Creating a Model Multidisciplinary Engineering Program

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Abstract

In order to provide an engineering education that meets contemporary demands to expand students' disciplinary breadth and range of problem solving, integrate rather than compartmentalize research and teaching experiences, and establish pervasive and significant experiential and teaming experiences throughout the course of study, Purdue University's College of Engineering has created a Multidisciplinary Engineering (MDE) program. The traditional vertical structure of the College of Engineering at Purdue has created excellent research and learning environments with proven success in equipping graduates and conducting world-renowned research. However, the same structure can also promote what is sometimes referred to as the "silo" effect where departments and schools focus primarily on specialized concerns to the detriment of collaborative and multidisciplinary efforts. The horizontal structure of the MDE program is tailored to build interfaces between new and existing engineering and science. In addition, it facilitates the College's ability to quickly respond to and offer courses, undergraduate research experiences, and degrees in emerging engineering fields without the need to create entire new departments. Presented in the paper is an overview of the MDE program structure, its component themes and the specific courses currently being created at Purdue University.

Background

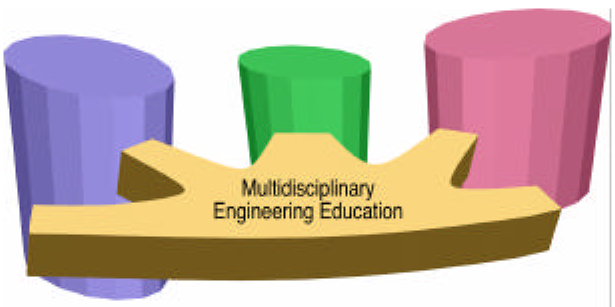
The last major shift in U.S. engineering education curricula occurred after World War II when government investment in university research increased, and "engineering science" emphasizing scientific and mathematical foundations replaced empirical design. This model worked well with the national imperative to build a research infrastructure that supported military and space superiority over the Soviet Union [1], and its curriculum legacy remains in our engineering classrooms. Students still gain technical knowledge on a narrow set of concepts applied within specialized disciplines taught by professors engaged in excellent research within discrete engineering fields. But the engineering world has changed since Sputnik. Fast-moving, global, multidisciplinary industrial environments require graduates to have not only the traditional technical knowledge of their predecessors but also a new and broader skill set. Engineers must now understand and apply several disciplines to solve complex problems, adapt to new technology and changing situations, combine ideas to synthesize creative solutions, and work effectively on teams while having excellent communication skills [2].

Building an efficient engineering education model to meet contemporary demands is also critical in light of current challenges besetting engineering education. The national attrition rate of engineering students surpasses 40% [1]. Less than two percent of U.S. high school graduates earn engineering degrees, over a million engineering jobs go unfilled [3], and the potential for minorities and women in the technical workforce remains thwarted [4]. Widespread beliefs prevail that engineering education is "hampered by outmoded instructional techniques and fragmentation of knowledge by disciplinary specialization" and is not “relevant, attractive, and connected” [5]. While engineering education deficiencies are often enumerated, many believe curriculum improvements cannot easily be made with the engineering educational approach of the last 50 years [6].

As the nation shifts engineering focus, however, engineering education is again responding to national needs [7]. The NAE National Research Council Board on Engineering Education, NSF Engineering Education Coalition Program, and the Accreditation Board for Engineering and Technology (ABET) Engineering Criteria 2000 ushered in a movement to reshape curricula. To build on these pioneering initiatives, educational reform must develop graduates as successful professional contributors and lifelong learners in global, multi-disciplinary markets; be flexible to support diverse career aspirations; be agile to rapidly transform in response to emerging social demands; and have a profound understanding of the importance of teamwork [8, 9].

Basic Program Structure

The traditional vertical structure of the College of Engineering at Purdue has created excellent research and learning environments with proven success in equipping graduates and conducting world-renowned research. This structure can, however, also promote what is sometimes referred to as the “silo” effect where departments and schools focus primarily on specialized concerns to the detriment of collaborative efforts. The fragmented situation can keep participants from informing and being informed by each other’s progress. Within this vertical structure at Purdue, however, the proposed MDE program (see Figure 1) provides a horizontal infrastructure that can help build the necessary interfaces between new and existing programs.



(Figure 1) Vertical silos with horizontal MDE

As new technologies emerge, they may not fit within the traditional engineering definition of disciplines but instead cut across existing boundaries. The dilemma remains as to what organizational format these technology areas need. The creation of new departments, with required administrative overhead, eventually reaches the point of diminishing marginal return in terms of an optimal allocation of resources. The formation of new departments is also a time consuming process, and, as new technologies emerge, we need the ability to quickly respond and enfold these technologies into the teaching and learning processes. Lastly, new technologies have an ebbing of emergence and decline that is not well accommodated in the semi-permanent departmental structure. The horizontal infrastructure of the MDE program increases the College of Engineering’s ability to quickly respond to and offer courses, undergraduate research experiences, and degrees in emerging engineering fields without the need to create entire new departments

Lastly, the MDE program addresses what Atman and Turns [10] call an unsolved knowledge integration problem of how to promote the transfer of information across classes, concepts, and disciplines. The program will be instrumental in surmounting what the Boyer Commission calls a major barrier to multidisciplinary research and study: “the pattern of university organization that creates vested interests in traditionally defined departments. The limitations on this kind of structure are recognized in every university by defining new departments, approving new programs, and creating new centers in which to house courses, often experimental, that do not fit into the disciplines. But those centers repeatedly must call on the departments to teach the courses, knowing that the departments may balk at doing so since the interdisciplinary programs deplete staffing for their own departmental courses" [11]. MDE will help pioneer elements of *organizational reform* that will be crucia l to disseminating new knowledge from emerging multidisciplinary fields.

MDE Program Component Themes

The critical findings by experts in learning, pedagogy, and assessment fields support the MDE program emphasis on *multidisciplinary efforts, teaming*, and *integration of research and teaching*. Research shows that cooperative and collaborative approaches to instruction will enhance learning in general [10, 12-14], and, specifically, faculty are more likely to use active forms of teaching and learning if they are in an environment that encourages multidisciplinary collaboration and team work (Astin, cited in [5]). According to the National Research Council, learning must connect to other fields of inquiry through practical applications related to the students' experience [15]. By creating these mental "stepping stones," students will more readily realize the applicability of knowledge from one context to the next [5]. As new material fits into these existing cognitive structures, the motivational and learning benefits will include providing context, establishing relevance, and teaching inductively.

Multidisciplinary Emphasis

The MDE program draws on recommendations of the National Commission on Education to establish multidisciplinary environments. Students begin participation in multidisciplinary study during lower division courses and in customizable academic majors that prioritize student needs rather than departmental convenience [15]. Engineering and science faculty are currently develop ing and will teach new multidisciplinary courses including: *Physical Properties in Engineering Systems*, *Integrated Science for Engineers and Scientists, Multidisciplinary Modeling and Computational Methods, Manufacturing and Assembly, Communication Systems Engineering, Multiscale and Multisystems Engineering, Multidisciplinary Engineering Design, Nonlinear Dynamics and Chaos in Biological Systems*, and *Engineering Management and Entrepreneurship.* Students will select technical electives from a broad representation of engineering and science courses. They will also gain experience with and appreciation for multidisciplinary teams and will be exposed to emerging areas of technology that cross discipline lines.

Teaming Emphasis

Over the past ten years, education in engineering has seen a significant increase in the emphasis on design and on the wide range of teamwork skills that engineering students will need when they enter the workplace [7, 16-19]. In the program outcomes at the heart of Engineering Criteria 2000 accreditation guidelines, students are mandated to be able to function on multidisciplinary teams in addition to acquiring traditional engineering knowledge of mathematics, science, and engineering and gaining experience in engineering problem solving and system design [20, 21]. As such, the MDE program recognizes the importance of integrating the teaming and design experience into the engineering courses and will provide pervasive and significant opportunities throughout all eight semesters of the program. We anticipate these extensive opportunities in teaming will help students develop critical thinking capacities, improve written and oral communication, and expand interpersonal relationship skills.

Integrated Research and Teaching Emphasis

A primary MDE program goal is to provide a unique educational context where faculty from multiple disciplines integrate current research with classroom instruction. As evident in course descriptions below, the core MDE courses are designed around research themes that cut across traditional discipline boundaries, and students will be systematically exposed to emerging research. Teams of leading faculty in key research areas of emphasis, will teach classes. As junior faculty members are brought to campus for their expertise in emerging technology areas, the MDE program will provide an infrastructure to integrate educational components of their research programs into future MDE undergraduate courses. The MDE infrastructure will also give new faculty members experience in modern, research-based pedagogies. It is envisioned that by recruiting these new faculty members to team teach MDE courses, and their laboratories will provide additional opportunities for undergraduate research in emerging technology.

Program and Course Framework

The framework of the MDE program has three major threads that synergistically bind a student's undergraduate learning experience. These include: *a design thread*; *an experiential learning thread*; and *a cross-cutting discipline curriculum thread*. Each of components is described below.

<u>Design Thread</u>

The purpose of design experiences threaded through the MDE program is to collaborate with industry to give students a substantial experience with the computational methods and design practices used by practicing engineers. Students will gain comprehensive technical knowledge and the capacity to analyze, integrate, and apply basic engineering principles in emerging technological areas. Design is an integral part of both the EPICS service-learning experience and the two-semester MDE design sequence.

The major focus of the capstone design sequence will be the senior design project. This project is modeled after the extremely successful senior project design used by the Department of General Engineering at the University of Illinois at Urbana-Champaign. In the proposed Purdue MDE course, students from a variety of plans of study will work together in teams on company-sponsored projects. At the end of the fall semester, students will start the senior project that will be the focus of the spring semester. Each project group will work with a faculty adviser and an engineer from a sponsoring company. The task of each group will be to solve the company's problem or prove it cannot be done. Students will be encouraged to build working prototypes of their solutions and be required to prepare an extensive written report and presentation to the company sponsors and professors. Obtaining company sponsors, using resources of the Purdue Research Park and the Purdue Technical Assistance Program, will be one of the major developmental tasks. Students will also have extensive pre-professional experience with oral and written communication, project management, time management, formal teamwork study, and management practices.

<u>Experiential Learning Thread</u>

The MDE program offers a series of experiential learning opportunities in service-learning and/or undergraduate research experiences. For each of three semesters, students select a track that meets their diverse needs and interests. Students may elect to take all semesters in the same track or may reserve one semester to participate in the other option. Students wishing to continue either of these experiences into their senior year will be able to do so as a technical elective.

Service-Learning Track - the EPICS program will be the service-learning vehicle through which MDE students develop their professional "soft skills" in authentic design experiences that provide sustained support for community service organizations. EPICS is an award-winning academic credit program initiated at Purdue to address the dual needs of teaching engineering design and meeting community needs for access to expertise in engineering and technology. Under the EPICS program (http://epics.ecn.purdue.edu/), multidisciplinary teams of undergraduates partner with local not-for-profit community organizations to define, design, build, test, deploy, and support engineering-centered projects that significantly improve the organization's ability to serve the community. EPICS will integrate highly mentored, long-term, large-scale, team-based multidisciplinary design projects into the MDE curriculum to help students develop teamwork, communication, and project management skills. MDE students will receive academic engineering credit for their participation on EPICS teams during their sophomore and junior years. Each team of eight to twenty undergraduates from various engineering and other disciplines and a faculty or industry advisor will be paired with a community partner. Teams work with partners to define projects and will continue interactions during development, testing, deployment, and subsequent support of the fielded project.

Undergraduate Research Track - the second experiential learning option for students is research participation. Since the MDE courses will be taught by faculty from key research areas and will draw heavily from active research centers, students will be directly exposed to research topics and active researchers. We will introduce students to research opportunities during the sophomore MDE courses and will establish a website to direct students to additional key research areas connected directly to the MDE curriculum or in laboratories and associated centers across engineering disciplines. Students participating in this track will write a summary paper each semester as a reflection on their research experience.

Cross-Cutting Discipline Curriculum Thread

Integrated Science for Engineers and Scientists - scientists have also been traditionally trained within strict disciplinary boundaries. While modern research, particularly in the life sciences, uses a more inclusive problem-solving paradigm, this process is only recently segueing into the educational arena. The BIO 2010 report by the NRC [22] and a *Science* special section on Mathematics in Biology [23], suggest a need for an introductory, integrated science curriculum that crosses disciplinary boundaries. We propose to create such an integrated science course that will meet the needs of both engineering and science students, integrate concepts from biology, chemistry, and physics, and introduce biology into Purdue's undergraduate engineering curriculum for the first time. Topics in the proposed *Integrated Science* course will begin with the basic chemistry of life and the organization of cells and then move on to more advanced topics such as enzyme kinetics, photosynthesis, genetics, and information in living systems. Each topic would emphasize how understanding the biological system requires concepts and tools from other traditional disciplines. This integrated approach will give students a more complete view of the interconnected nature of modern science and inculcate a multidisciplinary mindset early in their educational careers.

Courses in the Multidisciplinary Core - at the core of the MDE curriculum will be the MDE I-VI course series as described below. Each course is team taught by instructors who have expertise in the key research areas. Each course will include cross-cutting themes in engineering and science. MDE II, V, and VI form a programmatic cluster of courses that will innovatively unify disparate fields with modules highlighting basic engineering principles. In each course, engineering and science systems will provide the context and illustrate the use of these principles. Instructors from multiple fields will communicate with significant depth the same principles through the use of "best pedagogical practices" and relevant real-world examples. Example designs will show details of the paradigms and allow control points for systems to be analyzed and discussed. Specific courses currently under development include:

MDE I: PHYSICAL PROPERTIES IN ENGINEERING SYSTEMS is intended to supplant existing engineering courses on statics and dynamics as well as physics courses on electricity and optics that have historically required mostly pre-college math skills for problems solving. MDE I will present physical properties of matter as they interact within engineering systems. The course will include all classes of properties - including electrical, magnetic, optical, thermal and mechanical - presented through tensor mathematics to ensure students retain the sophisticated programming or math tool skills learned at the freshman level.

MDE II: MANUFACTURE AND ASSEMBLY will present students with assembly concepts that encompass viruses, microelectronics, cars, computer programs, chemical plants. Students will understand how the basic principles of engineering bring understanding to how parts are made and assembled. Students will explore the fundamental principles of mass production, modular design and quality control as well as “green” manufacturing, cradle-to-grave life cycle management, and recycling. Modules include bioreplication, microelectronic production, and polymeric materials manufacturing. Students will learn how viruses and bacteria reproduce and will understand how the assembly of viruses, mutation, and resorption of dead material show mass production, quality control and recycling principles. Students will examine issues that impact profitability. Wafer size, chip defect rate, the millions of tons of base to wash away photoresist, and computer disposal will be the platform to explore mass production, quality control, “greenness,” and the cradle-to-grave life cycle. Students will maximize efficiencies of atoms and energy, learn where materials come from and end up, and understand global effects of local decisions.

MDE III: NONLINEAR DYNAMICS AND CHAOS IN BIOLOGICAL SYSTEMS will introduce these fast-growing areas of applied mathematics and their impact in both biology and engineering. This already-piloted class will expose students to computational methods employed by engineers to solve multidisciplinary engineering problems. This course highlights the computational dimensions of the interface between engineering and biology. Students will be introduced to nonlinear dynamics in biological systems with an emphasis on geometric analysis and biological examples. The systems covered will gradually grow in dimensionality and complexity of behavior from first order systems to oscillating systems and then to chaotic systems. Examples from recent literature will be included to provide a real-world context for the nonlinear ordinary differential equations and to give students a window into cutting-edge research.

MDE IV: MULTIDISCIPLINARY MODELING AND COMPUTATIONAL METHODS will introduce engineering students to the use of computational methods commonly used to solve multidisciplinary and multi-scale engineering problems. Students will gain a working knowledge of how practicing engineers use modern computational methods and design practices to solve complex multiphysics problems involving transient phenomena that are computationally intensive. The course blends theory and application to help students solve complex engineering problems, perform error analyses for particular applications, and understand the limitations and trade-offs of the methods. The course will be divided into elementary and more intensive computational methods. It will provide a firm foundation of the engineering applications and a theoretical understanding of methods associated with: linear algebraic equations, optimization, curve fitting, numerical integration and differentiation, accuracy and reliability of numerical solutions, ordinary differential equations and partial differential equations. In addition, we will collaborate with industry leaders during the development phase of the course to determine a select number of computational tools and simulation packages to introduce to the students.

MDE V: MULTISCALE AND MULTISYSTEMS ENGINEERING will show the vertical integration of physics and engineering in nanoscale and macroscale systems. Students will look at systems design within each system and as an aggregate, will learn basic principles of how the nanoscale fundamentally differs from the macroscale in environments such as physics and chemistry, and will explore issues such as scalability, modularity, and systems integration at all length scales. Teaching modules may include a large computer network that displays length scales from the nanoscale (gates) to the microscale (transistors) to the macroscale (computer). Integration issues will be looked at through a number of systems such as integration of linearly processing computers with a network that performs parallel functions. The human body shows modularity, systems integration, and multiple length scales. Modern air travel serves as a paragon of the multiscale systems-of-systems concept with multiple levels of interdependent systems, ranging from individual flight control elements to baggage-handling to air-traffic control.

MDE VI: COMMUNICATION SYSTEMS ENGINEERING will show that communication is an integral part of the universe and how all matter (cells, people, electronics) of advanced and intelligent systems depends upon sending and receiving data on multiple scales. Basic communication principles will include transmittal and reception of data, noise, information processing, and data storage. Advanced concepts such as information theory and collective behavior of multiple integrated systems will be explored for communication optimization. Teaching modules may be bio-related, such as the neuromuscular systems where macroscopically the brain must communicate with the muscles via a complex network of nerves. Microscopically, this entire process works via cell-to-cell communication. Even on the nanoscale, communication happens during DNA transcription to proteins and between organelles. Another potential teaching module is the Internet. Information must travel on the Internet, be processed, and stored efficiently between computers as well as within computer chips, drives and even individual transistors.

Entrepreneurship for Engineers - this course will allow multidisciplinary engineering students to understand and experience fundamental principles of innovation and entrepreneurship. Student teams will develop a comprehensive business plan as well as the marketing and financing strategies for a proposed business. The course will involve short primers in the areas of accounting, marketing, and finance but will emphasize content specific to the context of entrepreneurship:protecting intellectual property, organizational forms, venture and angel capital, ownership structures, and mobilizing strategic and financial capital in the midst of uncertainty.

Multidisciplinary Selectives - MDE students will choose two MDE Selective courses during their senior year. The MDE Selectives will be a beneficial platform for junior faculty teams to incorporate emerging knowledge into the classroom. Selectives will focus on interfaces between disciplines, such as information technology, bioengineering, and nanotechnology. As national priorities and field-defining research change, Purdue key researchareas, and, in turn, MDE Selectives will reflect those shifts.

Web-based Supplements – students can tailor the MDE program to their long-term interests by opting to take fundamental engineering science courses, such as thermodynamics or fluids, from any engineering discipline that offers such a course. With this programmatic flexibility, however, students entering the MDE course sequence may not share a common starting framework. It is believed this barrier can be overcome with the use of technology. Therefore, a web-based multimedia "leveling-ground" is being created that accommodates the diverse backgrounds and learning styles of students taking MDE classes. The multimedia infrastructure will facilitate students' ability to review fundamental concepts based upon their background and pace. In addition to providing student self-assessment, the modules will also inform faculty regarding pace at which students go through the modules, modules most visited, and results of self-assessments. The faculty interface is envisioned to be a useful tool to guide class discussions and provide feedback on instruction

The MDE Program Course Sequence

The MDE program shares a first year common to all Purdue freshman engineering students. Course sequences ensure students are exposed to pedagogical themes and provide valuable experiences with team-based learning and multidisciplinary perspectives in each semester. Advanced topics and multidisciplinary experiences begin in the sophomore year. These core MDE courses offered early in the program allow students to either choose an area of interest on which to focus through senior year selectives or choose a variety of selectives for a broad program of study. The program will affect multidisciplinary curriculum reform with its easily replicable structure. The interested reader is encouraged to go to the program website at https://engineering.purdue.edu/ENE/Undergrad/MDE for more information.

The MDE curriculum has been designed to prepare MDE graduates for multiple career paths. Clearly, the introduction to research and cutting-edge topics in the undergraduate courses will prepare students to enter graduate school and study further in these areas. The program is also designed to provide the broad educational base needed in many entry-level engineering positions.

Summary

The MDE will play a significant role in modeling the effective integration of new, multidisciplinary fields into the preexisting regimen of academia. MDE will be part of shedding institutional rigidities that restrain and hinder the educational shifts necessary to meet contemporary demand and will demonstrate a flexible, futuristic program that keeps pace with technological advances and quickly adapts courses to reflect new opportunities. With its horizontal, cross-cutting structure, the MDE program can incorporate new curriculum without undue encumbrances of departmental structures to meet multidisciplinary engineering needs. The MDE program will change the institutional landscape and also engage students in a new level of academic potential. It will change the fundamental experience of teaching and learning engineering. Equipped with a new and broader skill set, our graduates will gain a foundation of multidisciplinary connections and be better prepared to participate in emerging worlds that are revolutionizing the engineering industry. The first cohort of students will begin taking classes during the Fall of 2005.

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