Lean Engineering Education: Driving Content and Competency Mastery

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Preface

The role and scope of the mechanical engineering discipline and profession continues to evolve rapidly. The undergraduate mechanical engineering curriculum, the engineering student experience, what mechanical engineers do in practice, and how they do it, has been changing not only as a result of technological innovations that expand the scope and reach of the discipline, but due to the emergence of engineering practice, engineering education, and standards of quality on an increasingly global scale.

The ASME’s ongoing Vision 2030: Creating the Future of Mechanical Engineering Education (V2030) program, operating under the auspices of the ASME Board on Education, has four primary goals:

1. to re-examine the engineering practice perspective and broadly define the engineering knowledge, skills and competencies that mechanical engineering graduates should have to successfully launch into engineering practice and progress in their early professional years;
2. to provide recommendations for the development of professional skills and competencies in the engineering graduates that will produce the leadership required for developing and implementing the technology and policy that will bring new solutions for the challenges facing local and global industry, governments and society;
3. to provide recommendations and exemplary approaches to the mechanical engineering education curricula that effectively produce the desired results in alignment with degree program accreditation standards; and
4. to move to change degree program accreditation standards as needed in response to Vision 2030 research findings and recommended actions.

The specific ASME V2030 recommendations are based on a rich set of data from over 2,500 contributors drawn from the experience of engineering managers and early career engineers in industry, university mechanical engineering department heads and faculty, and education leaders in ASME. In addition the work has been informed by exemplary work done by the National Academy of Engineering (NAE, 2005) –
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Grand Challenges for Engineering; Engineer of 2020; Educating the Engineer of 2020; and Changing the Conversation – the National Science Foundation/University of Michigan (5XME Project) and scores of other individuals and institutions who have been a part of the meetings, workshops and conference sessions used in the process vetting and extending of the original V2030 concepts since 2009.

Current Context of ME Education and Practice

Blurring disciplinary boundaries. The earliest engineering disciplines, civil, mechanical and electrical, have given rise to distinctive engineering specialties and application-based disciplines, such as aeronautical, chemical, biomedical, environmental, industrial and nuclear engineering. A classic definition of mechanical engineering is that it embodies the generation and use of thermal energy and power and the design and use of tools and machines to produce products.

In the past, mechanical engineering problems were defined as those dealing with energy and mechanisms, i.e., bending, breaking, heating, cooling, and moving. Today, the range of applications of the mechanical engineering discipline has expanded greatly to include biological and information-based systems, advanced materials, micro/nano-devices, and many others. Currently, the types of problems and products that mechanical engineers work on are not easy to categorize, and they often include elements of other engineering disciplines and the basic sciences. Many contemporary engineering problems are considered to be multi-disciplinary in nature and require systems thinking in problem formulation and solution. It is clear that we must educate engineering students for a technological era of increased scope, scale and complexity – while assuring competency in the application of fundamental, foundational principles and helping students move from the conceptual, to the imagined, to the simulated, and ultimately to the real.

Diversity and retention. In the US, for example, with mechanical engineering having the largest enrollment of the engineering disciplines, and also the largest number of undergraduate women, the percentage of women and of other underrepresented of minority groups in mechanical engineering has remained essentially constant at about 15% over the past decades. Despite significant and continuous growth in ME enrollments and efforts by government, industry and universities to increase
awareness of scope and opportunity in the field, the current mechanical engineering educational process is not yet attracting and retaining enough women and minorities. Our principal concern is for the future vitality a profession that does not reflect the society in which it exists and for whom it serves.

Value added engineers. As discussed above, corporations have the ability to source their engineering expertise worldwide, e.g., the 24/7 design processes that have been adopted in the automotive and computer industries. If the mechanical engineering profession is to remain viable, it will depend on the ability of its workforce to provide value to their employers in this around the clock, around the world work environment. Engineering expertise will be required at a higher intellectual level than currently if value is to be added to the engineering and the business processes. For example, expertise related to communication, innovation, and leadership will be required to a much larger degree in accelerated product development. Topics such as these are typically not a significant part of the mechanical engineering curriculum.

Greater sophistication, often at the interface between basic science and engineering and at the systems level, and leadership for innovation also exert their influence on the kinds of engineering skills needed in the workforce. Consequently engineers, while always faced with an increased need to continually learn and sometimes reinvent themselves over their careers, must continue to reinvent themselves for technology, systems and influential roles not in place a decade ago. Therein also lie some implications for re-thinking aspects of undergraduate engineering education. Whether change takes the form of curricular restructuring, change in the content of degree programs, or both is the task ahead for educators.

Innovation and leadership. These elements will be paramount to a thriving industrial base, a global reach, and sustainable resolutions of the challenges facing the planet. As the economies become more sophisticated and developed, there emerges a greater dependence on the creative power of the engineering workforce, the process of bringing new ideas to market and, just as importantly, the global cooperation needed required to resolve the truly big sustainability challenges.

Creative invention by engineers is essential to innovation, but so to is leadership. The transformation of an invention into an innovative
product or process requires personal leadership skills that produce and strategic and critical-mass collaboration. Truly sustainable solutions are needed in companies and they need enabling public policy. Sustainable growth for companies, countries and the planet should be foremost in our graduates’ thinking – and preparation. The technical breadth and impact of a mechanical engineering education must result in graduates are practically adept in the short term but are also prepared to see the “big picture” systemically.

Curricular outcomes that stress systemic design/build skills combined with big picture context and impact awareness could lead to a broader environmental, economic and political role for engineers if professional skills, particularly communications and leadership, are more fully developed. These areas have major implications for degree programs, their content, and their approach to teaching that content.

Global issues. Attention to global issues in engineering practice will become more important to design, product development, and engineering services. Global grand challenges include the scarcity of potable water, developing alternative sources of energy, renewing infrastructure, and assuring sustainable development. Engineers must play and increasing role in fostering cooperation among countries, industries, and educational institutions if we are to respond effectively to these global challenges.

Sustainable economies. Economic decisions must be driven not only by short- but also by long-term perspectives in all areas of professional activity, especially engineering as applied to product development and in the innovation process. In an increasingly commercial, market-driven world, this is a challenge. Mechanical Engineers must occupy prominent, influential roles toward a more sustainability-driven economic future. Sustainable, not unlimited, growth is central to future solutions. Engineering educators, industrial leaders and public leaders must work in concert to address this issue.

ASME V2030 Action Agenda - Creating the Future of Mechanical Engineering Education

What type of curriculum, or curricular change, is needed? By what processes shall institutions determine how to further refine their mechanical engineering programs? Excellence comes from a blending of
standardization and innovation and in doing so under constraint — economic, political, physical, institutional, etc. Institutions vary and the vitality that comes from balanced standardization and diversity needs to be systemically embraced. But with any change, core legacy, contemporary engineering fundamentals, and the problem conceptualization and solving abilities of mechanical engineering graduates must be retained.

The ASME Vision 2030 team envisions a more flexible, holistic, and more practice-oriented undergraduate curriculum with a strong, integrated, professional skills component. The curriculum should include major active, discovery-based learning opportunities such as a design spine or other experiences. The curriculum should emphasize problem definition, solving and impact and include systems level experiences. Breadth is most important, with depth possible in a particular area of the student’s choosing or the department’s professed strengths.

What should Mechanical Engineering education look like as we move towards 2030? Seven aspects of the educational landscape emerge as target areas for curricular evolution on mechanical engineering undergraduate degree programs.

RICHES PRACUTURE-BASED EXPERIENCE

Action: Offer more authentic practice-based engineering experiences such as the design spine or design portfolio approach throughout the undergraduate program.

Among the greatest concerns noted among current ME graduates by their employers, as well as the early career engineers themselves, are — simply put — a lack of practical experience in how devices are made and work, a lack of familiarity with industry codes and standards, and a lack of a systems perspective and approach to the design and product development process.

STRONGER PROFESSIONAL SKILLS

Action: Develop students’ professional skills to a higher standard.

Both industry supervisors and early career engineers emphasize that graduates need stronger professional skills, e.g., interpersonal skills,
negotiating, conflict management, innovation, oral and written communication, and inter-disciplinary teamwork. To meet this need, a systematic focus on integration of such skills into curricula must approach the priority given to technical topics. Incorporation of a multi-year design spine, or portfolio approach, which incorporates such skills development integrated with technical competency development into curricula, is urged.

MORE FLEXIBLE CURRICULA

Action: Create curricular flexibility and efficiency with core requirements and specialization options.

To enable students to develop understanding of mechanical engineering fundamentals but also offer greater strength in context and realization of design, a better systems perspective, and the possibility of focus in an area of interest, there is a need for greater flexibility in the degree path. Thus, the model of a required ME “core” set of fundamental classes, followed by a concentration area is suggested, echoing recommendations of earlier studies.

Action: Modify ABET mechanical engineering degree program accreditation criteria to allow more flexibility.

To enable curriculum change and encourage more flexible curricula, modify ABET ME program criteria to no longer requiring equal thermal and mechanical competencies, but preparation for professional work in one and/or the other, with significant exposure to the area not emphasized.

GREATER INNOVATION & CREATIVITY

Action: Create a curriculum that inspires and enables innovation and creativity.

The chance to produce practical and technical innovation to solve real-world problems and to be of greater value to society is one of the most inspiring aspects of the profession. Developing student creativity and
innovation skills, through explicit curricular components that emphasize active, discovery-based learning — such as a design spine or portfolio, or other authentic extracurricular engineering experiences — can also enhance motivation, retention, and serve as a potential launching pad for a next generation of innovators.

TECHNICAL DEPTH SPECIALIZATION

Action: Focus on post graduate education for specialization.

Additional technical depth and specialization in mechanical engineering topics, plus increasingly sophisticated professional skills, will be required in many aspects of industry, according to both the ME department heads and industry managers. Increasing the availability of professional Master's degrees provides increased opportunity for graduates and practitioners to meet such a need.

NEW BALANCE OF FACULTY SKILLS

Action: Increase faculty expertise in professional practice.

To produce graduates with the practical and professional skills described above, diversification of faculty capabilities is required. Employing more faculty members with significant industry experience and creating continuous faculty development opportunities for exposure to current industry practice is urged. Faculty with experience in product realization and innovation, project management and business processes, with understanding of the use of industry codes and standards in different contexts will impart a greater and more authentic sense of the world of practice to students. The institutional expansion and industry support of full-time, tenure or long-term contract faculty positions such as the Professor of Practice or Clinical Professor is urged.

Action: Advocate the modification of ABET criteria for faculty numbers and qualifications.

ABET Criteria should address metrics for minimum faculty size and student to faculty ratio to ensure program quality in design and also
address measures that increase the proportion of significantly practice-experienced faculty.

**Constrain – and Re-engineer – the Undergraduate Program**

It is not necessary to add courses or content to a nominal 120–128 semester hour, four year baccalaureate degree program. However, there must be more effective use of existing technical content, the general education program, technology based instructional methods and even the employment of co-curricular activities. Recognizing that the four-year engineering education program containing all of the attributes previously described may not contain as much technical content in some ME sub-specialty areas, we suggest that undergraduate programs be designed with the expectation that most in-depth technical specialization will come later. Strong articulation with graduate programs is warranted as the nature of graduate education may change due to a differently educated undergraduate entering a graduate program.

The ASME Vision 2030 team has recognized that there is no single approach to addressing and executing the desired changes in mechanical engineering education, but has laid out a number of interventions that should be taken together. What is of particular concern is the degree of industry manager consensus on the shortcomings in graduates’ skills and competencies, in areas that ME programs often believe are a core strength of their programs. The Vision 2030 task force therefore has recommended that engineering education be re-thought significantly, with a renewed focus on practice-oriented skills and competency development.

The concept of Lean Engineering Education as explored by the authors of this book offers a tantalizing vision of addressing some of the shortfalls of current mechanical engineering education, particularly the skills and competency deficiencies, and to reconcile content and competencies in mechanical engineering programs.

Although engineering disciplines have specialized further from their roots of civil, mechanical and electrical engineering into a multitude of engineering specialties, they have remained strong in conveying the engineering sciences. However, with the organization of suppliers within the Tier structures, when content has to be applied to develop a more evolved machine, manufacturers have to resort to systems engineering as a way of integrating or adapting components or sub-systems.
While systems engineering by its nature is content-focused, lean engineering is focused on workforce development, in the form of competency development. From the first days of its conception, lean engineering’s primary goal was the further qualification and training of employees, to enable and empower them to carry out their daily tasks while giving them the freedom to self-organize and authority respond to production defects. In order to achieve this goal, workforce development had to focus on the development of competencies such as systems thinking, recognizing cause-effect chains and networks, and working in teams, to name just a few. Because of its focus on developing these competencies, lean engineering seems to be a logical complement to systems engineering, thereby complementing content with competency.

It is in this spirit of bringing together content and competency that this work opens the doors for new thinking in mechanical engineering education. ME programs of the future must provide for content and competency at the same time; a focus on content alone will not suffice. The ASME Vision 2030 study has shown that content without integrated competency does not serve the needs of engineers, industry and society, neither today nor in 2030. The readers are strongly encouraged to consider the contents of this book in their own environment, and to be inspired in adapting their curriculum.

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