing of questions for which there is only one correct answer must be replaced by discovery learning and learning with understanding. Faculty must guide students to discover engineering through the process of active investigation which: nurtures curiosity, initiative, and risk taking; promotes critical thinking; develops students' responsibility for their own learning and habits of life-long learning; and fosters intellectual development and maturity.

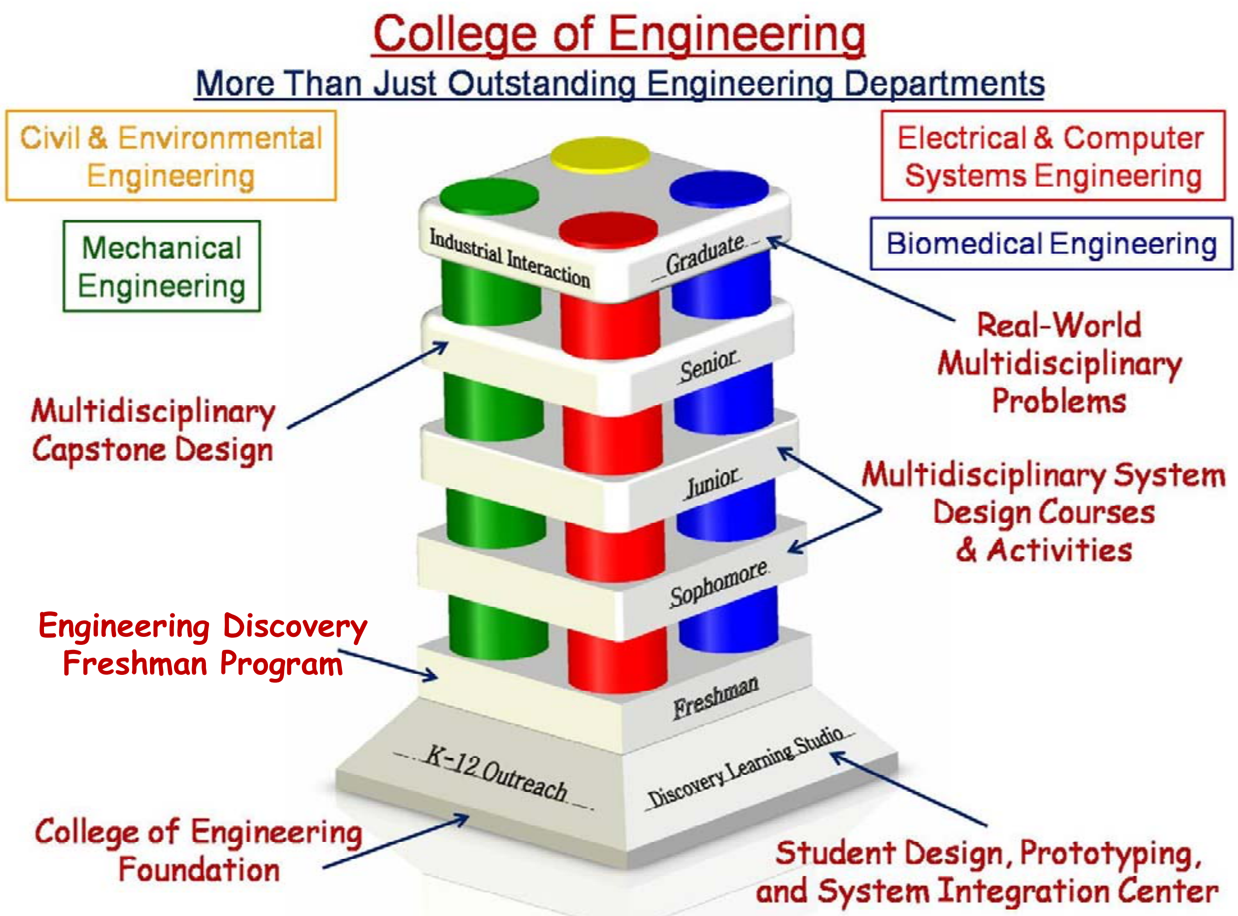
The situation for industrial professional engineering is very similar, as they are products of our failing engineering educational system. This situation has been exacerbated by the current economic crisis and is captured by the cartoon (right).

The National Science Board of the U.S. has stated that a continuation of the status quo in engineering education in the United States is not sufficient in light of the changing workforce demographics and needs. The status quo in engineering education is characterized by: lecture-mode faculty teaching and passive student learning; the exclusive silo structure of a university College of Engineering which deprives students of exposure to all disciplines and the multidisciplinary systems nature of modern engineering; and a reward system for faculty and students that promotes marginal teaching and accepts memorization in place of true understanding.

Clearly, a transformation is needed – for faculty and how they view teaching, for students and how they view learning, for each engineering department and its chair and how it views its role in collaboration with other departments in preparing students to be 21st-century engineers, and lastly, for the reward system for both faculty and students to enable this transformation to take root. New generations of students, with different backgrounds, interests, skills, and needs, must be attracted to and enthused about the profession of engineering and better prepared, in both technical and non-technical areas, to creatively advance technology and solve the problems the 21st century will present.

College of Engineering Response

Shown below is a 21st-century vision for a College of Engineering. The college must be more than just the sum of the engineering departments, each operating in its own silo.

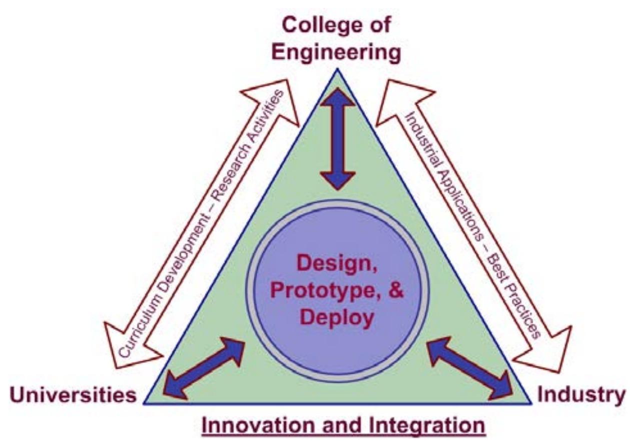


A 21st-century College of Engineering must respond to these urgent needs in three ways:

- K-12 Outreach that includes not only STEM disciplines but all students, e.g., humanities, social sciences, business, as all will play key roles in addressing the innovation crisis. This outreach must be fully integrated into the College of Engineering, as it is foundational. All engineering departments must be fully involved and informed.

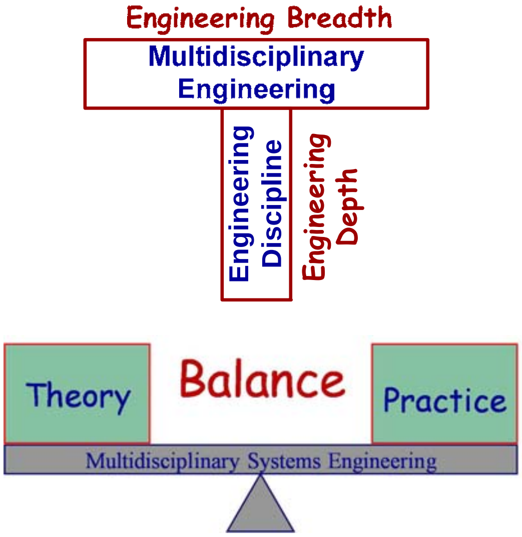
- Transformation of students, faculty, curricula, administrators, and facilities within the College of Engineering based on a Discovery Learning philosophy and a multidisciplinary systems approach to problem solving.
    - Discovery Learning is at the core of a College of Engineering and is best defined by the student commitments or outcomes it brings about rather than the teaching methods used: critical thinking, independent inquiry, responsibility for one's own learning, and intellectual growth and development. There are a range of strategies used to promote learning, e.g., interactive lecture, discussion, problem-based learning, case studies, but no exclusive use of traditional lecturing! Instructors assist students in mastering and learning through the process of active investigation. It is student-centered with a focus on student development. The faculty member is now the "guide on the side" rather than the "sage on the stage."
- Renewed emphasis on genuine University – Industry Interaction to create a culture of innovation both throughout the College of Engineering and within industry partner companies. This interaction must be one of mutual collaboration, as only through a balance of theory and practice, i.e., academic rigor and best industrial practices, can the challenging multidisciplinary problems be solved.

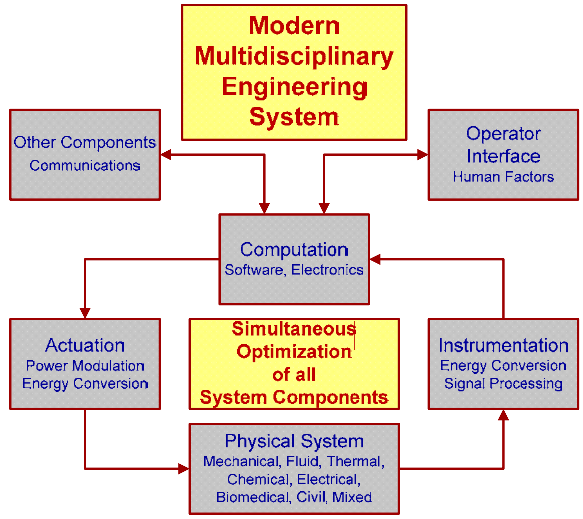
Importance of Industrial Interaction



What is the best way to train a student to become a practicing engineer? As shown (right), only through industrial interaction – knowing the types of problems engineers face, the concepts, processes, and tools they use to solve those problems, and the personal and professional attributes essential to be an engineer leader – not a follower – but an independent-thinking leader in our technological society – can we develop engineering curricula to transform our students. A key element for success as an engineer is balance – balance between theory and practice – between modeling & analysis and experimentation & hardware implementation. A transformation is essential – for both students and faculty!

As shown below, modern engineering systems are multidisciplinary requiring, from the start of the design process, integration and simultaneous optimization of the physical system, sensors, actuators, electronics, computers, and controls. This requires a new type of engineer, one with disciplinary depth and multidisciplinary breadth and a balance between theory and practice.





K-12 Outreach and Integration into the College of Engineering

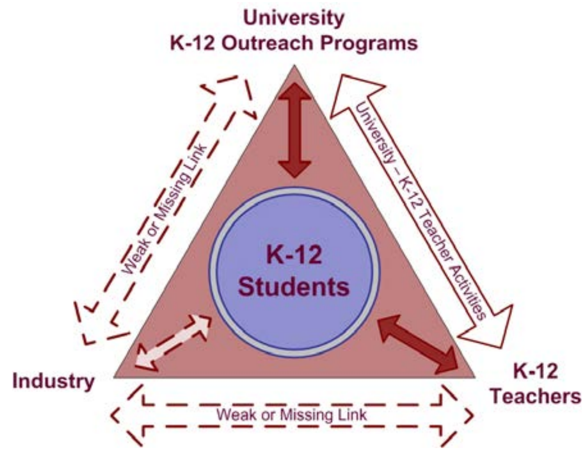
As a new decade begins, there is more and more emphasis from K-12 education and private / public funding agencies on STEM (science, technology, engineering, and mathematics) activities. STEM initiatives seem to be the focal point now for addressing the innovation crisis in the U.S. While this emphasis is essential, the focus is too narrow and exclusionary.

Students with no interest or particular talent in the STEM area may feel irrelevant to solving the innovation crisis. Teachers in non-STEM areas may also feel irrelevant. Students as early as the fourth grade are segregated into a college-bound STEM track and the “other” track, the irrelevant one. Parents may justifiably feel frustrated that their children are not valued for their individual abilities and passions when they do not conform to the perceived valued path as indicated by the proliferation of STEM charter schools and programs.

The message to our students must be that they are each vital to solving the innovation crisis and this message must be delivered early and often and in the context of real-world problems. They need to set high expectations for themselves, as we set high expectations for each of them. They need to discover their passion and their talents and take ownership for developing those talents knowing that in doing so they will play a vital role in transforming the world we live in. Engineers can make a vital contribution by setting a professional example and giving a real-world context to what young students study. We all know amazing things happen when together we attempt the seemingly impossible!

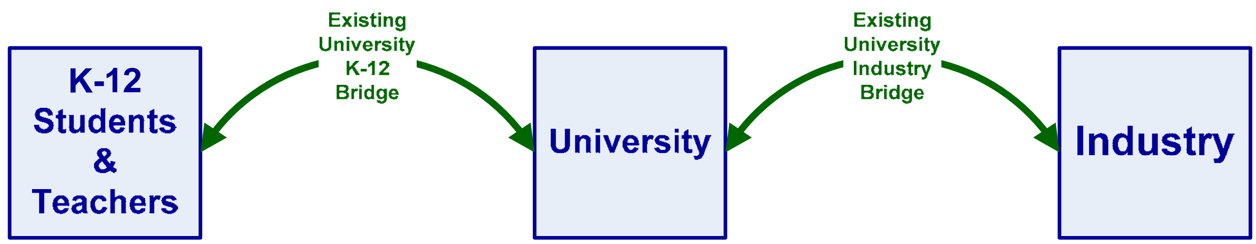
There are usually existing and developing programs between a university and local K-12 programs.   Their main purpose is to enthuse K-12 students about science, technology, engineering, and mathematics through various activities and prepare students for success at the university and beyond.

As the diagram (right) shows, there is, however, a critical missing element – meaningful, sustained interaction with industry and its needs and challenges. K-12 students and teachers need a direct and sustained connection to show the context of all that is taught and the role engineers, scientists, and mathematicians, as well as professionals in business, humanities, and social science, play in solving society's problems in energy, environment, sustainability, health care, water shortage, and poverty, for example, both here and throughout the world.

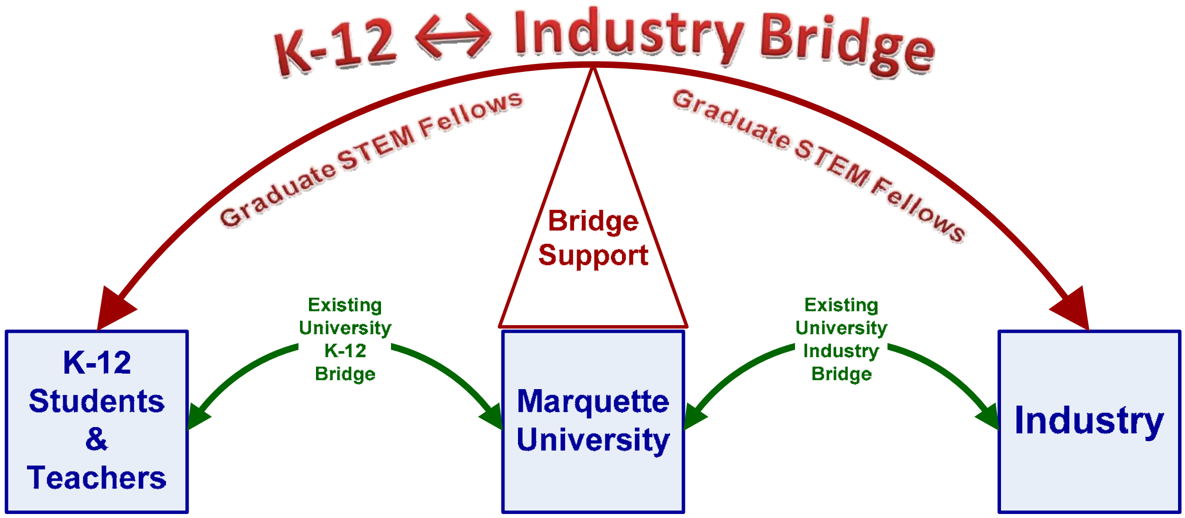


The best way to develop STEM curricula and create innovative STEM practitioners is through context: placing actual multidisciplinary problems in front of students early. Through industrial interaction the students will be able to know the types of problems engineers, scientists, and mathematicians face. They then will be able to observe the concepts, processes, and tools used to solve those problems, and develop the personal and professional attributes essential to be a technological leader: an independent-thinking leader in our technological society. Students need to be shown the difference between studying engineering, science, and mathematics and becoming an engineer, scientist, or mathematician with hands-on, minds-on experiences that happen early and often during their education.

While the present situation is far from ideal, this does not mean that it is uncorrectable. The diagram below shows that typically there are existing and developing programs between a university and industry and between a university and K-12 programs. These programs are shown below as bridges with the university as the middle island.



Marquette University is creating a *Culture-of-Innovation Bridge* (shown below) between the K-12 world and the world of industrial problem-solving, with the Graduate STEM Fellows comprising a *Community of Innovative and Integrative Engineers, Scientists, and Mathematicians* serving as the mentors and guides.



This will give the K-12 teachers and students a direct, sustainable connection to real-world problem solving through this bridge to the industrial world. Up to now, their main connection to the industrial world has been through the university, and mostly second hand. This bridge will have traffic in both directions with the travelers being K-12 teachers and students, industrial engineers, and applied scientists and mathematicians, with the Graduate STEM Fellows acting as facilitators and catalysts for change. The project themes are all multidisciplinary and will come from the STEM disciplines of engineering (mechanical, electrical, biomedical, civil, and environmental), applied mathematics, computer science, and physics.

As a result of this bridge, instructional STEM modules will be created that will have relevance and life-changing impact. In addition, inquiry-guided learning will replace exclusive straight lecturing and the posing of questions for which there is only one correct answer. Teachers will guide students to discover engineering, science, and mathematics through the process of active investigation which nurtures curiosity, initiative, and risk taking; promotes critical thinking; develops students' responsibility for their own learning and habits of life-long learning; and fosters intellectual development and maturity. New generations of students, with different backgrounds, interests, skills, and needs, will be enthused about the technological professions and be better prepared, in both technical and non-technical areas, to creatively advance technology and solve the problems the 21st century presents.

There are <u>five objectives</u> for this endeavor. They are the development of: (1) a human-centered, real-world-problem focus in the teaching and research of STEM topics; (2) professional attributes – team building, leadership, critical thinking, communication, mentoring, and social awareness; (3) partnerships among K-12, university, and industry environments; (4) STEM knowledge from research and application in teaching; and (5) STEM interest for K-12 students. These five objectives will have significant positive outcomes for the four constituent groups this project focuses on, namely:

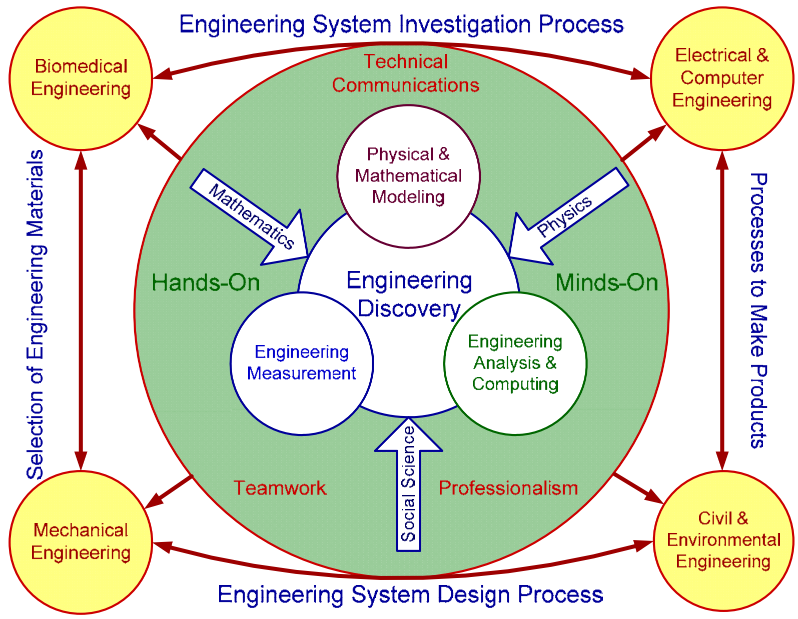
1. <u>K-12 Students</u> through enhanced inquiry-guided learning and exposure to real-world problems, the problem-solving process, and the role engineers, scientists, mathematicians, as

well as sociologists, artists, psychologists, business people – indeed people from all disciplines – play in meeting society's urgent needs.

2. K-12 STEM Teachers and Non-STEM Teaching Colleagues through enhanced inquiry-guided teaching techniques and exposure to STEM professional activities to ensure relevant content and sound pedagogy. Instructional modules to support this content will be created with the guidance of the STEM Fellows and industrial collaborators.
3. Graduate STEM Fellows through an appreciation of the need for a balance between theory and practice in applying their research to solve real-world problems and the importance of communicating their work to all audiences, both technical and non-technical.
4. Marquette University Engineering, Science, and Mathematics Departments in developing critical-thinking, culture-changing, technological leaders for society to identify and solve urgent needs through industrial involvement, while at the same time motivating K-12 students to follow in their footsteps.

Multidisciplinary Freshman Engineering Program

The focus here is on curriculum transformation, in particular, the multidisciplinary freshman engineering program. The diagram (right) shows all the elements of this two-course, two-semester program for all freshman engineers called *Engineering Discovery*, started in the fall 2008 semester at the Marquette University College of Engineering.



The course descriptions for Engineering Discovery 1 & 2 are given below.

Engineering Discovery 1

This course introduces the student to the practice of multidisciplinary systems engineering and engineering problem solving. Professionalism, teamwork, and technical communication are stressed. The Engineering System Investigation Process (modeling, analysis, and measurement) is applied to fundamental electrical, mechanical, fluid, thermal, and electromechanical systems using MatLab and LabVIEW. Elementary computer programming is developed. The Engineering Design Process and the role graphical communication – visualization, sketching, and computer graphics – plays in that process is studied. Students become proficient in the use of a three-dimensional computer graphics software. 3 credits – Fall Semester – One 50-minute lecture and two 110-minute studio (24 students maximum per studio) sessions per week – No prerequisites

Engineering Discovery 2

Students apply the Engineering System Investigation Process to actual multidisciplinary energy-related products, systems, or processes. They also work in small teams and apply the Engineering Design Process to an energy need or problem they have chosen and researched. Students develop broad technical understanding, as well as in-depth technical knowledge in energy systems, and also come to appreciate the manufacturing and materials choices, the design decisions, and the business and human-values aspects of present-day energy devices and systems. Internet-based documentation and presentation are emphasized. In addition, engineering computing using MatLab and LabVIEW, along with computer programming, to solve common multidisciplinary engineering problems is studied. 3 credits – Spring Semester – One 50-minute lecture and two 110-minute studio (24 students maximum per studio) sessions per week – Prerequisite: Engineering Discovery 1

The Engineering Discovery program objectives are:

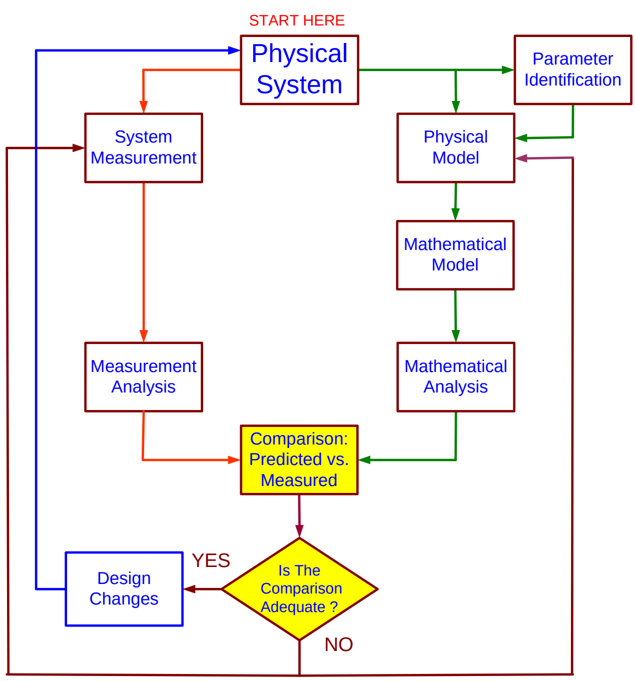
- Students will integrate problem solving, teamwork, oral/written/graphical communication skills, and computer usage in engineering system investigations and also design projects that benefit people and society.
- Students will begin to develop the professionalism, leadership, ethical behavior, social awareness, creativity, and critical thinking essential for the practice of engineering.
- Students will recognize the relevance and importance of science and mathematics and the role of business in the practice of engineering.
- Students will understand the importance of physical and mathematical modeling, analysis (both numerical and analytical), and measurement, i.e., the essential elements in the engineering system investigation process, and how this process leads to invention and innovation.
- Students will experience engineering within the various engineering disciplines and recognize the importance of the various disciplines and their interrelationships and similarities.
- Students will gain confidence about their future career as an engineer and their learning of engineering.

By the end of the first year, students will be able to:

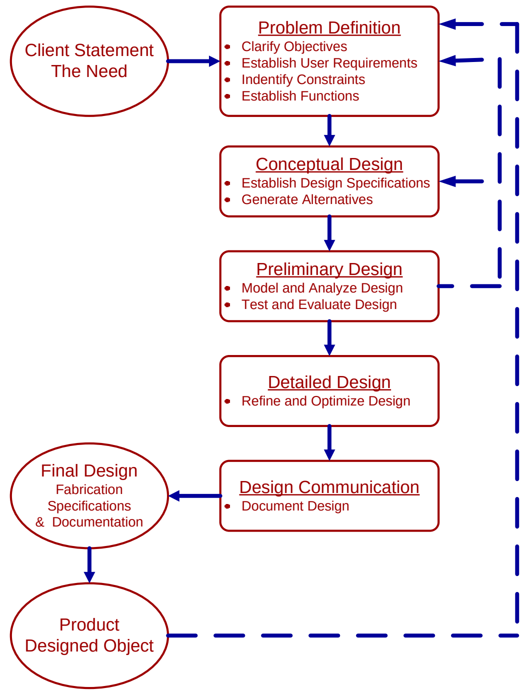
- Apply understanding of the multidisciplinary engineering system investigation process to simple dynamic physical systems.
- Predict behavior of simple dynamic systems through the application of mathematics and science principles to engineering problems.
- Use team work to apply the engineering system design process to societal problems with an integration of business and ethical concerns.
- Demonstrate written, oral, and graphical communication skills in the presentation and solution of engineering problems.
- Demonstrate critical thinking in the use of technology to solve engineering problems.
- Demonstrate increased confidence about their choice of an engineering career and their learning of engineering.

The two processes that are at the core of this program are the Engineering System Investigation Process and the Engineering Design Process, both shown below.

Engineering System Investigation Process



Design Process



The first-semester course starts with a two-week Deep-Dive Design Event focusing on Human-Centered Design (understanding the need, generating concepts, prototyping concepts, and evaluating concepts) and the needs come either from the developing world or from the university community. As an example, in 2009, the program consisted of:

- 240 Freshman Engineers in 60 Four-Person Design Teams
- 60 Sophomore Engineering Mentors
- Six Design Challenges
- The design challenges focused on the University Community and were chosen by a team of 16 sophomore-engineer summer interns based on the following criteria: motivational, challenging, level of complexity, resource availability, user accessibility, project scope, and quantifiability.
- The six design challenges were: campus security, dormitory efficiency, dinning-hall efficiency, crosswalk safety, personal storage, and climate acclimatization.
- Final presentations were made by all teams followed by a college-wide celebration.

The two-course *Engineering Discovery* sequence allows students to gain a glimpse of the structure of engineering knowledge, the potential depth of theoretical science and mathematical knowledge behind engineered systems, and to become familiar with engineering practices and design processes. Students complete their first year with the capacity to answer the following questions:

- What does an engineer do? What makes engineering challenging and exciting?
- How is the fundamental body of knowledge in science and mathematics used in the practice of engineering?
- What basic skills are required of all engineers?
- What kind of an engineer do I want to be?

In summary, a transformative first-year engineering experience has been created with the goal to immerse students (seen in studio, right) in the experience of what it means to be an engineer. Students start the process of becoming an engineer, not just studying engineering. They focus on multidisciplinary engineering system investigations and discovery learning. The interaction of technology, business, human values, and complexity to achieve innovation is directly experienced by students through the application of the engineering system design process to real-world problems. The students embrace a new attitude towards learning and knowledge. They are expected to come prepared for class, ready to learn and dynamically interact. Faculty have a new attitude towards teaching, mentoring students, and addressing different learning styles: kinesthetic, aural, visual, and written. Active, integrative, inquiry-guided teaching is becoming the norm. Changing attitude and behavior is difficult for all involved, but it is happening!

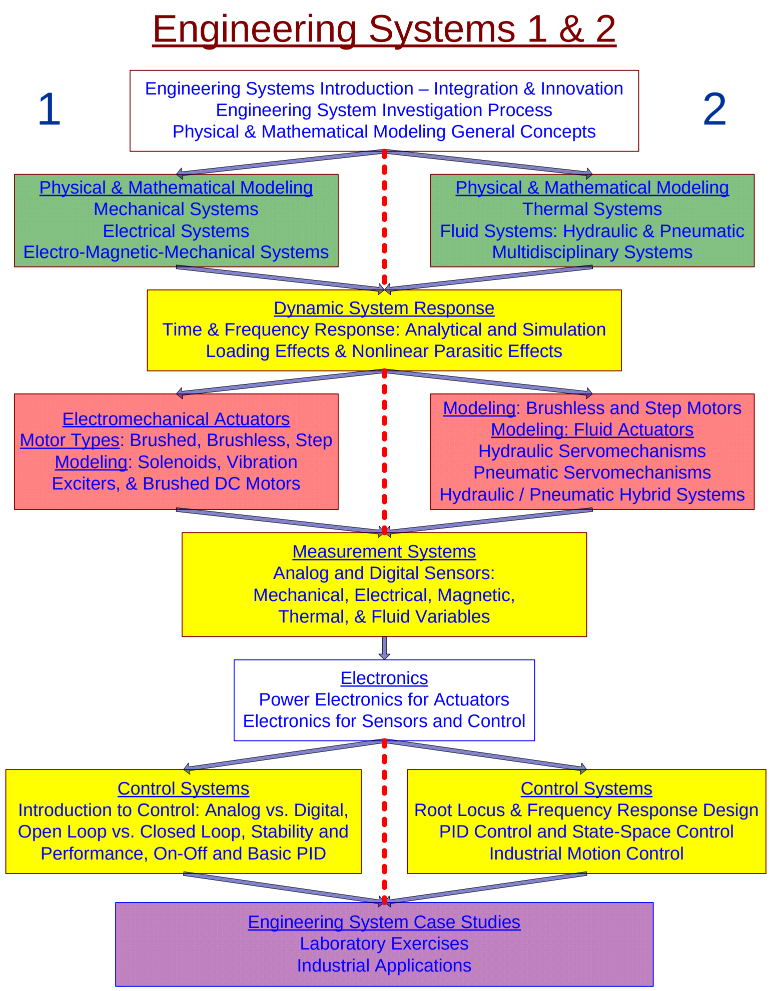
2nd- and 3rd-Year Multidisciplinary Engineering Systems Courses

Second- and third-year multidisciplinary engineering systems courses which are integrated with a balance between theory and practice are necessary to maintain engineering breadth during those years as students pursue disciplinary study and also to prepare students for the senior multidisciplinary capstone design experience and eventual engineering practice. The diagram below shows these two courses as Engineering Systems 1 and 2, with the following course descriptions. These courses will be offered starting in the 2010-11 academic year.

- Engineering Systems 1
  Electromechanical engineering systems and the Engineering System Investigation Process. Physical and mathematical modeling of mechanical, electrical, magnetic, and electromechanical systems. Dynamic analysis: time response and frequency response; analytical and numerical simulation. Electromechanical actuators: solenoid, vibration exciter, and brushed dc motor. Introduction to measurement systems: analog and digital;

motion, electrical, and magnetic sensors. Electronics for actuators, sensors, and controls. Introduction to control systems: analog vs. digital, open-loop vs. closed-loop, stability, and performance. Introduction to On-Off and PID control. Industrial case studies emphasizing integration. Laboratory exercises throughout the course. Extensive use of MatLab and LabVIEW. 2nd Year, 3 credits: two 50-minute classes, two 110-minute studios.

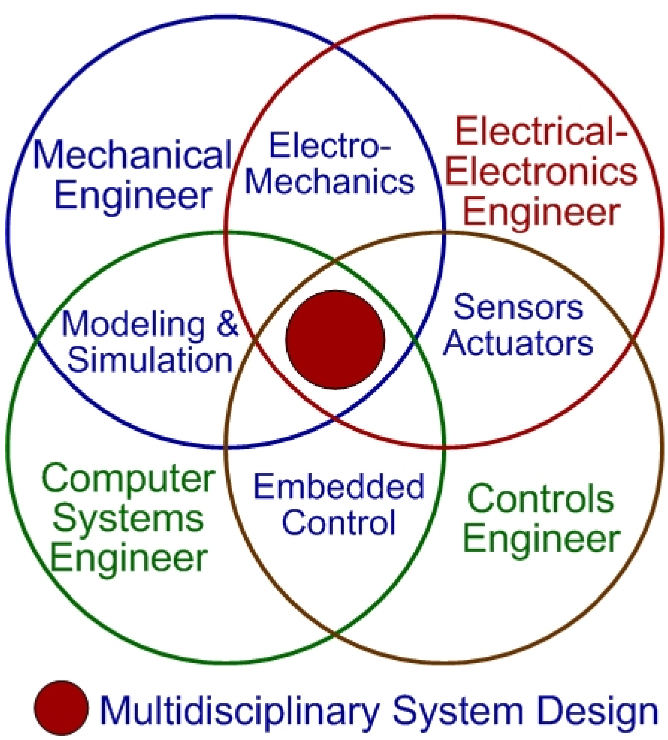
- Engineering Systems 2
  Multidisciplinary engineering systems and the Engineering System Investigation Process. Physical and mathematical modeling of thermal, fluid, and multidisciplinary systems. Dynamic analysis: time response and frequency response; analytical and numerical simulation. Electromechanical actuators: brushless dc motors and step motors. Fluid actuators: hydraulic and pneumatic. Measurement systems: analog and digital; thermal and fluid sensors. Electronics for actuators, sensors, and controls. Control system design: root-locus and frequency-response methods, PID control, state-space control, industrial control. Industrial case studies emphasizing integration. Laboratory exercises throughout the course. Extensive use of MatLab and LabVIEW. 3rd Year, 3 credits: two 50-minute classes, two 110-minute studios.



Senior Capstone Design Experience

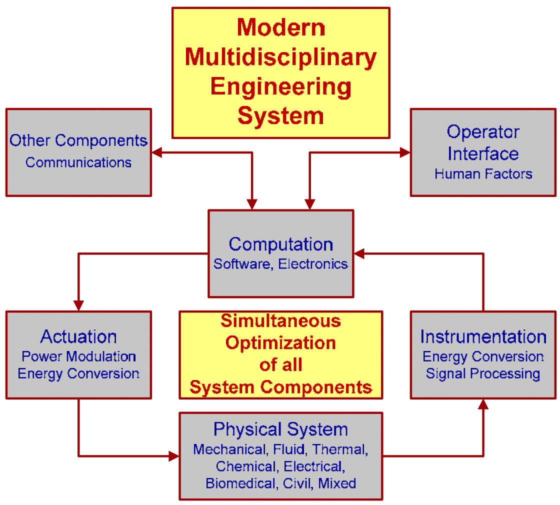
All engineering departments are required to have a senior-level, multidisciplinary, culminating, capstone design team experience. The goal is correct, but the implementation has very often failed. Corrective action is being taken immediately.

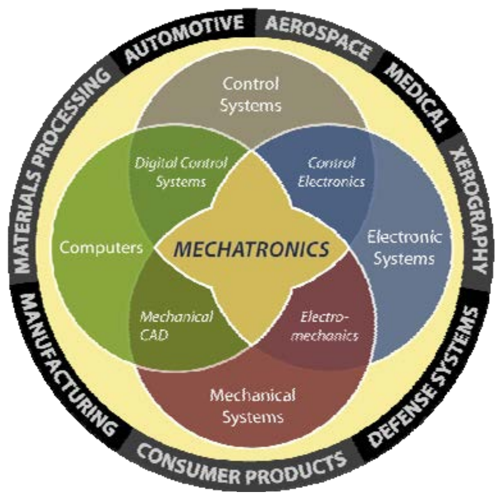
- Too often this course becomes a design-build-test exercise with the emphasis on just getting something done. Students rarely break out of their disciplinary comfort zone and thus fail to experience true multidisciplinary system design.
- In evaluating concepts, a modeling-and-analysis approach must replace any design-build-and-test approach, but this modeling is multidisciplinary and crosses domain boundaries. This rarely happens in this course.
- Multidisciplinary teams must apply human-centered, model-based design techniques.
- The course focus must be on multidisciplinary system design and integration, working outside one's comfort zone, learning new skills, concepts, tools (hardware and software), and not being afraid to fail.
- This course should not be all about deliverables (i.e., getting something built, getting a report submitted), but should reflect how multidisciplinary teams work in modern engineering practice, i.e., each team member with depth in a technical area but also breadth across many areas so as to be active participants in the total system design.
- The diagram below shows a typical core team for a multidisciplinary engineering system design. To this must be added discipline-specific expertise (e.g., biomedical, civil, environmental, chemical, nuclear), but this core team is most typical in modern engineering practice.



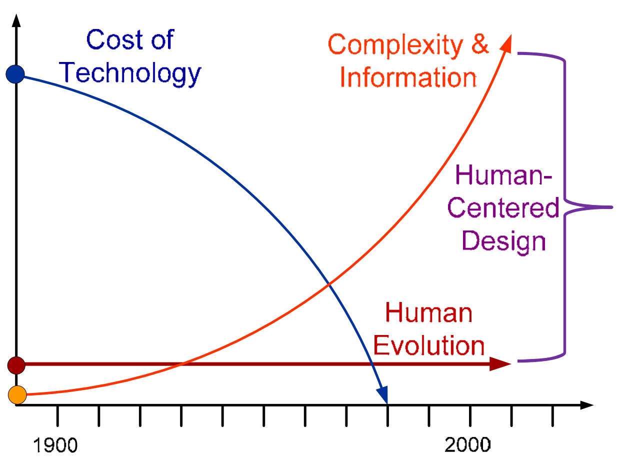
Multidisciplinary Systems Engineering: Mechatronics

Multidisciplinary engineering system design deals with the integrated and optimal design of a physical system, including sensors, actuators, and electronic components, and its embedded digital control system (diagram below on left). The integration is respect to both hardware components and information processing. An optimal choice must be made with respect to the realization of the design specifications in the different domains. Performance, reliability, low cost, robustness, efficiency, and sustainability are absolutely essential. It is truly a mechatronic system, as the name "mechatronics" does not just mean electro-mechanical (diagram below on the right).



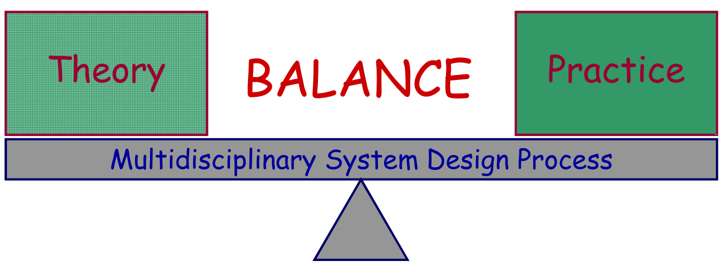


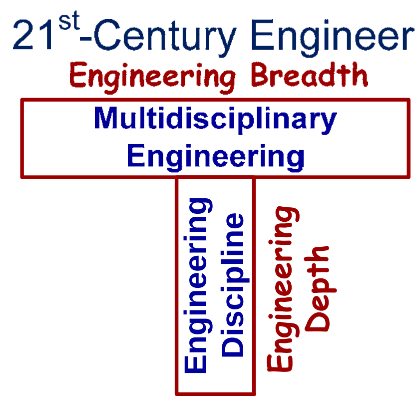
There are two keys to innovation through mechatronic system design. The first is Human-Centered Design (HCD). HCD requires interdisciplinary collaboration, an iterative process with frequent prototyping, and engagement with real people. As the cost of complexity has decreased dramatically, the quantity of complexity and information has increased just as dramatically, while human evolution, our ability to deal with inherent complexity in powerful systems, has remained constant (see diagram right). HCD helps bridge the gap.



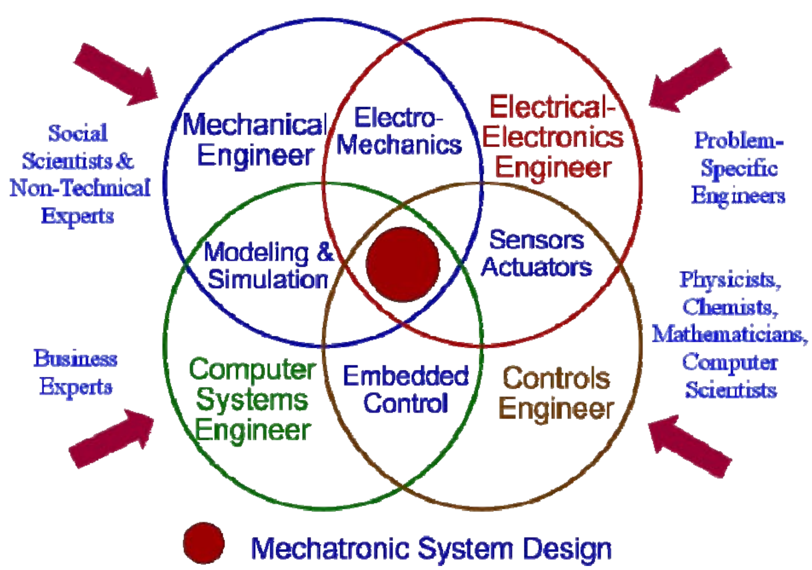
The second key is system-level, model-based design. Once a system is in development, correcting a problem costs 10 times as much as fixing the same problem in concept. If the system has been released, it costs 100 times as much. System-level, model-based design addresses this head on. The best multidisciplinary system design companies excel at communicating design changes across disciplines, partitioning multiple technologies present and allocating design requirements to specific systems, subsystems, and components, and validating system behavior with modeling and simulation (virtual prototyping) of integrated mechanical, electrical, and software components.

Undergraduate engineering education today is ineffective in preparing students for multidisciplinary system integration and optimization – exactly what is needed by companies to become innovative and gain a competitive advantage in this global economy. While there is some movement in engineering education to change that, this change is not easy, as it involves a cultural change from the silo-approach to a holistic approach. In addition, problems today in energy, environment, health care, and water resources, for example, cannot be solved by technology alone. Only a comprehensive problem-solving approach addressing the issues of feasibility, viability, desirability, usability, and sustainability will lead to a complete, effective solution. As the diagrams below show, the modern professional engineer must have depth in an engineering discipline with multidisciplinary engineering breadth and a balance between theory and practice.





A modern multidisciplinary system engineering design team – a mechatronic system design team – most often takes the form shown below, with all participants knowledgeable in controls, as it is such a pervasive, enabling technology.



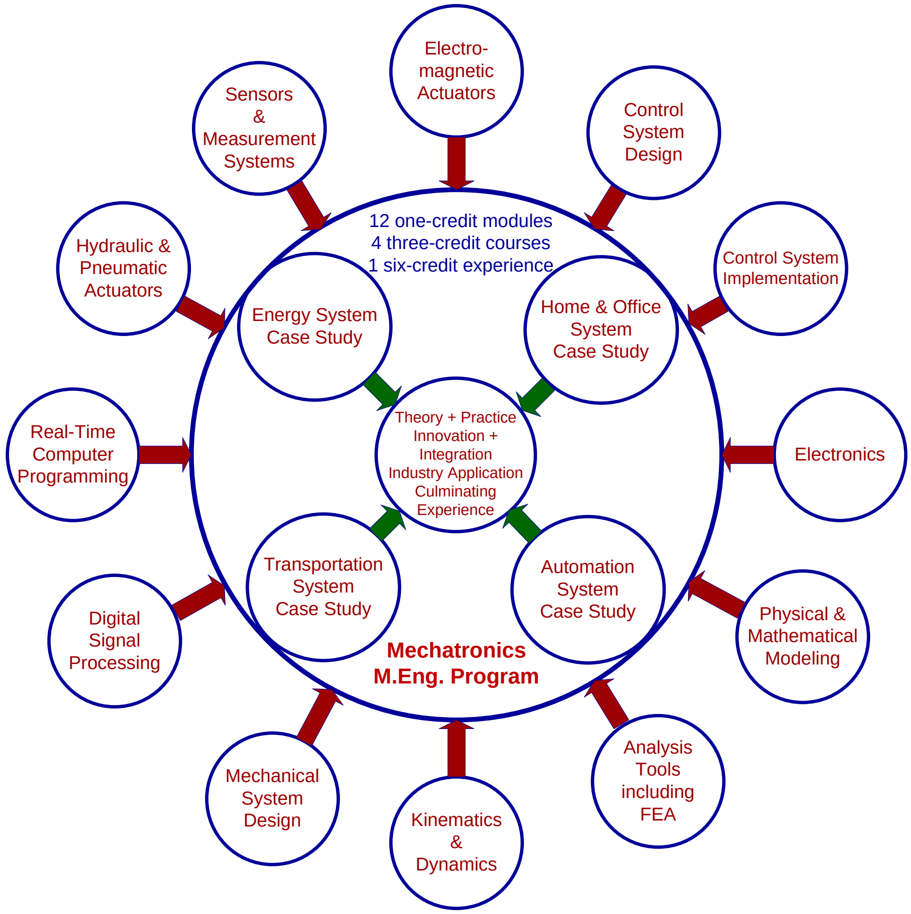
Innovative Graduate Program: Master of Engineering in Mechatronics

Engineering programs need more than four years to be truly effective. Practicing engineers usually pursue a graduate degree to fill the gaps in their undergraduate education and gain further knowledge and insight. Typically the graduate degree is more of the same with less relevance, practicality, integrative insight, and hands-on experience, and more in-depth theory that often is way beyond what most practicing engineers will ever use. They are siloed degrees in siloed institutions that often become very specialized. Most industries need problem solvers across disciplines rather than experts who know one thing really well. These graduate programs involve a selection of 10-12 three-credit courses from several departments, usually chosen by the student for scheduling convenience. Integration of concepts is left up to the student, as graduate courses are rarely taught in an integrated way. Each is its own stand-alone entity.

Aggravating the problem is the fact that practicing engineers cannot take a one-to-two-year leave of absence from a company to get a graduate degree. While practicing engineers can take courses by distance education, a three-credit course offered in a semester format can often be overwhelming from a time-commitment point of view and further complicates the integration of concepts. Students learn better in small chunks and not always at the same rate. In addition, the current distance education model is flawed as it tries to capture a lecture, with a camera in the back of a room, and not a learning environment.

The masters degree must change to respond to the needs of the modern practicing engineer. What is needed is a balance between theory and practice, between academic rigor and the best practices of industry, presented in an integrated way that feeds the needs of modern practicing engineers and the companies they work for. The new *Master of Engineering in Mechatronics* program attempts to remedy these deficiencies. The diagram below represents a new approach to graduate engineering education. The key element is the one-credit module which:

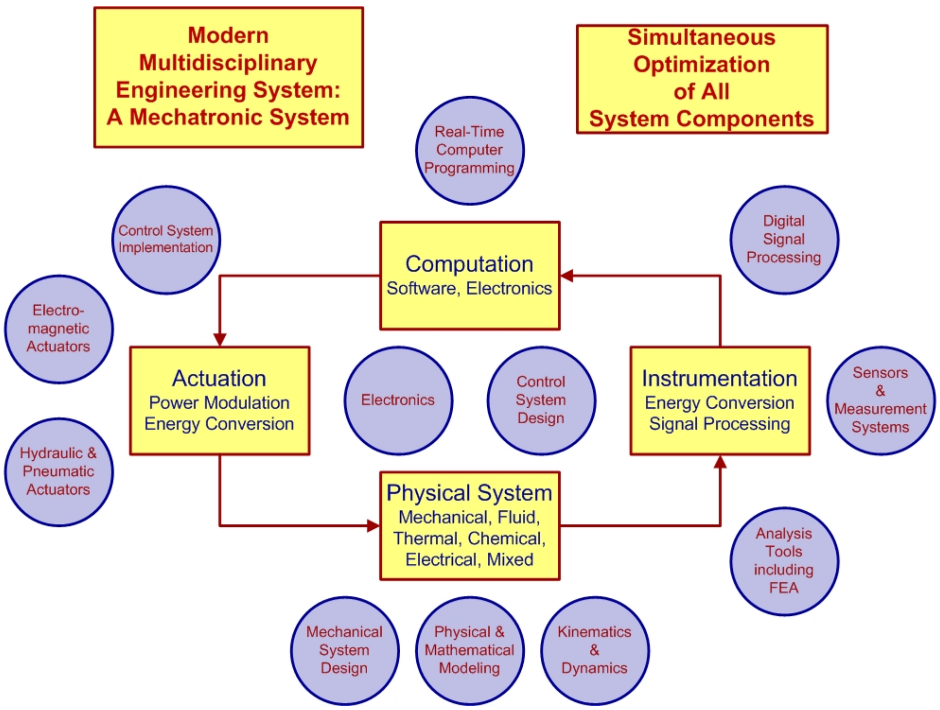
- Balances theory and practice where concepts are application-driven, not theory-driven. Important industry applications are studied with the goal to relate physical operation to engineering fundamentals through modeling and analysis.
- Identifies and understands industrial best practices by dissecting them into engineering and mathematical fundamental models.
- Achieves innovation by assembling these fundamental models into new products and processes.
- Analyzes both existing and new products and processes using computer simulations within a topic area.
- Demonstrates hardware to show system realization and validity of modeling and analysis results.
- Shows videos of industry systems and interviews with industry experts.
- Discusses best practices to achieve sustainability of products.
- Maintains flexibility through 15 one-hour blocks of instruction – a 5-week mini-course or longer if preferred.



All instruction is done via video with instruction interlaced with industrial interviews, laboratory experiments, and editorial sidebars – not just a camera at the back of a room. The modules can be used by both non-degree and degree-seeking students, and also for industry short courses.

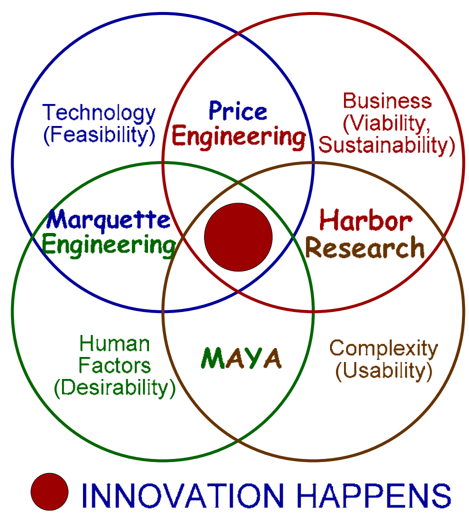
These modules all then feed into four three-credit, case-study courses, taking the student from the user and problem, to concept, to implementation, while emphasizing integration, trade-offs, and optimization at every step. These three-credit courses can be created to focus on a variety of needs, e.g., health care, wind power. An on-site culminating experience concludes the program allowing the student to put it all together in a six-credit integrated experience.

The diagram below shows the integration of these modules in a multidisciplinary engineering system design. Different modules can be added, while others deleted, depending on the application area.



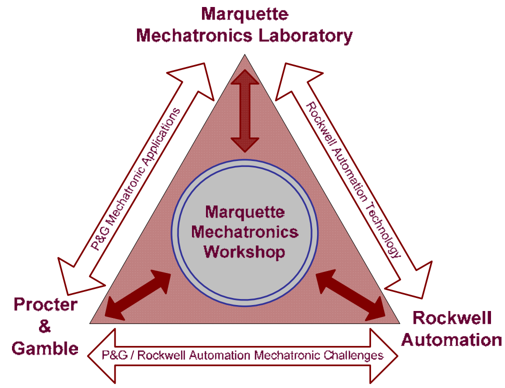
This program doesn't yet exist, but there is widespread industry and university support for its development. The content for these modules and courses resides in textbooks, industry application papers, and the minds of engineers and professors, so the development challenge is great, but the need is urgent! Modules and courses are presently being developed. Examples of the type of presentation for the Modeling Module can be found at http://mechatronics.eng.mu.edu/~publicshare/Movies .

Industrial Innovation Consortium



To aid a company in fostering innovation and creating a culture of innovation within, to assist in enhancing their engineering workforce with the latest technology, tools, and design approaches, and to give engineering students the opportunity for industrial interaction throughout their four years, a College of Engineering needs to create an Industrial Innovation Consortium, where thought leaders and industry leaders can collaborate to solve specific customer problems, develop broad new solutions, and create best practices that help re-shape industry as we know it today. Created in the summer of 2009, this consortium (see diagram, right) consists of: Price Engineering, a Wisconsin-based company specializing in system integration; MAYA, a world company focused on managing complexity; and Harbor Research, a world company focused on business research and strategy.

On December 14-17, 2009, Professors Kevin Craig, Phil Voglewede, and Mark Nagurka assembled 40 elite Procter & Gamble (P&G) and Rockwell Automation (RA) engineers at the P&G Corporate Engineering Technology Laboratory in Cincinnati, OH, for a one-of-a-kind workshop (see diagram, right) focusing on mechatronics, i.e., modern multidisciplinary systems engineering, and the urgent needs of both companies in this area vital to innovation for both companies. RA engineers make motors and electronic drives and P&G is one of RA's largest customers, as P&G engineers make the machines that make the consumer products we are all familiar with. A mechatronic approach to design gives each company a significant competitive advantage in the global marketplace.



Workshop Leaders
John Pritchard (left) RA
Jon Mclaughlin (center) P&G

P&G and RA Engineers
Discovery Learning at the
Highest Level

The Mechatronics Workshop was not a class or lecture; it was a real workshop. Its purpose was to foster innovation and collaboration now and in the future for both companies. It was interactive and participant-focused; participants learned from each other. It was all about insight. The Marquette professors presented a little, discussed a lot, and listened always. They gave new views, new concepts – always with the intent to enhance understanding and insight!

This is the second mechatronics workshop organized and delivered by Marquette Engineering Professors Craig, Voglewede, and Nagurka for RA and P&G. The first workshop was held in August 2008 at Marquette. A mechatronics workshop is planned for May 2010 in Italy between RA and Tetra Pak, another RA customer, with Marquette Engineering leading the way!

Conclusion

A 21st-century College of Engineering must be transformed – curricula, faculty, administrators, facilities – to become more than the sum of its engineering departments so that students can be transformed to become the critical-thinking problem solvers the world desperately needs.