Vision 2030
Creating the Future of Mechanical Engineering Education

Phase 1
Final Report

Center for Education
December 2011
“Either the engineering profession will broaden greatly or the society will suffer because the matching (between society and technology) will be too haphazard..., a greater engineering needs to evolve...it will come to embrace much more the issues at the technology-society interface.”

Simon Ramo
National Academy of Engineering

Scientists discover the world that exists; engineers create the world that never was”

Theodore von Karman
California Institute of Technology

We’re looking for kids who think of the world in terms of finding solutions to big problems..., we want to attract students who might have a wider world view that those in the traditional math and science laden programs featured at the nation’s top technical schools....”

James Plummer
Dean of Engineering
Stanford University
Foreword

Change normally occurs when there is a compelling need, and this is particularly true with engineering education. There have been many studies over the years focusing on engineering education and the need for change, but most of them have had little or no impact unless they were associated with a major societal need. The arms race and the shift from engineering practice to engineering science after WWII, the emphasis on science and space during the 1960’s, and the unfortunate short lived emphasis on sustainability and energy in the late 1970’s and early 1980’s all resulted in change.

Today there should be no confusion as to the societal need. The Grand Challenges articulated by the National Academies clearly express societal needs. But what is fundamentally different now than even five years ago or thirty years ago during the first energy crisis? The differences are great with a growing need for alternative clean energy sources, food and fresh water shortages that are prevalent in many regions of the world, global political and social unrest due to many factors not the least of which is poverty, and growing concerns for the environment. Couple all of this with the financial collapse of many institutions and the financial chaos that many governments are experiencing and we have the need for pervasive and comprehensive change. What is engineering’s role? Certainly the technical aspects of energy, clean water, food scarcity, and the environment concern the engineer. But is there a need for much greater and broader participation of the engineer?

Engineering’s history of invention of both products and processes has served this country well for over two hundred years, but the recent confluence of events is suggesting that, as Simon Ramo said, “a greater engineering needs to evolve.” Hallmarks of these changes will hopefully be not only increased invention but also the implementation of invention or innovation. Innovation will require leadership, and that leadership should be from engineers who have the technical insight and ethical courage to solve the grand challenges facing this planet for the benefit of all its inhabitants. We can no longer leave our fate entirely in the hands of often ill informed politicians, lawyers, and business executives. Engineers must take leadership roles not only on technical projects but in society generally. Engineers must lead in their communities, in local, state and federal governments, and engineering must lead us to a sustainable world. There are probably no second chances, now is the time for action, and we have to get it right. Now is the time for engineering leadership, our country needs it and our planet needs it.

What does this mean for what and the way we teach our students? Our students will need to lead not only technically but also socially, politically and ethically. Future engineers
will need outstanding communication and people skills, business sense, a global perspective, and an unparalleled understanding of our environment to be successful. This implies a compassion and passion for our planet, ethics beyond the bottom line, not unlimited growth but sustainable growth, an understanding of the importance of economic growth, and more importantly an appreciation for the equitable distribution of that growth.

This report presents new data on the status and long-term outlook for mechanical engineering and mechanical engineering technology education from industry leaders, department heads, faculty, and practicing engineers. We make the case for the need for substantial change in the educational process, and we present possible scenarios for change. In some cases our conclusions and recommendations are based on reading between the lines or, as is discussed by Sharon Parks’ in *Leadership Can be Taught*, listening to the music beneath the words.

Hopefully the first edition of this report and its subsequent editions will inform and stimulate thinking and motivate action about what we can and need to do. Ultimately it will be the faculty at our engineering schools that will take on the challenges and make the changes.

This study is the result of input from a large number of individuals and a sustained effort by the Vision 2030 Task Force and ASME staff. The ASME Foundation provided the initial funding that made our work possible. My thanks to them all.

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Executive Summary

The role and scope of the engineering practice is transforming rapidly. What mechanical engineers and mechanical engineering technologists do, and how they do it, are changing due to meeting global challenges, expansion of the disciplinary boundaries, and rapid technological innovation. Dominant engineering organizations in 2030 will be those successful at working collaboratively and fostering global partnerships. Successful mechanical engineers in these organizations will be individuals who, in addition to technical knowledge, have depth and skill in communication, management, global team collaboration, creativity, and problem-solving. In addition to being skilled in working collaboratively and in virtual design teams, mechanical engineering practitioners need innovation skills that encompass practical understanding of how things are designed, produced and supported in a global marketplace. In this report, we suggest changes in mechanical engineering education to meet this dynamic, challenging environment. It is the culmination of three years of sustained effort by the Vision 2030 Task Force and ASME staff, with significant input from the mechanical engineering community. The ASME Foundation provided critical support enabling the work of the Task Force.

The Vision 2030 committee was composed of representatives from industry and education, including both engineering and engineering technology educators. The constituents of mechanical engineering education were mechanical engineering and mechanical engineering technology academic department chairs/heads, faculty in these programs, their academic deans, industry practitioners (including engineering management), and government agencies. These groups helped frame the significant questions to be addressed, participated in information gathering, and reviewed the committee’s work as it progressed. As used in the committee’s work and reports, the term “mechanical engineering profession” includes the endeavors of both mechanical engineering and the mechanical engineering technology graduates.

The Vision 2030 Task Force pursued two primary objectives: help define the knowledge and skills that mechanical engineering or mechanical engineering technology graduates should have to be globally competitive, and, to provide, and advocate for their
adoption, recommendations for mechanical engineering education curricula, with the goal of providing graduates with improved expertise for successful professional practice.

An assessment of recent engineering education literature, multiple surveys of stakeholder groups, including mechanical engineering department heads, industrial supervisors, and early career engineers, were completed and involved over 3000 respondents. Using these data and formative assessment by the Vision 2030 Task Force members, numerous open-forum and panel discussions sessions at major education conferences and ASME meetings, including interaction with the ASME Industrial Advisory Board, provided additional input to the Task Force. These efforts enabled the identification and validation of overarching issues facing the mechanical engineering profession, as well as the development and refinement of a vision of the future of mechanical engineering education.

Perspectives from industrial and academic stakeholders and constituencies were critical to the formation of recommendations (specific data are presented in detail in the report). These perspectives were not always consistent, which illustrates the complexity of the educational process and the competing needs of industry and society. For example, only 14% of the industrial supervisors cited recent graduate’s problem solving and critical thinking skills as a strength, yet 57% of early career engineers and 48% of academic department heads rated these areas as strengths. Additionally, survey results indicate successful mechanical engineers must possess, in addition to technical fundamentals, expertise in broad problem-solving skills (beyond narrow technical problems), innovation and global team collaboration.

These perspectives are set in the context of rapid transformation of the role and scope of the mechanical engineering profession. The blurring of disciplinary boundaries within engineering practice and the growing importance of social, political and environmental considerations require mechanical engineers be excellent communicators, possess strong management, global-team collaboration, creativity, and problem-solving skills. In addition to technical knowledge, the role of the mechanical engineer in addressing “grand challenges” of sustainable engineering, energy, and human health requires educational change to achieve these new areas of strength. To develop and
implement creative solutions, mechanical engineering education graduates must possess leadership and innovation skills, in addition to their technical fundamentals.

**Recommendations**

The task force recommends strengthening the following aspects of undergraduate mechanical engineering education curricula: creating curricula that inspire innovation and creativity, increasing curricular flexibility, offering more authentic practice-based engineering experiences, developing students’ professional skills to a higher standard, implementing effective strategies to attract a more diverse student body, and focusing on post-graduate education for specialization.

To provide more curricular flexibility and to incorporate new applications and emerging technologies, departments should designate a set of classes as their mechanical engineering core, which all students would be required to complete. This core would consist of the first course in the fundamental ME discipline areas. Once a student completes their core set of classes, they should be able to choose a concentration area, and complete additional courses in that concentration area to develop technical depth. The specialty concentration areas should fit the program’s region and faculty, e.g., provide exposure to emerging areas (bioengineering, nanoscience, etc.) of mechanical engineering.

To strengthen the practical experience component of graduate’s skill sets, a significant ‘practical experience’ component should be added to curricula (already a strength of many mechanical engineering technology programs). A proven, successful approach uses a design/build/test spine in which a design course is present in the freshmen, sophomore, and junior years, where student teams tackle increasingly difficult design and build projects. Ideally, this design spine would be multidisciplinary in nature, providing the students with multiple experiences working with people from other majors as they progress through their curriculum. This sequence is completed with a yearlong senior capstone design course that has a focus on system design, building, testing, and operation.

We recommend the development of professional skills in the engineering graduate to produce engineering leadership characteristics required for implementing engineering
solutions to help solve the complex challenges facing companies, regions and planet. Professional skills such as a complex system-level perspective, inter-disciplinary teamwork, leadership, entrepreneurship, innovation, and project management should be central features of the design spine.

A systematic focus on integration of such skills into curricula must approach the priority currently given to technical topics. Employing more faculty with significant industry experience and creating continuous faculty development opportunities, including exposure to current industry practice, is urged. The hiring of “Professor of Practice” faculty with experience in product realization and innovation, project management and business processes, use and understanding of codes and standards in different contexts, could impart a greater, and more authentic, sense of the world of mechanical engineering practice to students.

The mechanical engineering profession and its academic programs have one of the lowest percentage of women within the various engineering disciplines, and, similar to all engineering fields, a low percentage of underrepresented groups. To successfully attract underrepresented groups to the field of mechanical engineering, the message about the positive impact mechanical engineering profession has on improving the world should be communicated. Recruitment messages, mentorship, increasing faculty diversity, and emphasizing the idea that mechanical engineering is really about solving problems that impact people lives, are all important strategies. Many of the curricular changes suggested above, especially those that reinforce connection of engineering study to contextual real-world solutions that help people and society, have been shown to increase student retention and diversity. This message should be infused into the first-year engineering courses to ensure higher retention of underrepresented groups. Service-based projects requiring innovative solutions should be made available for students ranging from the first-year to the senior-year.

At the graduate level, additional technical depth and specialization in mechanical engineering topics, plus increasingly sophisticated professional skills, will be required by aspects of industry, according to both department heads and industry managers. Increased availability of professional Master’s degree programs provides opportunity for graduates and practitioners to meet such a need.
These recommendations reflect findings of previous reports, such as the two NSF 5XME workshops, and the Carnegie Foundation’s reports. In addition, many of these recommendations are not new and some have been implemented and integrated into curricula by a number of mechanical engineering or mechanical engineering technology programs were they have been shown to have a successful impact on desired departmental outcomes. But, such changes and modifications have not been implemented in the pervasive manner necessary to impact the bulk of mechanical engineering education.

A partnership between industry, professional societies, government, and academia is needed to successfully implement these recommendations to develop the full potential of engineering education and engineering leadership. For example, ASME could facilitate faculty-practitioner exchange programs, and practice-based endowed faculty chairs. To enable curriculum change and encourage more flexibility, modifications to the ABET general criteria and program criteria for mechanical engineering (ME) and mechanical engineering technology (MET), e.g., in the ME criteria, no longer requiring both thermal and mechanical competencies, but preparation for professional work in one or the other, with exposure to the area not emphasized, are recommended. Another helpful change would be if the ME Program Criteria addressed a minimum faculty size/student ratio to ensure program quality in design and encouraged an increase in the proportion of “practice-experienced” faculty within programs.

Successful implementation of a more holistic curricula will produce graduates who have skills and abilities to coordinate, manage and lead global projects, graduates who can enable sustainable growth, graduates who can create their own jobs and jobs for others, graduates who are always thinking about the world’s grand challenges, graduates who become involved in policy decisions at many levels of society, and graduates who become leaders in society to enable sustainable solutions for the good of all.
1. Introduction

1.1 The Case for Change

The role and scope of the engineering practice is transforming rapidly. What mechanical engineers and mechanical engineering technologists do and how they do it are changing owing to the increased need to attend to global challenges, expansion of the disciplinary boundaries, and rapid technological innovation. These and other factors broadly impact the engineering profession, place increased professional expectations on the engineer, and serve as motivators for significant change within the educational process and its content.

Our over-arching conclusions are that now is the time for substantive change in the education of mechanical engineers and mechanical engineering technologists, and now is the time for engineering leadership in public and private sectors. Based on the results of three years of work, we offer the following observations.

Innovation and leadership

Innovation and leadership will be paramount to the US industrial base, the global success of the US economy in the 21st Century, and sustainable resolutions of the challenges facing our planet. As the economies of other nations become more sophisticated and developed, the US economy will more and more depend on the creative power of the engineering workforce and the process of bringing new ideas to market and, just as importantly, global cooperation and creativity will be required to resolve the challenges facing our planet. Creative invention by engineers and engineering technologists are essential to innovation, but so is leadership. The implementation of an invention to become an innovation requires leadership. Leadership in the public and private sectors is needed now more than ever owing to the issues facing both the U.S. and the world. The technical breadth of mechanical engineering and mechanical engineering technology education means that graduates are better prepared to see the “big picture”. This big picture thinking could lead to a broader environmental, economic and political role for the engineer and engineering technologist if professional skills, particularly
leadership, are fully developed. The latter areas have major implications for degree programs and their 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. Increased cooperation among countries, industries, educational institutions, and nations must occur if the profession is we are to respond effectively to these global challenges.

With the advent of organizations such as Engineers for a Sustainable World, Engineers Without Borders and others and the publication of the “Grand Challenges for Engineering” facing the world by the National Academy of Engineering (2010), there are opportunities for mechanical engineering education to participate in activities focused on improving human health and alleviating poverty in the developing world. Many students find such activities attractive and very rewarding, as they provide a framework within which to apply their engineering skills to improve the quality of life of people in less fortunate circumstances.

**Sustainable economies**

Sustainable economies must be driven by long-term perspectives in all areas of professional activity, especially engineering as applied to product development and in the innovation process. Mechanical engineers and mechanical engineering technologists must occupy prominent roles toward sustainable economic futures. Truly sustainable solutions are needed in companies and at all levels of society. Sustainable growth for our companies, our country and the planet should be foremost in our graduates’ thinking. We believe industry and the public must understand that sustainable, not unlimited, growth is central to future solutions. Engineering educators, industrial leaders and public leaders must work in concert to address this issue.
Redefinition of workforce needs

The redefinition of workforce needs is a challenge for engineering as product conceptualization, design, manufacturing, and technical services have converged within the invention process. 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 work force. However, basic engineering skills, very applied and hands on, is a stated need by industry.

In addition, the critical need to reestablish world-class manufacturing points to growing need for a redefined and growing engineering technology workforce. Full employment in the US can only be obtained if we produce and build products, and much of that must come from world-class manufacturing. Consequently engineers and engineering technologists, while always faced with an increased need to continually learn and sometimes reinvent themselves over the span of their careers, must begin to reinvent themselves for their respective roles. The implications for re-thinking engineering education are compelling. Further, a relative resizing or restructuring of the engineering and engineering technology content and student populations may be a long-term consequence of future work force needs.

As discussed above, corporations have the ability to source their engineering expertise worldwide, e.g., the 24/7 design processes adopted in the automotive and computer industries. If the mechanical engineering profession in the US 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 curricula.

Blurring of disciplinary boundaries

The earliest engineering disciplines, civil, mechanical and electrical, have given rise to distinct 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.

**Diversity and work force retention**

The fraction of women and members of minority groups in the mechanical engineering profession has remained essentially constant at about 15% over the last thirty years. This situation exists despite significant efforts by government, industry and academia to increase the attractiveness of the field to both groups. The current mechanical engineering educational process is not attracting and retaining enough women and minorities.

Equally as important is the retention of individuals in engineering practice. Our environmental scan and review of the literature show that significant numbers of engineers leave the practice of engineering within ten years after the receipt of their baccalaureate degree. Reasons vary, but the most frequently cited reason is that work assignments do not make meaningful and sufficient use of their skills.

**Characteristics of incoming students**

Incoming engineering students have interests and characteristics distinctly different from those of even a few years ago. This age group places a high value on interaction, team activities and social networking. As an example, in their social
interaction, they use digital devices such as cell or smart phones and laptop computers for essentially continuous and instantaneous communication. Studies have shown that these students do not respond readily to many of the traditional messages about engineering as either a course of study or a profession.

The demographics of the engineering student cohort will also be a factor in the decades ahead. As the minority groups continue to grow through mid-century, the number of incoming students who are members of under-represented groups will increase. Greater ethnic and racial diversity of entrants into engineering programs will occur, and most of these students will be first generation students with relatively little pre-college exposure to engineering.

*Global work force changes*

The US leadership in engineering education is currently challenged by changes occurring with the European Union (EU) in response to the Bologna Accord (2010). The Peoples Republic of China (PRC), while rapidly expanding its university system, is now looking at the quality of its institutions and instructional programs. India is considering increasing the number of its Institutes of Technology, as well as developing doctoral programs competitive with those in the US and EU. Globally, new and existing mechanical engineering programs are applying for and receiving, accreditation from the Accreditation Board for Engineering and Technology (ABET) for their undergraduate programs.

These developments are positive and could lead to greater innovation in our efforts to develop sustainable solutions to the challenges facing our planet but will require a rethinking of US engineering education. The National Science Foundation 5XME (2007, 2009) workshops, the results of which have been integrated into this work, have looked at US mechanical engineering education from the perspective of needing to add five times the value over their counterparts in countries such as India or China where currently engineering salaries are significantly less than those in the US resulting in outsourcing of many engineering jobs. As foreign economies grow, this difference will decrease, and the longer term arguments will focus on global cooperation and the need for cultural expertise. Global competition will remain for products and services driving
the need for greater innovation through engineering. However, sustainable global success in alleviating poverty, providing energy, clean water, enough food, and a clean environment will become the benchmarks for success.

The case for substantive change in engineering education is strongly implied by the observations above. This assertion is validated by our surveys and educator workshops that touched a very broad segment of engineering constituencies. The one thing that is clear is that we must engage all of our constituencies in the change process: educators, our students, the graduates and industry. The data seems to indicate that all stakeholder groups must embrace change and the process of change. Industry must fully engage our graduates with challenging, exciting, and meaningful careers, and they must hire the right mix of engineers and engineering technologists. Whether change takes the form of curricular restructuring, change in the content of degree programs, or both is the task ahead for educators. We fully expect responses of academia to vary widely owing the great diversity within the engineering and engineering technology programs across the nation.

1.2 Goals, Assumptions, and Methodology
The goals for the Vision 2030 task force were to:

- Make a case for change in mechanical engineering and mechanical engineering technology education.
- Recommend improvements to mechanical engineering and mechanical engineering technology curricula.
- Promote and provide information for the development of engineering skills to solve technical and societal problems.
- Provide academia and industry with useful information regarding mechanical engineering workforce development and a clearer picture of industry expectations in the workforce.

The task force assumed that the above goals were motivated by the need to prepare engineering graduates to work in organizations that can range in size from a large corporation to a small startup company. Assumptions for our work are: (1) mechanical
engineering and mechanical engineering technology education needs to be responsive to the changing global engineering environment and resulting change in the nature of engineering practice; (2) the tools used by mechanical engineers and mechanical engineering technologists, particularly those related to computing, design, data acquisition and communication, will continue to increase in power, sophistication and utility; (3) there is consensus that the committee should use a green field, or blank sheet, approach to mechanical engineering education, e.g., adopt a “what should be done,” and then a “how do we get there” philosophy; and (4) both engineering education and engineering practice work in partnership to develop the full potential of engineering and engineering technology graduates.

The stakeholders in mechanical engineering and mechanical engineering technology education were considered broadly to comprise academic department chairs, faculty, deans, students, industry practitioners and managers, and government agencies. These constituent groups help the task force to frame the key questions to be addressed and the overarching issues to be addressed in our recommendations.

The following methodological tools were used to develop a contemporary viewpoint on the goals of our work:

- An assessment of the literature of the past 30 years that has addressed the engineering and engineering technology education. Key documents of this assessment are listed in the Bibliography.

- Multiple surveys of each of the stakeholder groups that addressed issues related to mechanical engineering education and practice.

- Open forum sessions at the 2009, 2010, 2011 ASME International Mechanical Engineering Congress and Exposition (IMECEs), and a Distinguished Lecture and workshop at the 2010 American Society for Engineering Education (ASEE) Annual Meeting.

- Focused half day workshops at the 2009, 2010, 2011 ASME International Mechanical Engineering Education Conferences (Department Heads meeting)

- A focused workshop on engineering technology, E-ET Workshop, at the University of Houston in 2010

- Participation of task force members in the NSF 5XME Workshops, particularly at the 2009 IMECE.
Several task force meetings during the course of our work to review and assess result of the surveys and formulate preliminary recommendations.

A 2009 – 2010 survey effort by ASME focused on mechanical engineering and mechanical engineering technology leaders and industry supervisors of mechanical engineers.

A 2010-11 survey of early career engineers by ASME.
2. Review of Previous Recommendations

This section contains brief reviews of the general issues facing the engineering profession, a review of some of the recent recommendations for changes in mechanical engineering education, and some of the visions for the future of mechanical engineering. Taken as whole, this literature has provided the Vision 2030 Task Force with a significant portion of the context in which our recommendations have been developed.

2.1 Overarching issues facing the engineering profession

The National Academy of Engineering’s The Engineer of 2020 (2004) envisions the future and attempts to predict the role engineers will play in the future. To do this, it uses scenarios based on broader strategic themes – biotechnology, natural disaster, and world conflict. The guiding principles of The Engineer of 2020 are that the pace of technology innovation will continue to be very rapid, the world will increasingly be globally connected, social and business groups involved with technology innovation will be increasingly ethnically diverse and multidisciplinary, and social, cultural and political forces will continue to shape technical innovation. The case is made that social issues (population, health and the global economy) are central to engineering practice in the future, and argues for the need to place engineering practice in an advanced technological context driven by breakthrough technologies, specifically biotechnology, biology, chemistry, nanotechnology, materials science and information technology. It further argues that while past responses to the increase in engineering knowledge entailed creating new undergraduate engineering disciplines, this subdivision of knowledge may be an inappropriate response in academia, and in the future, core knowledge advances should be applied to achieve interdisciplinary solutions to engineering problems.

Educating the Engineer of 2020 (2005) continues these themes and structural changes in the scale, scope and practice of engineering. It notes the increasing complexity and scope of engineering systems in energy, environment, food, product development, and communications. In addition, the domains of engineering interest now include the biological/nano-materials/information areas. These areas are based on ever smaller and smaller spatial and time scales, which necessitates melding together the
physical, life, and information science knowledge domains. Changes in the practice of engineering include increasing use of multidisciplinary teams, and a widening difference between engineering science and engineering practice and an internationalization of the global engineering workforce. The report also makes note of the decreasing fraction of US born or educated engineers in the world-wide engineering profession, which signals a change in the social context of engineering. Concurrent forces on the professions include the global population increase (primarily in developing countries) and in many countries at or below the poverty level, an increase in life expectancy, and intertwined global economies.

The report from the ASME 2028 Global Summit (2008) identifies a number of critical uncertainties that global societies face: the will to make the choices and investments for the grand challenges facing the world, gaining sufficient international cooperation, the time and money required to address environmental priorities, the ability of societies to change and build on lessons learned, and enabling young people to be educated in technical disciplines. Critical challenges facing the engineering profession generally include increasing public awareness with respect to new technologies, enabling lifelong learning, taking leadership roles, enabling informed public decisions, taking a lead in multidisciplinary and systems engineering, and developing partnerships and collaborations between the many organizations involved in addressing complex, society-wide problems. Results of a survey of engineers conducted as part of the ASME 2028 Global Summit indicate,

- Over 90% of the respondents expect to work on interdisciplinary projects and to coordinate multiple disciplines to complete more complex projects.
- Over 80% of the respondents said they will need to acquire considerably more knowledge and skills.
- 72% of the respondents indicate that much of that knowledge would be outside the traditional domain of mechanical engineering.
- 75% of the respondents say they will need a range of soft skills to work globally.
- 75% of the respondents indicate they would need better business processes, products and process designs for working in developing regions.
- 25% and 30% of the respondents indicate that they would use biotechnology and nanotechnology respectively.
In Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education (2008), Duderstadt indicates that, despite the growing importance to society of engineering practice, the profession tends to be held in relatively low regard compared to that of other professions. The report also noted that industry tends to view engineers as disposable commodities, replaceable by less expensive off shore engineering services.

Surveys have repeatedly shown that K–12 teachers and students generally have a poor understanding of what engineers do. An NAE project, Changing the Conversation (2008), identified, tested and disseminated a small number of messages intended to improve public understanding of engineering. The report noted that previous public outreach efforts have been ad hoc, and few metrics have been used to assess the results. Most of these past efforts targeted high school students, and most current messages are framed to emphasize the strong links between engineering and mathematics and science, which many consider as discouraging potential students. These traditional messages ignore other, more attractive characteristics of engineering: creativity, teamwork and communication. The recommended re-branding of engineering will require modifying and improving its appeal to different groups, especially minorities and young females. Recent reports have indicated that the percentage of US girls interested in STEM has not changed in the last 10-20 years despite the millions of dollars spent to engage them. Survey responses reveal that girls found the following two messages the most appealing: Engineering makes a world of difference (boys also rated this highly), and Engineering is essential to our health, happiness, and safety (boys did not rate this highly). Not considered to be appealing by any of the survey populations was the message, Engineers connect science to the real world.

2.1 Visions of the Future of Mechanical Engineering

The reports summarized above describe significant societal problems to which engineers should be applying their expertise. There is a great deal of discussion in these reports about the additional skills and abilities that will be required of engineers in the future. Many of these reports suggest that engineers can add additional value to society via the breadth of their intellectual capabilities, their ability to innovate, and their
leadership in addressing major societal challenges.

Reflecting global issues, such as environment and health, the vision of the ASME 2028 Global Summit was:

*Mechanical Engineering will develop engineering solutions that foster a cleaner, healthier, safer and sustainable world.*

Accordingly, the ASME Summit’s goals for mechanical engineering practice were to: develop new technologies to meet grand challenges in energy, environment, food, housing, water, transportation, safety, and health; create global, sustainable engineering solutions to meet the basic needs of all people; foster global partnership and locally appropriate development; and connect practitioners with the joy of discovery, creation and application of engineering solutions to improve human life.

*Engineering for a Changing World* (Duderstadt, 2008) presents a vision of engineering as the profession addressing the world’s challenges and asserts engineering alone has the knowledge base to support innovation and value creation. The report asserts that engineers must be able to add significantly more value through greater intellectual breadth and a capacity to innovate and argues for elevating the status of engineering as a profession to increase its prestige and influence. Duderstadt believes that a professional culture, e.g., in law and medicine, is needed to shape, rather than react to, corporate pressures.

The vision of engineering within *Changing the Conversation* (2008) is,

*No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. We are counting on engineers and their imaginations to help us meet the needs of the 21st Century.*

The vision of mechanical engineering education given in the ASME Body of Knowledge report (2004) was:

*Mechanical engineering seeks to broaden its attraction to highly capable students, including women and other traditionally underrepresented groups. Innovations in mechanical engineering education will prepare these students to pursue their individual interests well beyond the perceived boundaries of the discipline’s traditional roles.*
2.3 Recommendations for Changes in Mechanical Engineering Education

The reports reviewed by the task force contain a number of specific recommendations and strategies for mechanical engineering education. These range from how students learn to be engineers, responding to globalization, to competitiveness of the US-based engineer, and to increasing ethnic and gender diversity. The global economy demands far broader skills from engineers than simply mastery of scientific and technological knowledge.

Looking at engineering education’s progress, the Carnegie Foundation’s Mann report (1918) recommended generalized engineering curricula and periodic self evaluation by the engineering profession. The more recent Grinter report (1955), sponsored by ASEE, recommended: strengthening the teaching of basic sciences with emphasis on math, physics, and chemistry; including six engineering science courses (mechanics of solids, fluid mechanics, thermodynamics, heat and mass transfer, electrical theory, and materials as the common core of engineering curricula; and teaching engineering in the real-world context of analysis, design, and systems. However, only the first two recommendations were widely adopted, and by the mid-1960’s, most engineering programs became focused on analysis and research.

The ASME Body of Knowledge report (2004) was co-authored by members of the Body of Knowledge Task Force formed by the ASME Council on Education in 2003-04. The authors felt that a four-year Bachelor of Science Degree could prepare a mechanical engineering education graduate for life-long learning, but could not provide rigorous technical depth. The report identified drivers for change in mechanical engineering education to be complex interdisciplinary systems, new technologies, blurring of boundaries among disciplines, globalization of competition, bioengineering, declining support for universities, and student interests that go well beyond traditional perceived boundaries of the discipline. The report also discussed the expansion of the mechanical engineering discipline from heat engines, power, and mechanisms to also encompass the life sciences and nanotechnology applications. The report did not address the question of whether or not the bachelor’s degree would be able to produce globally competitive
Duderstadt’s *Engineering for a Changing World* (2008) recommends the creation of professional, practice-based engineering graduate degrees as the entry level requirement for the practice of engineering. Undergraduate engineering education would be reconfigured and broadened as an academic discipline, taking on similarities to the arts and sciences.

The *Engineer of 2020* (2004) report recommended increased use of multidisciplinary and virtual global teams to assemble, evaluate, and manage projects; the broadening of engineering education for greater understanding and appreciation of history, philosophy, culture, and the arts; and providing engineering students with a history of their profession by using case histories of past successes and failures. The report, while making recommendations about what should be added, did not address the thorny problem of how the curriculum should be altered to accommodate these changes.

The NAE’s *Educating the Engineer of 2020* (2010) recommends a focus on “how to learn” to do engineering and on the application of what has been learned. It suggests an earlier and stronger introduction to engineering practice within undergraduate programs, with the students experiencing the iterative process of designing, analyzing, building, and testing. It further recommends an emphasis on multi-disciplinary learning and the use of case studies relating engineering successes and failures. Additionally, project-based engineering education, increased study of economics and its relationship to solving most engineering problems, development of an intellectual framework for studying, understanding, and developing large-scale complex engineered systems were all recommended. The report also suggested that the BSME degree should be considered a pre-engineering degree, since the authors felt that adequate depth in a specialized area is not possible with a bachelor’s degree that includes these additional features. It was also recommended that engineering programs be accredited at both the bachelor’s and Master of Science Degree levels.

Two articles, Downey (2005) and Akay (2008), make the case that engineering problem solving should include focused activity on problem definition, so that the technical and non-technical dimensions of a problem are addressed from the beginning of the design process. In addition, problem definition should include collaborative work
among people who define problems differently. Akay argues that a new *renaissance engineer* is needed and could be developed by focusing on the context within which a problem exists before engaging in a technical problem solving exercise. He views a renaissance engineer as a creative thinker and strategist who will consider the sciences, arts, and current social elements in their solutions.

Downey (2005) recommends development of alternative pathways to an engineering degree. For example, engineering science, engineering design, engineering and management, or engineering and policy could all form building blocks for a less prescribed engineering educational path since they don’t necessarily bear the burden of including large blocks of traditional disciplinary content. He acknowledges the challenge of integrating a broader form of problem definition into engineering education, especially teaching students to locate and use both technical and non-technical bodies of knowledge.

Williams (2002) suggests a need to end the segregation of engineering education from general higher education, stating...“engineering students need to be educated in an environment where they get used to justifying and explaining their approach to solving problems and where they get used to people who have other ways of defining and solving problems.”

Crawley et al. (2007) have led a US/European curricular reform effort involving about 20 universities, documented in the book, *Rethinking Engineering Education: The CDIO Approach*. This initiative emphasizes education of students who are able to ‘*Conceive-Design-Implement-Operate*’ complex value added engineering products in a modern team based environment. Their goal is to educate students who are able to master a deeper working knowledge of technical fundamentals, lead in the creation and operation of new products, processes, and systems, and understand the importance and strategic impact of research and technological development on society. The CDIO initiative has developed a syllabus for engineering education to help meet these goals, in which the themes of innovation and sustainability are an important part.

The NSF sponsored 5XME Workshops of 2007 and 2009 explored necessary transformative change in mechanical engineering education and research in the USA. The 2007 workshop report proposed that the primary challenge for mechanical engineering education in the USA is to educate mechanical engineers who will provide five times the
value added, as compared to the global competition. The general recommendations of the 2007 NSF 5XME Workshop were that the bachelor’s degree should introduce engineering as a discipline, and be viewed as an extension of a traditional liberal arts degree;

With an interest in implementation, the 2009 NSF 5XME workshop recommended a number of mechanical engineering curricular changes:

- A professional (or design) “spine” offering engineering reasoning, engineering synthesis and other professional skills during all four years is needed. The professional/design spine should have a common theme such as the engineering grand challenges.

- The fundamental topics central to an ME curricula are mechanics, thermal sciences, materials, design and manufacturing, and systems and controls. A first course in these topics should be required, with further study as an elective.

- The curricula should be sufficiently flexible to prepare graduates for a wide variety of careers.

One of the 2009 5XME curricula recommend by the workshop comprised 25% basic mathematics and science, 25% mechanical engineering principles, 25% social science and general education, and 25% problem solving and design. The other path emphasized learner driven education that is a highly flexible degree path, emphasizing professional skills, after the fundamental core.

During the 5XME meetings, Warren Seering reported his survey work of early career MIT mechanical engineering graduates. These results shed light on time-honored portions of a mechanical engineering education curriculum. He asked graduates to respond on the frequency of use of topics like underlying sciences and mathematics, mechanics of solids, dynamics, thermodynamics, and fluid mechanics. The resulting data indicated that usage rates were very low, between never and hardly ever (once or twice a year). He also asked graduates to respond on the frequency of use of skills like engineering reasoning, systems thinking, communications, teamwork, professional skills, and independent thinking. These data indicated usage rates in the range of “frequently, on most days,” to “pervasively, for most everything I do.” Then the graduates were asked where they learned these respective knowledge areas and skills. Unfortunately,
from the educational viewpoint, for the most part, the knowledge/skills infrequently used were learned at MIT in their mechanical engineering program and the frequently used skill/knowledge sets were obtained elsewhere.

*Educating Engineers* (Sheppard et al., 2009) examines the strengths and weaknesses of current engineering education, and helps address the question about what is being done in academia. It raises concerns about students’ preparation for engineering practice and the under-representation of women and minorities. Based on an assessment of current educational practices in mechanical and electrical engineering feature, an emphasis on the acquisition of technical knowledge, distantly followed by preparation for professional practice is norm. The dominant curricular model found, described by the authors as the “building block” approach, puts theory before practice, following the post WWII engineering science model. However, research on how people learn technical topics, e.g., Dreyfus (1986), shows that competence develops through a process of guided experiences that resembles an apprenticeship process. The authors argue for a “networked components” educational structure where components of engineering science, laboratory work and design activities interact in an approximation of professional practice. Additional recommendations include professional practice problem solving for deep learning, laboratory experiences that are integrated, problem based and collaborative, design projects throughout the curriculum, and ethics and professionalism integrated into the curriculum.

The American Society of Civil Engineers (ASCE) has examined the current state of civil engineering education, contained in the second edition of their Body of Knowledge (2008) report. This report proposes changes in the education and pre-licensure experience of civil engineers. They propose that the master’s degree be the first professional engineering degree, along with an expansion of outcomes to encompass 24 outcomes for civil engineers. These outcomes are organized into three categories: foundational, technical and professional. Bloom’s taxonomy (1956) is used to describe the minimum cognitive levels of achievement for each outcome. The ASCE believes that tomorrow’s civil engineering graduate should master more mathematics, natural sciences and engineering science fundamentals; maintain technical breadth; acquire broader exposure to the humanities and social sciences; gain additional professional practice
breadth; and achieve greater technical depth, i.e., specialization. The baccalaureate degree is seen as a foundational stem upon which extensions for continued professional depth and transition to non-engineering career paths can be grafted. Further, the master’s degree should introduce engineering as a profession and become the requirement for professional practice, and the doctoral degree needs to be enhanced with an emphasis on breadth as well as depth, linking discovery with innovation.

In summary, over the past thirty or more years, common themes and recommendations have arisen on educating engineers for practice. Some of them have been driven by industry, but most by societal need. Engineering schools have responded in a generally passive manner to many of the recommendations of external bodies, and the curriculum has gone through a gradual process of change since the 1950’s when the Grinter Report was published.

For mechanical engineering, the inclusion of more technical course content and experience in design has been the most significant, pervasive curricular change since the 1970s – 1980s. Nevertheless, the mechanical engineering undergraduate curriculum has evolved to a nearly standard format and structure, and the distribution of major content categories has been nearly constant since the 1960s despite a gradual reduction in faculty-student contact hours, laboratory contact hours, and overall degree credit hour requirement. Industrial concerns generally have focused on the readiness to work of baccalaureate graduates, knowledge of industrial practice, hands on skills, and aptitude for design.
3. **Changes in the Mechanical Engineering Profession**

Changes and improvements in mechanical engineering education need to be in alignment with mechanical engineering practice. Mechanical engineers operate in a rapidly changing global engineering environment that is changing the nature of mechanical engineering practice. This section describes the expectations of what mechanical engineers in professional practice should know and be able to do. As a framework for this discussion, three areas of mechanical engineering practice are addressed:

- a. The characteristics of the mechanical engineering profession that differentiate it from the other engineering professions,
- b. The expanding scope of the mechanical engineering profession, and,
- c. The required mechanical engineering knowledge and expertise for success in engineering practice.

3.1 **Changes in ME and MET Practice**

Graduates at the baccalaureate level have been educated and trained to address problems and design products centered on the performance of engineered devices and processes. The technical issues they deal with involve motion of mechanical systems, determination of forces and energy consumption to achieve a given design goal, reliability, safety and serviceability. The device can range from a micrometer-scale electro-mechanical system to a large thermal power plant and very scale in between. Device complexity is also part of the design paradigm. Today engineered devices and systems contain perhaps a few to thousands of working components, all of which must reliably function to achieve the design goal and meet a customer need. Frequently, design success is achieved using a blend of traditional engineering subjects and basic physical, chemical and biological sciences.

In the past, large firms tended to organize their engineering staff into very narrow technical disciplines. Engineers were organized by departments, sections and groups, each having a very specialized role within the engineering endeavor and business process. These groupings were generally technically focused, say, avionics, electro-mechanical design, testing, guidance, navigation and control, materials and processes,
mechanical design, propulsion, structures, thermal design, etc., depending on the company and its business purposes. Traditionally, mechanical engineers fit very well into many of these specialized roles. Smaller firms, with an equivalently small engineering staffs, tended to hire mechanical engineering and mechanical engineering technology graduates, and place them in positions requiring use of a broad skill set. These individuals were asked to perform job functions over a wide range of technical areas. Mechanical engineering and mechanical engineering technology education graduates fit well into this role.

Recently a number of larger firms have moved toward an engineering employment structure more typical of that of smaller companies. With an emphasis on cutting costs, i.e., reducing staff and the potential for outsourcing routine and detailed design work, engineers are now expected to take on a broader range of tasks. This new breed of industry-based mechanical engineers is thus facing changes in employer expectations. These engineers are expected to be more of a generalist, or as some describe the situation, they are systems engineers.

**Expanding scope**

Mechanical engineering is one of the largest, broadest and oldest of the engineering disciplines. Mechanical engineers use scientific and engineering principles of energy, materials, and mechanics to design and manufacture systems, machines, processes, and devices of all types. With this foundation, mechanical engineers are well suited to move into an expanded scope of duties beyond traditional roles, as being demanded by changing business models and the rapid expansion of technology, communication, and world-wide engineering talent. By virtue of the breadth of technical subjects within the realm of mechanical engineering, mechanical engineers are in a better position to move into this new environment than those in many other engineering disciplines. Mechanical engineers and their many skills can and do contribute to a number of areas, including sustainability (energy, water, building systems, etc.), energy conversion, energy resources (traditional fossil-based and renewable), engineering management, environmental (both remediation and protection), manufacturing, materials, structures, systems design, and transportation. Such activity can be undertaken in a broad range of industries and their associated products and services. However, many other
engineering disciplines (some of which are specialties of mechanical engineering) are focused on a particular industry or the application of a narrow expertise or technology.

Consider these examples.

- Aerospace engineers create vehicles, such as airplanes, spacecraft and missiles.
- Chemical engineers establish, design and implement various chemical and continuous processes to produce an end product.
- Computer engineers analyze and evaluate computer systems, both hardware and software.
- Applying the principles of biology and chemistry within an engineering framework, environmental engineers develop solutions to environmental problems.
- Mining engineers, including mining safety engineers, find, extract, and prepare coal, metals, and other minerals (often as feedstock for the chemical engineering systems mentioned above).
- Petroleum engineers search for oil or natural gas reservoirs, followed by the extraction of these resources.

While mechanical engineers often work in the industries mentioned above, it is worthwhile to note that the reverse is not generally true. For instance, it is not common for a chemical engineer to work within the world of aircraft design. In addition to their technical skills, mechanical engineers in the future will become more involved in planning and scheduling project activities. This may include tasks such as estimating required resources to complete an activity, which may involve staffing estimates, equipment and materials estimates, collaboration with manufacturing, and definition and implementation of test requirements.

A seminal work in the study of engineering knowledge and how engineers learn is *What Engineers Know and How They Know It* (Vincenti, 1990). Using case studies drawn from the aeronautical engineering but applicable to mechanical engineering as well, Vincenti develops a comprehensive framework for thinking about the structure of engineering knowledge. His components of engineering knowledge include descriptive knowledge, the properties of an artifact, and procedural knowledge – how the artifact is
designed and built. He postulates that there is taxonomy of engineering design knowledge, including fundamental design concepts, engineering criteria and specifications, theoretical tools, quantitative data, practical considerations and design instrumentalities.

3.2 Requirements for future success in engineering practice

The blurring of disciplinary boundaries within engineering practice has been faced by industrial organizations for the past several decades. Industrial organizations have confronted the issues of whether engineering staffs should be made up of a group of engineering specialists or an assembly of generalists whose combined talents cover all the required engineering specialties?

In a similar fashion, mechanical engineering education is facing the question of whether it should – at the baccalaureate level – continue to educate technical specialists versus generalists who have additional, non-engineering skill sets. Knowing how to develop new knowledge based on a research effort, knowing how to design based on that research, or having the ability to analyze a complex part or process is not the same skill set as being able to apply current technology to build a viable part or implement the process in an economical manner nor is it necessarily the same skill set as needed for innovation. However, all skill sets are critical to the success of the engineering enterprise and for the eventual resolution of the challenges facing our planet. The taking of an invention of a product or process to implementation, that is innovation, requires a holistic education that includes excellent people skills and leadership. Thus, the education defining the preparation of future engineers and engineering technologists may consequently require much different educational paths, degree programs or degree levels than those of the present.

Successful industrial organizations will be those defined by increased innovation through integration of new methods of communication and partnership in the engineering and business processes. Nascent highly technical industries tend to initially require engineers with graduate degrees until businesses begin to scale up their processes, but research engineers will need engineering practitioners help on the factory floor to make any engineered product practical and scalable. Recent and future advances in computer-
aided design, materials, robotics, nanotechnology and biotechnology are tending to decentralize the process of designing and creating new devices. Consumers will be demanding better products and services: including higher quality and the potential for mass customization, and personalization. Mechanical engineering practitioners will fit well into leadership roles where engineers have more latitude to design and build their devices locally using indigenous materials and labor—creating a renaissance for engineering entrepreneurs.

Successful mechanical engineers in industry will be individuals who, in addition to technical knowledge, have excellence in communication, management, global team collaboration, creativity, and problem-solving skills. In addition to being focused on collaborative working environments and virtual design teams, mechanical engineering practitioners will need to better understand the global marketplace in terms of economics, user needs, values and culture. An engineer must have the skills to sell ideas to management and/or customers who, in many cases, will not be engineers, or who will come from a different cultural background. An engineer in industry must understand the impact of local, national, international regulations and standards on placing a final product or process in service and most importantly, must understand the long-term sustainability issues associated with the product or process. Otherwise, mechanical engineers will be unable to take on more leadership responsibility in the business world.

In summary, the growing complexity and multi-disciplinary nature of engineered systems, the rapid emergence of new technology, and the globalization of the engineering endeavor all have an impact on graduates in varying degrees and ways. This means that no one body of knowledge and no single model of the future educational paradigm will fit both engineering and engineering technology. It is clear that understanding the social, political, and environmental considerations of an engineering problem will become even more important to engineers and mechanical engineering education as well the ability to effectively lead innovation and change in industry and in society.
4. Challenges and Opportunities for Mechanical Engineers

The Vision 2030 Task Force used the ASME Global Summit (2004) and NAE Grand Challenges reports as starting points to identify areas where mechanical engineers can provide leadership in the development of innovative and sustainable solutions to the challenges facing the world’s societies. These areas include environment, human health, energy, security, multi-scale systems, engineering skills and computation. In this section we discuss these areas and indicate how they motivate and support changes in mechanical engineering education. Our treatment of each is necessarily brief and intended only to provide a sense of the breadth and depth of the technical and professional challenges for the mechanical engineer.

4.1 Environment

Mechanical engineering is critical to solving the world’s environmental challenges that exist during the life cycle of engineered products, structures and services, starting from resource extraction, to processing, design and product development, operations, transportation systems and finally to the processes and mechanisms for reuse, recycling and disposal. Mechanical engineers design heating, cooling, ventilation systems through energy generation and conversion in the built environment—green building design, energy management, and operations. They also contribute to air, ground and water pollution abatement technologies.

**Sustainable product development**

Mechanical engineers have the opportunity to be at the forefront of sustainable human development and sustainable product development. Mechanical engineering plays essential and critical roles in defining user and customer needs and in translating them into design specifications, often in a co-design process with the appropriate stakeholders. Energy innovators, in particular, have the most impact in the front end of the design process for sustainable products. Development of sustainable materials and manufacturing processes are also essential aspects of sustainable engineering.

Rapidly developing economies are adding to global environmental pressures and competition for energy, water, and other high-demand resources. In some areas of the world, unsustainable use of wood as a cooking fuel results in deforestation, increased flooding, and indoor air quality problems. Mechanical engineers will be challenged to
develop new technologies and techniques that support sustainable economic growth in a way that is appropriate in a regional context.

**Sustainable engineering for the developing world**

The infrastructure of both developed and developing countries is either aging or non-existent. Sustainable urban environments can be achieved through improved design and development of advanced materials and techniques to improve transportation, energy, water, and waste systems. For example, advances in informatics, software systems and robotics should make more automation possible in construction such that construction times will be reduced and costs lowered. Mechanical engineers can contribute to the development of innovative building designs and energy systems that have increased efficiency and reduced environmental impact.

The quality of life is impacted by the availability of clean water. There is a growing shortage of clean water on earth that, in today’s world, contributes to loss of human lives and disease. Clean water is not only needed for drinking and personal use, but also for sanitation, agricultural, energy, and industrial needs. Only about 3% of the planet’s water is fresh, but much of it is in the form of snow or ice. Moreover water contained in many groundwater aquifers is being used at a rate that exceeds the rate of natural replenishment. Desalination plants, for example, can be used to increase the world’s water supply, but these plants are expensive and require large amounts of energy to operate. Mechanical engineers can contribute to the design of innovative desalination, pumping, and distribution systems. Engineering challenges include the development of new technologies that improve recycling of wastewater, reduce water usage, and provide water to regions with severe distribution problems through decentralized distillation units.

### 4.2 Energy

Mechanical engineers will lead in the development of many technologies and strategies contributing to the portfolio of energy solutions for the world’s growing needs while still maintaining, or even improving, the current quality of life. A mix of energy supplies will be required to meet the world’s future energy needs. This mix will be derived from coal, petroleum liquids, natural gas, biomass, renewable energy sources, and atomic fission. In addition to developing energy technologies, improved efficiencies
and energy-use strategies are needed for buildings and for transportation.

In a broad sense, mechanical engineering and mechanical engineering technology education should include topics that provide an understanding of energy economics and of holistic approaches that balance local resources such as fuel and water. Energy economics should be stressed in the basic economics class in which most engineering students enroll. Furthermore, it is critical that mechanical engineers are able to communicate technical solutions to decision makers ensuring that policy and regulatory influences are appropriate. Technical communications course should teach to communicate science and engineering to the general public, legislatures and policy makers.

*Improvements in energy systems efficiencies* – Mechanical engineering has always emphasized efficiency in energy systems, whether it is in rotating machinery, automobiles, or power plants. The principles of efficiency should continue to be emphasized in such courses such as thermodynamics, heat transfer, and in technical elective courses. Future graduates should understand the trade-off between carbon dioxide reduction and increased power plant efficiency. A basic understanding of carbon capture and processing will likely be needed to allow for more efficient technologies to be developed. Mechanical engineers and mechanical engineering technologists should know how to appropriately apply sensors for effective energy management as multiple user levels.

*Energy conversion, storage and distribution* – Growing imperatives for increased usage of renewable energy, and continuing dependence on traditional energy sources require the development of clean, economical, and sustainable means of energy conversion, storage and distribution. Because transportation systems represent about one-third of US energy use, new and efficient energy conversion technologies will be needed. Advances in fuels, combustion, and related basic sciences will provide the fundamental basis for progress.

*Economical renewable energy* – Power derived from the sun provides less than one percent of the world’s total energy today but has the potential to provide much more. Only a small fraction of the sun’s power output strikes the Earth, but that amount provides 10,000 times as much as all commercial energy that humans use on the planet.
Barriers to exploiting solar power generation require innovations in capture, conversion, and storage. Mechanical engineering is the key to implementation and design of both solar thermal and solar voltaic systems, but much needs to be done to address the educational need in this area within the current frame of undergraduate and graduate education. Wind energy, while growing in sophistication and application, accounts for a similarly small percentage of electricity generation. Technical issues for wind power all relate to dynamic mechanical devices and systems, fluid-structure interaction, and acoustics. All of these topics lie within the domain of mechanical engineering and mechanical engineering technology.

_Nuclear energy_ – Nuclear energy provides approximately 20% of the US electricity base, and with plant re-licensing, this energy source will continue to play an important role in the future. In the long term, both fission and fusion technologies will play important roles. Fission power is a proven technology, and new reactor designs to supplement current boiling and pressurized water technologies have been under study for the past 15 years or more. Fusion power is yet in the research and development stage with the technological choice being magnetic confinement to produce a self-sustaining reaction. Each power generation option presents different technical opportunities for mechanical engineers and mechanical engineering technologists.

The aging workforce in the nuclear power industry, and the lack of new plant construction in the US poses both opportunity and peril for this segment of the energy industry. Opportunities for mechanical engineers and mechanical engineering technologists exist in every segment of the industry: plant design, operations, maintenance, waste disposal and regulation. The challenge lies in how academia responds with respect to the education at the undergraduate and graduate levels. The decline in the number of nuclear engineering programs in the US over the past thirty years also gives one cause for concern.
4.3 Human health and well-being

*Biomedical and assistive technologies* – Advances in bio-related technologies have already extended human life and increased the quality of life for all ages. One of the greatest success stories in the collaboration between doctors and engineers is the development of implantable biomedical devices, such as defibrillators, pacemakers, prosthetic devices and artificial joints. Assistive technologies play a vital role in developing opportunities and improving the quality of life for an aging population and people with disabilities. Demographics and improved medical care have contributed to an unprecedented aging population not only in the US but in most industrialized countries as well.

Mechanical engineers can take the lead in the development of innovative new prosthetics, assistive devices and diagnostic technologies. Advances can lead to more general advances in human-machine interaction and mind-body prosthetics. Another mechanical engineering challenge is to increase the reliability and reduce the costs of these technologies, perhaps through the use of neural science, MEMS and nanomechanical technologies.

*Personalized medicine* – Recent research has highlighted human differences in the susceptibility to disease and response to medicines. While the genetic blueprint is mostly the same for each person, subtle variants in about one percent of our DNA give us our identities. The mechanical engineering challenge is to develop better tools and devices that can assess a patient’s genetic profile and then provide the physician with a personalized medical framework in which to apply rapid and appropriate diagnoses and interventions. Advanced artificial intelligence software and monitoring technologies can guide medical diagnoses and treatments in a way that can be tailored to individual needs and circumstances. In addition, differential diagnostics through personalized monitoring can be used to empower individuals in their own health care and provide early warning of life-threatening conditions so that personalized interventions can be more effective.
4.4 Engineering skills for global collaboration

*Entrepreneurship and innovation*

As discussed in the previous section, the rise of engineering employment from large companies to small and medium-sized companies will continue with a growing emphasis on entrepreneurship and innovation. As more complex technologies require greater collaboration and sharing of intellectual property, changes will inevitably occur to produce equitable and beneficial results for the innovators and those that adopt and commercialize innovations. Because an important functional element of mechanical engineering and mechanical engineering technology education is design theory and design methods, the opportunity exists to reshape the educational process to address the needs for entrepreneurship and innovation in the future.

*Communication and collaboration*

The dominant organizations in 2030 will be those that are successful at working collaboratively and fostering global partnerships. The business world will be defined by increased productivity due to the integration of new methods of communication and collaboration. Mechanical engineering and mechanical engineering technology education will be restructured to meet the demands for individuals with technical knowledge who also have depth in communication, management, global team skills, and problem solving. In the recent past, mechanical engineers have focused on collaborative working environments and virtual design teams. We now need to better understand the global marketplace in terms of economics, user needs, values and cultures. Doing so will allow the ME profession to take on more responsibility in the business world.

Communication continues to be an important skill for mechanical engineers and mechanical engineering technologists albeit with a shift toward communicating solutions to the general population, as well as to clients in other cultures. Communicating to the general population is needed to provide opportunities for improved policy formation and political decision-making.

4.5 Multi-scale engineering

Mechanical engineers deal with systems at multiple scales, from the invisible micro- and nano-levels to large-scale or macro-level structures. Micro-machines and nanotechnology have the potential to strongly influence the direction of technological
development. Macro-engineering at the other end of the scale involves the manipulation of large scale human and natural systems, such as power plants, land reclamation, food production, climate change interventions, water transport, coastal protection, large flexible aircraft and space stations and other large complex construction projects. Engineers working at mid-century will also address the extremes of very large and very small systems that require a broad knowledge base and incorporation of a multi-disciplinary kind of engineering that is only now just beginning emerge. The challenge to academic institutions is that of reshaping undergraduate and graduate programs so that graduates can enter this new environment with the confidence and the abilities to contribute.

**Leveraging computational power and simulation**

Mechanical engineers are at the forefront of design, where scientific principles are brought to bear on the realization of new products and devices. The design process of the future will depend on skill sets that embrace the microscopic and biological world realms, as well as the technology of sensing and imaging. This design process will be an activity that is highly leveraged by multiple realities driven by intensive computation and visualization.

*Modeling of complex systems* – The modeling of complex systems, such as the human brain and the earth’s climate, involves a large number of variables with complex interactions. In the past, mechanical engineers have played a major role in the development of computational techniques, e.g., computational fluid dynamics and finite element analysis, for modeling complex system behavior. The critical future need is the ability to bring increasingly complex physical and biological behavior into the realm of engineering analysis. For example, the earth’s climate is a poorly understood physical system, and it imperative that we better understand the impacts of human activities on climate. Benefits from understanding brain function include developing algorithms for speech recognition and machine vision systems in automated factories. Engineering curricula should reflect an increased exposure to the capabilities of modern computational tools as they will be used for discovery and product development.

*Enhance virtual reality* – Training and communication can all be improved through the use of virtual reality. Virtual reality is a powerful tool for training
practitioners and treating patients. Engineers are creating entire systems, such as cars and airplanes, in virtual space to test design principles, ergonomics, safety, and maintenance. Engineering challenges that especially depend on mechanical engineering skills include three-dimensional solid modeling of the engineering artifact and accurately reproducing physical sensations such as sound, touch, and motion. The challenge for academic programs is a need to increase a systems view of design, whereby sensing, control systems and mechanical design are introduced in conjunction with one another. Future design teams must be led by MEs who have breadth that includes elements of computer science, artificial intelligence, quality control and reliability engineering.

### 4.6 Security and risk reduction

*Secure cyberspace and physical infrastructure* – Increased socio-political tensions around the world will demand an increased focus on managed risk and assessment with a view to public security, privacy, and safety. Maintaining the security of our food, water, transportation, energy, computing, and communication systems is a complex and continuing task. The mechanical engineering challenge for protection of infrastructure is the development of multi-layered physical and software security systems for infrastructure protection.

*Preventing nuclear attack* – Technologies are needed to prevent a nuclear attack, both from nation states and individual groups. The technology for production of fissionable materials suitable for making a weapon is known worldwide. The engineering challenges include how to secure fissionable materials, how to detect the materials, how to render potential devices harmless, how to respond to such an emergency, and how to determine who the responsible parties are. Mechanical engineering challenges include the development of passive devices and systems to detect and transmit real-time data on fissile materials.
5. An Assessment of Mechanical Engineering Education

Introduction

The conclusions and recommendations of this report are based on a variety of sources: a review of the relevant literature, surveys of mechanical engineering and mechanical technology education faculty and department heads, engineering and engineering technology deans/directors, surveys of industry leaders, surveys of our graduates, and inputs taken from workshops and conferences. Each group is a stakeholder in the education of mechanical engineering and mechanical engineering technology graduates. Their input is considered both an environmental scan and an *ad hoc* assessment of ME and MET education and practice.

Surveys of our constituencies were designed by the task force and administered by ASME through its Internet survey tool. Compilation of survey responses was done by ASME staff, and final analysis and interpretation were done by the task force. The initial round of surveys of spring 2009 was sent electronically to engineering deans, mechanical engineering technology academic officers (deans, or provost level managers), industry leaders, and department heads. Responses were on the order of 50-100, and they formed the basis for a more in-depth survey of industry leaders in Fall 2009. The response to the second survey was over 600 respondents, representing small, medium and large companies across a wide variety of industries. All of them are involved in hiring recent baccalaureate graduates.

The totality of the results gives rise to 14 broad categories to reflect the preparation of mechanical engineering and mechanical engineering technology graduates. Appendices A and B contain a comprehensive summary of our data. The following sections provide an overview of key findings.

Curricula Change Slowly

Curricular change occurs slowly and mechanical engineering programs have had essentially the same structure and content since the 1960s, when science-based engineering education replaced the shop, or practice-based education developed in the first half of the 20th Century. When asked how many times in the past 10 years have there been major curricular revisions, 79% of ME department heads indicated none to one
or two changes, and 46% of MET department heads indicated one to three changes. Most respondents indicated that the extent and substance of their most recent curricular modifications represent a kind of “tinkering on the edges” of their educational program. The motivations for such change to ME and MET curricula were characterized as the following.

- Adaptation to the 128 credit hour model for the four-year Baccalaureate Degree.
- Implementation of new, and modified courses, with adaptation to new teaching technologies.
- Curricular change in preparation for the ABET accreditation review.
- Response to a change in the academic calendar.
- Responding to industry input to improve employability of graduates.

One response regarding change in a ME curriculum seems to capture the sense of most of the responses received.

> Based on emerging fields in mechanical engineering and a desire for the ME program to stay relevant, we expanded sub-discipline offerings within the program. We also wanted to ensure we maintain an emphasis on the fundamentals so that our graduates could pursue specialization in almost any area in graduate school.

A number of respondents expressed a similar logic focused on the preparation for graduate employment in a wide range of industrial settings. Nevertheless, 69% of respondents to our survey in spring 2010, agree that major change is probable or highly likely in their undergraduate programs from 2010 to 2015.

**Comparison of the Academic and Industry Viewpoints**

Key questions on our surveys were focused on the potential for change in the undergraduate curriculum as a result of institutional and external forces. Responses obtained in the initial survey were generally confirmed in subsequent surveys and provide a consistent picture of the several factors that frame the educational environment.
Department heads are clear about strengths and weaknesses of their programs. When asked “What do you consider to be the greatest strengths of your undergraduate program?,” the majority of ME department heads mentioned the following.

- A broad foundation and strong fundamentals in science and engineering.
- Integration of mathematics, sciences and engineering.
- Strong design component in the curriculum.

Weaknesses cited by the department heads within ME undergraduate program are less specific and perhaps reflect a need for more introspection and analysis. Responses range from “none” to “[the program is] a bit antiquated.” Responses focusing on systemic educational issues included the following.

- Mathematical preparation of students.
- Lack of specialized electives and depth in technical specialties.
- Integration of theory with practice via laboratory experiences.
- Insufficient cross-curricular topical development.

With regard to the perceived strengths of their BSMET programs, MET program leaders indicated the following three items.

- Design skills.
- Strong basic (core) courses using engineering texts.
- Good facilities/equipment for hands-on experiences.

Perceived weaknesses of the BMET programs were cited as in three areas.

- Specific curricular weaknesses, e.g., thermal/fluids engineering or project management.
- Use of too many part-time faculty members.
- Resources, especially for laboratories and modern equipment.

Analysis of survey data from of industry focusing on the strengths and weaknesses of baccalaureate ME and BMET graduates provides an outcomes-based assessment of undergraduate education. With the aforementioned 14 categories of response, or attributes, derived from the surveys; a simple difference – strength minus weakness – in response rate for a given attribute provided a surprisingly clear picture of
Educational outcomes and the difference between viewpoints of academia and industry. Tables 5.1 and 5.2 show the attribute profiles for newly hired BSMEs and BSMETs, as of spring 2009. (These data were supported and strengthened by the Spring 2010 survey of industry supervisors as well.) While there is some overlap in the distribution of strengths and weaknesses, the overall pattern of differences provides an indication of outcomes of the two educational experiences that is not unexpected.

Table 5.1 indicates that attributes rated as strong for the BSME hires were electronic communication/information processing/computing. Technical fundamentals, interpersonal skills and teamwork were noted as reasonably strong attributes. Weak attributes were problem solving, critical thinking, oral/written communication, and knowledge of how devices are made and work.

**Table 5.1. Strengths and weaknesses of BSME hires.**
*(Spring 2009 industry survey. N = 381.)*

<table>
<thead>
<tr>
<th>Category</th>
<th>%Strength</th>
<th>%Weakness</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information processing – electronic communication</td>
<td>27</td>
<td>1</td>
<td>+26</td>
</tr>
<tr>
<td>Technical fundamentals – traditional ME disciplines</td>
<td>22</td>
<td>13</td>
<td>+9</td>
</tr>
<tr>
<td>Interpersonal/teamwork</td>
<td>19</td>
<td>10</td>
<td>+9</td>
</tr>
<tr>
<td>Computer modeling and analysis – software tools</td>
<td>17</td>
<td>2</td>
<td>+15</td>
</tr>
<tr>
<td>Communication – oral, written</td>
<td>3</td>
<td>14</td>
<td>-11</td>
</tr>
<tr>
<td>Practical experience - how devices are made and work</td>
<td>2</td>
<td>24</td>
<td>-22</td>
</tr>
<tr>
<td>Problem solving &amp; critical thinking - analysis</td>
<td>2</td>
<td>9</td>
<td>-7</td>
</tr>
<tr>
<td>Design – product creation</td>
<td>1</td>
<td>5</td>
<td>-4</td>
</tr>
<tr>
<td>Business processes - entrepreneurship</td>
<td>1</td>
<td>6</td>
<td>-5</td>
</tr>
<tr>
<td>Project management</td>
<td>1</td>
<td>3</td>
<td>-2</td>
</tr>
<tr>
<td>Overall systems perspective</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Technical fundamentals – new ME applications (bio, nano, info, multi...)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Leadership</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Experiments - laboratory procedures</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.2 indicates that strong attributes of BSMET graduates were computer modeling and knowledge of how devices are made and work. Major weaknesses were technical fundamentals and oral/written communication. Moderate weaknesses were noted as interpersonal skills, teamwork and a systems perspective.
Industry and academia were both asked what they considered the missing components in the ME undergraduate curriculum. Responses show only a few areas large difference (see Table 5.3). The largest differences (educator minus industry response) in opinion are seen as: embracing new technologies, communication skills, and knowledge of how things are made and work. Surprisingly, in comparison with academia, industry feels quite strongly that technical fundamentals is a missing component of ME undergraduate education and considers new technologies (new application areas) not important.

When industry is asked to consider how well new BSME graduates measure up on an absolute basis over these 14 attributes, a slightly different picture emerges (see Table 5.4). A new graduate’s knowledge of business processes shows up as weakness or of no concern (77%). Significant weakness were perceived to be a lack of practical experience and communication skills (~50%), knowledge of engineering codes and standards (73%), and an overall systems perspective (59%).
Table 5.3. Missing Components in the ME Undergraduate Curriculum.  
(Spring 2009 industry survey.  N = 381 for industry and 84 for educators.)

<table>
<thead>
<tr>
<th>Category</th>
<th>Educator %</th>
<th>Industry %</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical fundamentals – new ME applications (bio, nano, info, multi…)</td>
<td>27</td>
<td>0</td>
<td>+27</td>
</tr>
<tr>
<td>Interpersonal/teamwork</td>
<td>10</td>
<td>13</td>
<td>-3</td>
</tr>
<tr>
<td>Overall systems perspective</td>
<td>10</td>
<td>4</td>
<td>+6</td>
</tr>
<tr>
<td>Business processes - entrepreneurship</td>
<td>10</td>
<td>8</td>
<td>+2</td>
</tr>
<tr>
<td>Practical experience - how devices are made and work</td>
<td>8</td>
<td>22</td>
<td>-14</td>
</tr>
<tr>
<td>Design – product creation</td>
<td>6</td>
<td>2</td>
<td>+4</td>
</tr>
<tr>
<td>Communication – oral, written</td>
<td>6</td>
<td>16</td>
<td>-10</td>
</tr>
<tr>
<td>Problem solving &amp; critical thinking - analysis</td>
<td>4</td>
<td>3</td>
<td>+1</td>
</tr>
<tr>
<td>Leadership</td>
<td>4</td>
<td>3</td>
<td>+1</td>
</tr>
<tr>
<td>Experiments - laboratory procedures</td>
<td>2</td>
<td>1</td>
<td>+1</td>
</tr>
<tr>
<td>Computer modeling and analysis – software tools</td>
<td>2</td>
<td>5</td>
<td>-3</td>
</tr>
<tr>
<td>Project management</td>
<td>2</td>
<td>8</td>
<td>-6</td>
</tr>
<tr>
<td>Technical fundamentals – traditional ME disciplines</td>
<td>1</td>
<td>13</td>
<td>-12</td>
</tr>
<tr>
<td>Information processing – electronic communication</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.4. Industry assessment of recent BSME graduates.  A-Not important, B-Weak, not a program concern, C – Weak, D- Sufficient, E- Strong, F-Strong, needs more emphasis.  Values are percent of response (N = 600).  (Spring 2010.)

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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</thead>
<tbody>
<tr>
<td>Practical experience</td>
<td>2</td>
<td>12</td>
<td>55</td>
<td>23</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Communication (oral, written)</td>
<td>0</td>
<td>4</td>
<td>53</td>
<td>29</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Overall systems perspective</td>
<td>2</td>
<td>14</td>
<td>45</td>
<td>32</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Engineering Codes and Standards</td>
<td>9</td>
<td>27</td>
<td>45</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Problem solving &amp; critical thinking (analysis)</td>
<td>1</td>
<td>3</td>
<td>35</td>
<td>42</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Project management</td>
<td>11</td>
<td>28</td>
<td>34</td>
<td>23</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Design – product creation</td>
<td>2</td>
<td>8</td>
<td>31</td>
<td>46</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Experiments - laboratory procedures</td>
<td>10</td>
<td>6</td>
<td>30</td>
<td>44</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Business processes</td>
<td>15</td>
<td>34</td>
<td>29</td>
<td>18</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Leadership</td>
<td>6</td>
<td>19</td>
<td>27</td>
<td>40</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Interpersonal/teamwork</td>
<td>0</td>
<td>3</td>
<td>24</td>
<td>50</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Technical fundamentals (traditional ME sub-disciplines)</td>
<td>1</td>
<td>1</td>
<td>19</td>
<td>53</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>New ME applications</td>
<td>21</td>
<td>15</td>
<td>14</td>
<td>41</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Computer modeling/analysis – software tools</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>44</td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td>Information processing (electronic communication)</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>43</td>
<td>41</td>
<td>2</td>
</tr>
</tbody>
</table>
Prospects and Pathways for Change

Both ME and MET department head anticipate that changes in engineering practice will drive curricular change over the next 20 years. Factors that will drive this change center on the following themes:

- Global nature of engineering practice and business,
- More reliance on software for design and automation of best practices in design and manufacturing,
- Development of smart products,
- Focus on sustainability and energy as over arching challenges/practice foci, and,
- Increased need for inter-/multidisciplinary skills.

Major curricular changes anticipated by the ME department heads over the next 20 years as a consequence of changes in engineering practice touch on the following themes:

- New balance between fundamental (“core”) subjects and new areas of applied science and technology, e.g., nanotechnology,
- Increased interdisciplinary project work,
- Holistic, or systematic, thinking and problem solving,
- Advanced knowledge beyond the bachelor’s degree,
- Development of “smart” products,
- Focus on sustainability and energy as over arching challenges or the foci of the practice of engineering, and,
- Increased need for inter-/multidisciplinary skills.

If there is a tension between the extremes emerging from these responses, it is that basic engineering and professional skills sets need strengthening and that broader, multidisciplinary or interdisciplinary thinking gained through practice-like experiences need more emphasis. On another level, this apparent dichotomy emerges in the
contrasting views that the curriculum should reflect the needs of the work environment (tools, soft skills, thinking processes, etc.) versus a deeper technical/scientific preparation. Perhaps, the following comment sums up the center of opinion on this question.

Increase in “systematic [thinking]” or “considering the whole”, stronger conceptualization skills, retain fundamental science, but teach students how to teach themselves to learn how to apply the fundamental science to any new emerging technology. Teach more skills to do with “open thinking”, and rapid movement to align resources to a new problem.

To meet anticipated future changes in engineering and engineering technology practice, MET department heads predict a variety of impacts on the curriculum. The following capture over arching themes:

- Greater use and training in simulation and computer-aided “X”,
- Greater emphasis on professional skills, especially communication,
- Some understanding of global financing, and,
- Greater emphasis on energy conversion processes and technologies.

Pathways to new educational structures and practices are not clearly revealed in our surveys, and ME and MET department heads readily identify several barriers that face them in program reform: budget cuts, hiring freezes, faculty expertise, salary freezes, and some difficulty in obtaining funded research; mixed indicators on enrollment across the public and private schools; and reduced job opportunities and opportunities for internships in industry.

As these issues indicate, ME department heads generally focus on the future with little optimism – doing more with less and delaying expansion and investment plans. Some mention curricular reduction and smaller faculty sizes with less support for teaching assistants even in the face of increasing enrollments. Others mention an intensification of a bidding war for new faculty, the need for more private funds, and working closer with local industries. On a more positive note, better graduate students are expected, and an increase in enrollment in graduate programs. Some opined that creativity and even prayer are needed at this time.

About half of respondents to surveys in spring 2009 indicate that increased learning productivity will be needed to implement the suggested curricular changes. In
that same survey, 75% cite more efficient curricular planning as necessary, 43% foresee
greater use of instructional technologies, even as 28% called for additional content
(courses) in the curriculum.

There is strong indication from ME department heads, with a lower response from
industry, that formal education beyond the baccalaureate degree will be needed for the
knowledge base and industrial vitality in future (58% of industry responses and 79% of
academic responses in the spring 2010 surveys), but there is also a clear message that
denoting the master’s degree as the first professional degree is not supported by both
academia and industry. Further, there is not much support for creating professional
schools of engineering patterned after other professions, e.g., medical. Industry has a
strong preference for hiring engineers with the bachelor’s degree (45% of respondents in
the survey of spring 2010), and there is little support for requiring the master’s degree for
professional registration for mechanical engineers.

**Summary**

The following paragraphs briefly summarize what was learned from literature reviews,
surveys and face-to-face meetings with academia, industry, and engineers in the
workforce. Taken together, they form a framework for recommendations for mechanical
engineering and mechanical engineering technology education, and for ASME in its
advocacy role for the mechanical engineering profession as a whole.

**Stakeholder Observations**

**Observations from, and for, industry**

- Engineering managers indicate a lack of practical experience among
  ME graduates, and ME department heads generally agree.

- Engineering managers also indicate weak inter-personal and
  communication skills among the ME graduates but ME department
  heads disagreed.

- Engineering managers are not very interested in specific technical
  courses outside the traditional engineering fundamentals unless they
directly address their business interests, but department heads feel that
courses involving new technologies are important.
• Problem formulation and solving ability are important to both employers and graduates.

• It appears that industry hires too many engineers for tasks better suited to the educational background of a bachelor of science in engineering technology, increasing the necessary learning curve, and perhaps causing retention problems, reduced job satisfaction, decreased productivity and diminished creativity.

• Industry’s ongoing need for engineers with more practical experience could be an opportunity either for growth of engineering technology programs or perhaps a shift to a more practiced-based engineering degree, e.g., the Bachelor of Engineering or the Bachelor of Science in Engineering.

• It appears that industry needs to realign its workforce and training to better utilize young engineer’s enthusiasm and creativity. Much of this creativity occurs early in their career and can align with the young engineer’s passions.

Observations from, and for, academia

• As shown by Seering, new graduates both forget much of the technical content by graduation and never use much of it during their early professional careers.

• ME and MET degree programs do not typically attract high school students with interests and abilities outside of mathematics and science, nor do they attract minority and female students.

• Most engineering faculty members teach based on their own academic experiences and career paths, typically focused on considerable technical detail. They are the content providers of the educational process but, in many cases within ME education, appear to be preparing students to move on to a doctoral program rather than professional practice. This is in spite of the fact that most graduates enter into engineering practice in industry, not graduate work.

• An overwhelming majority of faculty, when asked how to develop communication and leadership skills in undergraduates indicate that these skills should be integrated into existing technical coursework.

• Mechanical engineering department heads feel that considerably more post graduate technical education is required and industry managers
appear to agree. Department heads generally favor the concept of bachelor’s degree plus a professional master’s degree (as opposed to the Master of Science), while industry managers are equally divided on the value of the master’s degree.

- Department heads feel that faculty time, resources and expertise are the most significant barriers to educational reform. The ABET accreditation process and requirements were considered the least significant barriers.

- About half of industry engineering managers and department heads agree that systems engineering content in undergraduate programs needs to be increased.

- About one third of both the industry engineering managers and academic department heads feel that knowledge of business processes, project management and leadership outcomes need to be stronger in the new graduates’ skill set.

**Observations from young engineers**

- There appears to be some workplace dissatisfaction with ME graduates, with a large number of them leaving engineering work to find more different careers. Curricular flexibility, giving students more ownership of their degree programs and better use of their talents in industry, could help retention and benefit both the graduate and their employers.

- Students and young engineers want to make a difference in society and for their employers.

**General observations**

- Most faculty members agree that the most compelling reason for substantial curricula change are the grand challenges facing our planet and that increased innovation, improved diversity of the student body improved learning outcomes (including professional skills) are necessary.

- It is doubtful that real academic change can happen at most universities without changing the reward structure for faculty members or the faculty expertise profile.

- Considerably more attention must be paid by academic programs to issues such as sustainable growth and innovation, particularly as applied to solving the challenges facing our planet. Program content
changes towards developing future leaders who will make a difference for industry, our nation and the planet should start at the undergraduate level.

- Partnership of industry and academia is needed to develop the full potential of engineering and engineering leadership.

- In order to fully engage the US workforce and to take advantage of technological innovation, the US must reinvent high technology/high value manufacturing. Given historical program orientations, this challenge provides a significant opportunity for mechanical engineering technology programs.
6. Recommendations - Curricula and Outcomes for 2030

Introduction

The previous sections have highlighted the many challenges facing mechanical engineering education. The desired skills, along with the strengths and weaknesses, of mechanical engineering graduates have also been assessed. In this section, a number of recommendations are proposed, including alternative curricular structures, to help ME and MET educators improve their programs to meet these challenges and strengthen the skills of their students.

Seven aspects of the educational landscape have emerged as target areas for change. They encompass a wide range, spanning the educational pathways of mechanical engineering and mechanical engineering technology, to the increasingly diverse practice of mechanical engineering. To accomplish these changes, what specific strategies can educators, industry, and government pursue? The following actions are urged for seven major outcome areas of curricular change.

Recommendations

GOAL: GREATER INNOVATION AND CREATIVITY

Action: Create a curriculum that inspires innovation and creativity.

The chance to produce practical or technical innovations to solve real world problems and to help people is one of the most inspiring aspects of the profession to prospective or young engineers. Developing student creativity and innovation skills, through explicit curricular components that emphasize active, discovery-based learning (such as a design spine/portfolio or other intensive extracurricular engineering experiences) can also enhance motivation and retention. The ‘grand challenges’ can be incorporated as elements into early design courses to help provide an engineering context and background for students as they take their science and mathematics courses. Service-based projects needing innovative solutions should be made available for students ranging from the first-year to the senior-year. Faculty members who can mentor and coach students through these experiences are also needed.
GOAL: MORE FLEXIBLE CURRICULA

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

There is a need for greater flexibility in the degree path to enable students to develop understanding of mechanical engineering fundamentals but also enable greater strength in context and realization of design, a better systems perspective and the student’s ability to focus on an area of interest. Thus, the model of a required “core” set of mechanical engineering fundamental topic classes, followed by a concentration area is suggested (echoing recommendations of earlier engineering education studies).

**Action:** Modify ABET criteria regarding student competencies.

To enable curriculum change and encourage more flexibility, modifications to the ABET general criteria and program criteria for mechanical engineering (ME) and mechanical engineering technology (MET), e.g., in the ME criteria, no longer requiring both thermal and mechanical competencies, but preparation for professional work in one or the other, with exposure to the area not emphasized, are recommended.

GOAL: RICHER PRACTICE-BASED EXPERIENCE FOR STUDENTS

**Action:** Embed more authentic practice-based engineering experiences.

It is imperative to strengthen aspects of the undergraduate mechanical engineering curriculum that enable mechanical engineering graduates’ practical understanding of how things work and are made. As per survey results, the greatest weaknesses noted by employers of current ME graduates, as well as by the early career engineers themselves, were a lack of practical experience in how devices are made or work, lack of familiarity with codes and standards, and a lack of a systems perspective. Therefore, all students should have a multi-year, practice-based engineering experience via a design spine, implemented using multidisciplinary design teams with a focus on device design/building/testing/operation. Other experiences strengthening the practical experience component of ME education are industry internships and cooperative education or extracurricular design/build experiences. Many schools have very
successful internship and cooperative education programs, taking advantage of the capabilities of industrial partners to provide direct industrial experience to students.

**GOAL: STRONGER PROFESSIONAL SKILLS FOR STUDENTS**

**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, oral and written communication, inter-disciplinary teamwork, leadership, and project management. 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/portfolio approach incorporating such skills development, integrated with technical competency, into curricula is urged. Extra-curricular activities, such as student professional societies, can also play a role in professional skill development.

**GOAL: TECHNICAL DEPTH SPECIALIZATION**

**Action:** Focus on post-graduate education for technical specialization

Additional technical depth and specialization in mechanical engineering topics, plus increasingly sophisticated technical skills, continue to be required by some aspects of industry, according to both department heads and industry managers. Increased availability of professional master’s degrees provides opportunity for new graduates and practitioners.

**GOAL: GREATER DIVERSITY AMONG STUDENTS AND FACULTY**

**Action:** Implement effective strategies to attract a more diverse student body.

As an engineering discipline with one of the lowest percentages of women and underrepresented groups, mechanical engineering needs to improve recruitment of a diverse student body and faculty by all means available. Recruitment messages, mentorship, faculty diversity, and emphasizing the idea that mechanical engineering is about solving the problems that impact people lives are all important strategies. Many of the curricular changes suggested above, especially reinforcing connection of engineering
study to contextual real-world solutions that help people and society, have been shown to increase student retention and diversity. This message should be infused into the first-year engineering courses to increase retention of underrepresented groups.

**GOAL: NEW BALANCE OF FACULTY SKILLS**

**Action:** Increase faculty expertise in professional practice.

To produce graduates with the practical and professional skills described above, diversification and broadening of faculty capabilities within a department is required. Employing more faculty with significant industry experience, i.e., incorporating the ‘Professor of Practice’ concept, 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 an understanding of the use of codes and standards in different contexts, will impart a greater and more authentic sense of the world of practice to students. Another useful strategy, in schools where mechanical engineering technology programs also exist, would be to cooperate more fully with MET faculty, who often have a more extensive industry background. Integrating ME and MET students and faculty within the project spine and capstone projects has proven to be an effective strategy.

**Action:** Modify ABET ME program criteria for faculty numbers and qualifications.

ABET ME Program Criteria should address metrics for minimum faculty size/student ratio to ensure program quality in design and encourage an increase in the proportion of “practice-experienced” faculty.

**GOAL: ENHANCE MECHANICAL ENGINEERING TECHNOLOGY**

**Action:** Embrace recommendations of Vision 2030

Many of the above goals and related actions are recommended for all mechanical engineering education programs, including mechanical engineering technology programs. But, while several of the recommendations above are already typically embedded in mechanical engineering technology programs, e.g., embedding a practical understanding of how things are made and work, there are specific recommended enhancements for
mechanical engineering technology programs stemming from the Vision 2030 work. Two-year programs should emphasize ensuring adequate “hands-on” skills appropriate to the program’s focus (typically the need of local industries), involve industry to a high degree (emphasizing that industry needs to support such engineering technician programs or they will lose this workforce development mechanism) and create a stronger focus on teamwork and interactions within the workforce. Four-year programs should develop an increased emphasis on the process of product design and innovation (critical to re-energizing manufacturing), develop a stronger emphasis on the critical thinking (e.g., data analysis, establishing and evaluating criteria and constraints, etc.) and systems engineering yet maintain the traditional practical engineering focus and product realization skill set of their graduates.

**Final Comments**

These recommendations are different than those of past curricular reform efforts, where the debate centered on the mix of math and science, engineering topics and design. It is critical that we maximize student skills in problem formulation/solution, innovation, and leadership. This skill mix will be needed for engineers to be successful in engineering practice and to support society’s drive for a sustainable future.

We envision graduates who are meaningfully engaged in mechanical engineering practice in areas they are passionate about; demonstrating skill, commitment and leadership within their organizations. Such graduates will practice innovation and creativity, adding value within all of their fields of endeavor, will lead development of technical and business solutions that are economically and environmentally sound, will provide local, regional and national leadership on important issues, e.g., the ‘grand challenges’ as related to social, economic, and environmental sustainability.

The ability to both formulate and to solve complex problems, involving both technical and societal aspects, will be the touchstone of the mechanical engineer of 2030. Accordingly, we believe that future technical solutions alone are not enough to meet business and societal needs. The mechanical engineering profession must ensure that solutions are implemented in viable economic, social, and environmental terms. This responsibility implies a richer professional framework in engineering education than
presently exists. It implies that engineering and engineers must assume leadership roles, not only in the workplace, but across all aspects of society.

We believe that now is the time for mechanical engineering education programs and their leadership to begin the reformation of the educational process as outlined above. These recommendations are not prescriptive, with a ‘one size fits all’ approach. We recognize that every ME and MET program must align curricula and educational objectives with their overall institutional mission, and the needs of their particular constituencies.

Many of these recommendations are not new, and some have been implemented and integrated into curricula by some mechanical engineering or mechanical engineering technology programs. These programs have demonstrated a successful impact on desired departmental outcomes. Many of our recommendations reflect findings of previous reports, such as the two NSF 5XME workshops, and those from the Carnegie Foundation. It is useful to point out that the ABET accreditation requirements for mechanical engineering education programs are not a constraining factor in program adoption of the Vision 2030 recommendations.

Partnership between industry, government, and academia is needed to successfully implement these recommendations and develop the full potential of engineering education and engineering leadership. Implementation of a design spine will require both intellectual and financial resources; buy-in from the faculty, use of industrial expertise as adjunct instructors, and increased workshop, laboratory and design studio space. Industry’s ongoing need for engineers with more practical experience presents an opportunity either for growth of mechanical engineering technology programs or a shift to a more practiced-based mechanical engineering degree, e.g., the Bachelor of Engineering in Mechanical Engineering.

Furthermore, recommendations for industry and ASME are made in concert with recommendations for academia – a strong partnership among all three must exist for successful reform of the educational process. For example, ASME could facilitate faculty-practitioner exchange programs, practice-based endowed faculty chairs, and an educational hub resource with content in areas such as codes and standards. Industry can
provide sabbaticals or internships to faculty, facilitate faculty-practitioner exchange programs and provide endowed chairs for ‘Professors of Practice’.

Substantive changes will be required in the traditional mechanical engineering curriculum to allow strengthening the areas of need highlighted by the Vision 2030 data and findings. Such changes may not be easy, whether they take the form of new directions in course development, shifts in faculty makeup and incentives, involvement of industry, or adjustments to program criteria. The advocacy role for ASME in promoting and supporting educational reform cannot be underestimated if educational reform is expected to succeed. Professional societies like ASME, all levels of academia, industry leaders and government policymakers must work together to accomplish forward movement for the good of the profession.

This document has been intended to get the ME and MET communities thinking, and hopefully acting on curricular reform. As one faculty member put it during our work over the last three years, “This is too important to not do something, and we have to get it right!”
Appendix A. Assessment of Mechanical Engineering Education and Practice, 2009-2010

Surveys of constituent groups and focused inputs were sought from industry, engineering faculty, ME and MET department heads and other education leaders, and the ASME Industrial Advisory Board. These inputs document the perceived strengths and weaknesses in the various mechanical engineering education and the current needs of engineering practice. Taken together, they comprise a scan of stakeholder environment for ME and MET education and inform in part the recommendations for curricular reform. The populations selected for each survey were from the ASME data base, including non-members but connected to the practice of mechanical engineering.

Surveys were conducted with the assistance of ASME’s electronic survey tool and include industry surveys in 2009 and 2010 and surveys of ME and MET department heads in 2009 and 2010. Additionally, the task force received input from ME department heads at the 2009 International Mechanical Engineering Education conference, a session at the 2009 International Mechanical Engineering Conference and Exposition (IMECE), and active participation in the 2009 NSF 5XME Workshop. An informal survey of the over 100 participants in a Vision 2030 distinguished lecture workshop of the American Society for Engineering Education (June 2010) also provided valuable observations from a large cross section of engineering schools. Presentations of the findings of the task force were made to the ASME Industrial Advisory Board in 2009 and at a topical session at the 2010 IMECE, both generating feedback on the findings and emerging recommendations.

Spring 2009 Academic Survey

A variety of inputs were obtained across the ME-MET spectrum and questions were formulated to touch on substantive academic, procedural and administrative issues affecting the educational process and programs. Initial results for ME department heads were discussed at the ASME International Mechanical Engineering Education Conference in March 2009.

Mechanical Engineering Department Heads

Respondents reported curricular changes spanning the 1999 to 2008 academic years. The majority of major curricular changes have occurred from 2005 to 2008, with the most occurring from 2007-2008. A graphical summary of responses is shown in Figure A1.

Typical reasons for making curricular changes include:

Reduction of credit hours to 128 (most frequently mentioned),
Introduction of new courses and strengthening one or more curricular stems,
Modification of existing courses,
Preparation for ABET review,
Curriculum flexibility and modification of technical elective and minor programs,
Change of academic year calendar (quarter to semester system), and,
Responding to advisory board recommendation or industry needs to improve employability of graduates.

![How many times in the past 10 years have there been major revisions to the undergraduate ME curriculum at your institution? (88 Responses)](image)

Figure A1. ME department heads survey. (Spring 2009)

One response seems to encapsulate the sense of the responses received.

Based on emerging fields in mechanical engineering and a desire for the ME program to stay relevant, we expanded sub-discipline offerings within the program. We also wanted to ensure we maintain an emphasis on the fundamentals so that our graduates could pursue specialization in almost any area in graduate school.

On the extent and substance of the most recent revision to the undergraduate curriculum, most responses indicated either “tinkering on the edges” or “repackaging” of courses of the curriculum. One respondent indicated that the “curriculum was made increasingly more rigid to ensure compliance with ABET.” The majority of the responses indicate the following actions.

Increasing a focus on design from first to fourth year.
Dropping, adding, and integrating courses in the thermal sciences and/or design and systems stems.
Changing the science base of the curriculum.
Introduction of professional aspect of the profession
Introduction of active learning strategies.

When asked “What do you consider to be the greatest strengths of your undergraduate program, the majority of responses mention the following three responses.

A broad foundation and strong fundamentals in science and engineering.
Integration of mathematics, sciences and engineering.
Strong design component in the curriculum.

A few respondents cited high student quality, multidisciplinary education, honors programs, semester abroad programs, and faculty who are deeply involved with the learning/teaching process.

As to weaknesses of the undergraduate program, responses received cited factors that relate mostly to resources, e.g., admissions process, faculty: student ratio, facilities, and enrollment (too high or low). Responses range from “none” to “[the program is] a bit antiquated”. Responses that focus on systemic educational issues included the following.

Mathematical preparation of students.
Lack of specialized electives and depth in technical specialties.
Integration of theory with practice via laboratory experiences.
Insufficient cross-curricular topical development.

A majority of the respondents indicate the following as the highest priorities to improve their undergraduate programs.

Increase curricular flexibility through elective courses and minor concentrations.
Increase faculty size.
Improve laboratory course and facilities.
Improve guidance in the capstone design course.

We then asked what the ME department heads would see as the major changes in engineering practice over the next 20 years. Responses varied but centered on the following themes.

Global nature of engineering practice and business.
More reliance on software for design and automation of best practices in design and manufacturing.
Development of smart products.
Focus on sustainability and energy as over arching challenges/practice foci.
Major curricular changes anticipated by the ME department heads over the next 20 years as a consequence of what is seen as changes in engineering practice touch on the following themes.

New balance between fundamental ("core") subjects and new areas of applied science and technology, e.g., nanotechnology
Increase interdisciplinary project work.
Holistic, or systematic, thinking and problem solving.

If a tension between two extremes emerging from responses to this issue, it is that basic skills sets need strengthening and that broader, multidisciplinary/interdisciplinary thinking gained through practice-like experiences need emphasis. On another level, this apparent dichotomy emerges in the contrasting views that the curriculum should reflect the needs of the work environment (tools, professional skills, thinking processes, etc.) versus a deeper technical/scientific preparation. Perhaps, one comment sums up the center of opinion on this question:

*Increase in ‘systematic’ or ‘considering the whole’, stronger conceptualization skills, retain fundamental science, but teach students how to teach themselves to learn how to apply the fundamental science to any new emerging technology. Teach more skills to do with ‘open thinking, and rapid movement to align resources to a new problem.*

We then asked the question: “What are the greatest barriers to curriculum change in you department?” The over arching theme of the responses is the conservative nature of the faculty and resistance to change, as well as adherence to old engineering paradigms. Underlying causes for this view included age of faculty, ownership of courses by individuals, requirements of ABET-accreditation, and faculty disagreement as to what changes are needed. Other common factors include:

Conservatism of staff [faculty] and professional bodies.
Conflict between research and the educational process.
Resources.
Time to implement changes.

Barriers to curricular reform and/or change at the institutional level received generally reflect those mentioned at the department level. General themes among the responses ranged from “none” to the following topics.

Over reach of institutional and/or state government management.
High level of inertia and commitment to current educational process.
Limitations imposed by humanities requirements and integration of engineering within a liberal arts/sciences university.

*Engineering and the humanities and social sciences* - Adjunct to the engineering curriculum is role of the humanities and social sciences in the educational process (Figure
A2). The question asked of department heads was “Do the humanities and social sciences courses at your institution provide adequate support and context for the ME program? All responses reflect some displeasure with the relation between engineering and the humanities and social science programs. Typical of the comments received are shown below.

Internal university accounting practices are a disincentive to allocate more course time to the humanities and social sciences.

Few humanities and social science courses complement the technically oriented curriculum of engineering.

![Figure A2. ME department heads survey. (Spring 2009)](image)

*Figure A2. ME department heads survey. (Spring 2009)*

*External forces on the curriculum* – Two questions were asked related to the current US economic downturn: What effects will it have on the ME program, and what might the response of to them? The following comments generally summarize effects already commented upon or felt by programs.

- Budget cuts, hiring freezes, salary freezes, and some difficulty in obtaining funded research.
- Mixed indicators on enrollment across the public and private schools.
- Reduced job opportunities and opportunities for internships in industry.

As to responses that departments might make to these forces, theme department heads generally focused on the future with little optimism: doing more with less to delaying expansion and investment plans. Some mention curricular reduction and smaller faculty sizes with less support from teaching assistants. Others mention an intensification of a scholarship bidding war, the need for more private funds, and working closer with local industries. On a more positive note, better graduate students are
expected, and thus an increase in enrollment in graduate programs. Some opined that creativity and even prayer are needed at this time.
Mechanical Engineering Technology Department Heads

For consistency, heads of MET programs were asked the same set of questions posed to the ME department heads. Despite the lower response rate owing to the number of MET programs across the US, the overall pattern of responses parallels those for mechanical engineering programs. Tables A1 and A2 summarize the MET results.

The extent of most of the reported curricular revision involved course revisions, reallocations, and combinations. Two programs reported significant re-working of the curriculum. Motivations for these curricular revisions include: employer, or market, demands, and changing technologies in the workplace.

As to strengths of their BMET programs, the MET department head responses include:

- Design skills,
- Strong basic (core) courses using engineering texts, and,
- Good facilities/equipment for hands on experiences.

Weaknesses of the BMET programs are cited as being:

- Specific curricular weaknesses, e.g., thermal/fluids engineering, project management,
- Use of too many part-time faculty members, and,
- Resources, especially for laboratories and modern equipment.

Table A1. MET department heads’ response to “How many major revisions to the BMET curriculum in the past ten years? (Spring 2009)

<table>
<thead>
<tr>
<th>Number of revisions</th>
<th>Count</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2</td>
<td>15.4</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>30.8</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>7.7</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>23.1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>15.4</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Table A2. MET department heads’ response to “What was the date of last your major curriculum revision. (Spring 2009)

<table>
<thead>
<tr>
<th>Date of curriculum change</th>
<th>Count</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb, 2004</td>
<td>1</td>
<td>7.7</td>
</tr>
<tr>
<td>2004</td>
<td>1</td>
<td>7.7</td>
</tr>
</tbody>
</table>
The view of the MET department heads on engineering and engineering technology practice over the next 20 years are tabulated in Table A3.

### Table A3. Major changes in engineering practice in the next 20 years seen by MET department heads. (Spring 2009)

<table>
<thead>
<tr>
<th>Year</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2008</td>
<td>2</td>
</tr>
<tr>
<td>2000</td>
<td>1</td>
</tr>
<tr>
<td>2006</td>
<td>1</td>
</tr>
<tr>
<td>2006-2007</td>
<td>2</td>
</tr>
<tr>
<td>2007</td>
<td>1</td>
</tr>
<tr>
<td>2008</td>
<td>2</td>
</tr>
<tr>
<td>2003</td>
<td>1</td>
</tr>
<tr>
<td>2002</td>
<td>1</td>
</tr>
</tbody>
</table>
To meet anticipated future changes in engineering and engineering technology practice, MET department heads predict a variety of impacts on the BMET degree program. The following comments capture overarching themes:

- Greater use and training in simulation and computer-aided “X”,
- Greater emphasis on soft skills, especially communication,
- Some understanding of global financing, and,
- Greater emphasis on energy conversion processes and technologies.

When asked about the greatest barriers to curricular change at their institutions, the METDHs responded generally in the same vein as did the MEDHs. One respondent out of the 12 responders mentioned rivalry between engineering and technology at his institution, as well as visibility and perceptions at the university level.

The survey for METDHs concluded with a series of questions relating to internal and external factors that might be considered and environmental scan for MET. Responses indicate the following factors were viewed as important.

- Primary sources of faculty for BMET programs is industry (64%), followed by graduate ME/MET programs (14%) and recruitment from other institutions (21%).
- The perceived need for BMETs about the same as in the recent past (57% of respondents). About 21% of respondents see some change (growth or reduction).
- Three quarters of MET departments do not offer graduate programs. Of those programs offering graduate degrees, the predominant terminal degree is the MSMET, with most degree seekers not writing a thesis.

**Spring 2009 Industry Survey**

This survey assessed the strengths and weaknesses of mechanical engineering graduates from the perspective of industrial managers and engineers. The survey was web-based and was sent to ASME members who supervise and/or hire entry-level mechanical engineers.

Responses were received from 381 engineers and managers. The size of the companies they represented ranged uniformly over five categories from small (1-230 employees) to very large (more than 46,800 employees). The range of industrial experience of responders is from about one year to over 30 years. The highest educational degree of the responders was: 44% BS in engineering, 27% MS in engineering, 13% PhD in engineering, and 13% in other fields.
Responses were organized by a text analysis program which sought common phrases, and 14 categories were created where common strengths and weaknesses of newly hired MEs are seen. Responses mentioning multiple strengths or weaknesses are sorted appropriately into multiple response categories, and because the same categories are listed in the strengths and weaknesses, there can be overlap depending on the distribution of the responses. A simple measure of weight, or importance, for a given category was adopted as the difference between the percentages for strength and weakness. For example, “interpersonal skills” is listed as strength by 19% of the responses and as a weakness by 10%, thus giving a weight measure of +9.

**Question No. 1. What are the strengths and weaknesses of recent BS mechanical engineering hires?**

The top four strengths of baccalaureate graduates are information processing, technical fundamentals, computer modeling and analysis, and interpersonal/teamwork skills. The three greatest weaknesses relate to practical experience: how devices are made and work, communication, and problem solving/critical thinking. These are the dominant response categories, with all other responses below the 5% level (Table A4). Interestingly, new applications and leadership are not mentioned as either a strength or weakness.
Table A5. Strengths and weaknesses of recent BSMET hires.
(Spring 2009 industry survey. N =381.)

<table>
<thead>
<tr>
<th>Category</th>
<th>%Strength</th>
<th>%Weakness</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information processing – electronic communication</td>
<td>4</td>
<td>0</td>
<td>+4</td>
</tr>
<tr>
<td>Technical fundamentals – traditional ME disciplines</td>
<td>2</td>
<td>14</td>
<td>-12</td>
</tr>
<tr>
<td>Interpersonal/teamwork</td>
<td>6</td>
<td>11</td>
<td>-5</td>
</tr>
<tr>
<td>Computer modeling and analysis – software tools</td>
<td>14</td>
<td>4</td>
<td>+10</td>
</tr>
<tr>
<td>Communication – oral, written</td>
<td>0</td>
<td>14</td>
<td>-14</td>
</tr>
<tr>
<td>Practical experience - how devices are made and work</td>
<td>31</td>
<td>9</td>
<td>+22</td>
</tr>
<tr>
<td>Problem solving &amp; critical thinking - analysis</td>
<td>0</td>
<td>4</td>
<td>-4</td>
</tr>
<tr>
<td>Design – product creation</td>
<td>4</td>
<td>0</td>
<td>+4</td>
</tr>
<tr>
<td>Business processes - entrepreneurship</td>
<td>0</td>
<td>2</td>
<td>-2</td>
</tr>
<tr>
<td>Project management -</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Overall systems perspective</td>
<td>0</td>
<td>7</td>
<td>-7</td>
</tr>
<tr>
<td>Technical fundamentals – new ME applications (bio, nano, info, multi...)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Leadership</td>
<td>0</td>
<td>2</td>
<td>-2</td>
</tr>
<tr>
<td>Experiments - laboratory procedures</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Sample comments regarding strengths are: “software knowledge – they pick up software interfaces very quickly”, and “well versed in fundamentals of engineering sciences.”

Representative weaknesses are: “afraid to get hands dirty and learn how products are made and assembled”, “have never disassembled and reassembled anything substantial”, “lack of understanding of manufacturing processes”, “not enough on finishing the project to the satisfaction of the sponsor”, “lack of ability to transfer engineering knowledge to practical problem solving”, “knowing which problem to solve”; “inability to get to the root of even basic problems”; “inability to define a problem and gain consensus from their customer”; “critical evaluation of FEA analysis results”; and “understanding the principles behind various software packages”.

**Question No.2. What are the areas of greatest strength and weakness of your recent BS mechanical engineering technology graduates?**

Industry responses (Table A5) indicate that the two major areas of strength of recent MET graduates are practical experience and computer modeling. The two major weaknesses are communication and technical fundamentals in traditional ME disciplines.
Table A6. Missing Components in the ME Undergraduate Curriculum.
(Spring 2009 industry survey. N = 381 for industry and 84 for educators.)

<table>
<thead>
<tr>
<th>Category</th>
<th>Educator %</th>
<th>Industry %</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical fundamentals – new ME applications (bio, nano, info, multi…)</td>
<td>27</td>
<td>0</td>
<td>+27</td>
</tr>
<tr>
<td>Interpersonal/teamwork</td>
<td>10</td>
<td>13</td>
<td>-3</td>
</tr>
<tr>
<td>Overall systems perspective</td>
<td>10</td>
<td>4</td>
<td>+6</td>
</tr>
<tr>
<td>Business processes - entrepreneurship</td>
<td>10</td>
<td>8</td>
<td>+2</td>
</tr>
<tr>
<td>Practical experience - how devices are made and work</td>
<td>8</td>
<td>22</td>
<td>-14</td>
</tr>
<tr>
<td>Design –product creation</td>
<td>6</td>
<td>2</td>
<td>+4</td>
</tr>
<tr>
<td>Communication – oral, written</td>
<td>6</td>
<td>16</td>
<td>-10</td>
</tr>
<tr>
<td>Problem solving &amp; critical thinking - analysis</td>
<td>4</td>
<td>3</td>
<td>+1</td>
</tr>
<tr>
<td>Leadership</td>
<td>4</td>
<td>3</td>
<td>+1</td>
</tr>
<tr>
<td>Experiments - laboratory procedures</td>
<td>2</td>
<td>1</td>
<td>+1</td>
</tr>
<tr>
<td>Computer modeling and analysis – software tools</td>
<td>2</td>
<td>5</td>
<td>-3</td>
</tr>
<tr>
<td>Project management</td>
<td>2</td>
<td>8</td>
<td>-6</td>
</tr>
<tr>
<td>Technical fundamentals – traditional ME disciplines</td>
<td>1</td>
<td>13</td>
<td>-12</td>
</tr>
<tr>
<td>Information processing – electronic communication</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Question No. 3. In order for your enterprise to be competitive in the global economy, what additional skills and knowledge do recent mechanical engineering graduates need?**

The two major areas for additional skills and knowledge for industry are practical experience and communication (Table A6). (Also included in Table A3 are frequencies for the 84 responses from ME department heads.)

**Question No. 4. What are the drivers that lead your company to hire outside the US?**

The factors most mentioned by the industrial respondents are global corporate presence (37%), cost and location of growth markets (18%), and talent pool (8%). Typical responses are, “Global presence to bring work location closer to our clients”, “To sell to and support international customers”, and ‘It’s cheaper to hire an engineer in another country’.

**Question No. 5. What are the drivers that lead your company to hire inside the US?**

The three factors most mentioned are local talent (33%), security and citizenship requirements (19%), and local demand (10%). Sample responses are, “customer base is dominantly domestic”, “need on site engineering to help keep new products in pipeline”, “US engineers have better communication and problem-solving skills”, “stronger engineering education”, and “aspects of business are export controlled.”
Question No. 6. Would your company prefer more breadth with respect to education within the BSME degree rather than depth?

Responses are 48% more breadth, 29% more depth, and 22% more breadth and depth. Sample comments include:

Technical breadth is important because engineering is multidisciplinary, and our engineers work on systems, not components. Breadth across all disciplines is important to work on multifunctional projects. Breadth to have a broader perspective on what it takes to get a project done and the collaboration needed across skill sets. New engineers would benefit from learning how engineering work is performed and managed.

More concentration in skills that will be utilized – thermodynamics, materials, manufacturing processes.

Both – depth enough to engage on a problem and breadth enough to understand context.

The 2009 ASME International Mechanical Engineering Education Conference

A plenary session was held at the International Mechanical Engineering Education Conference in March 2009 and attracted 85 department heads and engineering educators. At the session, they were asked to respond to a set of questions by the Vision 2030 Task Force. The responses are also compared to the industrial responses using the same set of 14 categories as listed in Table A4.

Question No. 1. What are the missing components in the traditional ME curriculum that will help prepare students for the 21st Century?

The leading category is technical fundamentals – new mechanical engineering applications – with about 25% of the responses. The next four are interpersonal skills and teamwork, overall systems perspective, business processes and entrepreneurship, and global issues and challenges.

A number of respondents indicate that, because ME departments are organized around the various sub-disciplines of the field, it has been difficult for the faculty to use an interdisciplinary approach to broad problems. Respondents also note that the curriculum needs to be more attractive to women. It is stated that curriculum revision should recognize that women are not motivated by the same things as men. For example, the profession should place more emphasis on its role in helping others. The respondents noted that the relative breadth of mechanical engineering is a feature that should appeal to women and minorities.

Note that relative to missing components, there are major differences between the engineering educator and the industry surveys. The major category for educators is new
mechanical engineering applications (bio-, nano-, info-) indicated by 27% of the respondents, while it was not mentioned once by the industrial responders. The top ranked missing components category for industry is practical experience (22%), while for the educators, it is indicated by only 8%. Representative comments are shown below.

Understanding of mechanisms on the molecular level.
Life science is a potential area with a technological focus.
Integration of courses using a system view and seeing the big picture.
Integrate the soft skills in the traditional courses.
Provide students with an awareness and appreciation of engineering in a global context.
Students do not have a background in the business sector, i.e., accounting, project operations, and the need to make a profit.
What you are working on has to have a business case.
Better value from general education, i.e., communication skills, technical writing skills.

*Question No. 2. What educational initiatives are necessary to ensure that mechanical engineers are prepared to help solve the grand challenges of energy, climate, water, quality of life, and poverty?*

Respondents note that the mechanical engineering profession, as it is the broadest of the engineering disciplines, can contribute to all of the NAE Grand Challenges (2010). They also say that a general “branding issue” exists for the mechanical engineering and in general the engineering profession. Other disciplines have added names like “environmental” or “bioengineering” to their names, which directly connects them with some aspects of the global challenges. It is noted that through extracurricular activities, competitions, and with national groups, e.g., Engineers Without Borders, students have the opportunity to be involved with the NAE Grand Challenges.

However, it is noted that the mechanical engineering curriculum is not explicitly aligned with these grand challenges. Suggestions are made that the definition and statements of engineering problems given to students needs to be changed to put them in the context of the grand challenges, e.g., use terms like “robotics for health care”, and “wind turbines for irrigation”. The titles of mechanical engineering courses could also be updated to reflect these issues. The issue of systems integration was also raised.

Some representative responses were the following.

Instill in engineering students an aspiration to work on broad issues.
Connect every course to quality of life issues at all levels.
Develop small case studies to address global challenges.
ME’s have not been in the leadership role for energy initiatives.
Energy has a clear connection to ME, but it is not apparent from our curricula and projects.
The fundamental core topics in ME – fluids, thermodynamics, and heat
transfer are central to the grand challenges. Every course should address the impact of these grand challenges.

**Question No 3. How will the practice of teaching change for the 21st Century?** Project/practice based learning is getting a lot of attention, will it grow and how? Is the professional school model, similar to medicine, a good idea?

Responses indicate that many institutions are implementing project based learning to various degrees. This approach models how projects are done in industry. There was interest in assessing project breadth versus depth, and the resources (faculty, space, and laboratories) required with this approach. The senior capstone design courses are currently considered to deliver project based learning experiences.

There is an interest in flexibility in the curriculum, so that students can take specialized courses such as courses on entrepreneurship if they so desire. There is a stated need for text modules, not textbooks, to integrate innovative material into the traditional courses. A recommendation was made to aggregate best practices from different institutions to be shared among peers.

Respondents are not in favor of a professional school model. Questions are also raised about the lack of industry support, and the additional cost to the student. There is also not a stated desire for a five year bachelor’s degree program, more credit hours and more courses, but more of an approach to broadening the content matter and integrating it into the existing curriculum. The need to instill professionalism into students from the first day of classes was discussed as well. Sample responses are the following.

Give students the option of tracks in management, leadership, thermal systems, and mechanical systems. Since there is a gap between the freshmen year and the senior capstone course for project based learning, there should be a design spine. We need look into what is learned and what is used in practice.

**Question No. 4. How can we substantially improve the communication and people skills, and the global awareness of our graduates? Can we do this without increasing the courses that our students take?**

There is agreement that the future of mechanical engineering education will be more about people, teaming, and leadership. The general response is that more courses are not needed, but the emphasis of existing courses should change. It is indicated that the communication skills of students is still an issue. The capstone courses are repeatedly mentioned as a means of dealing with these issues. A recommendation was also made that team projects should be integrated into most courses.

Development of partnerships with humanities and social science faculty and departments were discussed. Strong multicultural courses, study abroad programs, and
required courses with international exposure are also recommended. A number of schools have developed courses that use the Internet to partner with students in other countries.

**Question No. 5. Graduate education, particularly the Master’s Degree, has received little or no attention with respect to curricular content. What changes are necessary?**

Most of the respondents say they are satisfied with their current masters programs. The content and requirements of the programs vary widely. Most general programs give the students the option of choosing their own classes, and specialized programs have very distinct course requirements. Many of the masters programs are market driven, which depended on the urban/non-urban location of the school and nearby industry. Two general masters tracks were discussed, a terminal masters and a research masters. Some of the recommendations that came forth were the following.

Expand and promote undergraduate research opportunities to motivate students for graduate research.
Identify PhD level career opportunities in government agencies and industry.
Promote the stature of PhD candidates within universities and the stature of PhD’s in society. Increase ASME’s role in post-bachelor’s level education.

**ASME International Conference Session - November 2009**

A Vision 2030 conference session was held at the 2009 IMECE, and 31 department heads participated. Task force members facilitated roundtable discussions on key questions on mechanical engineering education. The questions and edited responses are summarized below.

**Question No. 1. Is substantial change in mechanical engineering education needed?**

Respondents reply uniformly in the affirmative. They indicated that the baccalaureate program offer more practical experience, more integration of fundamentals with design, meaningful interdisciplinary experience, understanding sustainability, introduction to global issues, learning to innovate, more flexibility to take courses in areas of specialization, increased student competitions, a smaller curriculum, a focus on student competencies, and systems perspectives. It was noted that efforts need to be made to make mechanical engineering as a major in college more attractive to women and minorities and that teaching methods need to be changed.

**Question No. 2. Should we work toward the Master of Science Degree as the first professional degree?**
The general response is “no”. Issues cited include graduate degree accreditation, no push for it by employers, and increased student costs.

*Question No. 3. Practical experience has been the most cited weakness for mechanical engineering curricula. Is this a concern and how would you address this issue?*

Responses include: internships, increased prototyping and design, build and test projects, design throughout the curriculum, service projects, student competitions, research experience, and additional laboratories.

*Question No. 4. What are the five subjects central to the mechanical engineering curriculum?*

The five subjects most mentioned by the respondents are mechanics (solid and fluid), materials, dynamics and controls, design and manufacturing.

*Question No. 5. What are five key professional skills that should be in the curriculum?*

The five subjects mentioned by the respondents are teamwork, communication, product design and fabrication, systems integration, and modern software.

*Question No. 6. What are five subjects outside of ME that should be in the curriculum?*

The five subjects that mentioned by the respondents are electrical circuits, communication, business, economics, and life sciences.

**Spring 2010 Industry Survey**

Web based surveys were sent to ASME industrial members, and 600 responses were received. Nearly half (47%) of the industrial respondents hold engineering positions, followed by project managers (18%), chief engineers (14%), and directors (7%). Slightly more than half of the industrial respondents are involved with the hiring of mechanical engineers, and about half directly supervise mechanical engineers.
Question No. 1. Consider the skill sets below, please indicate your assessment of your undergraduate program according to the following categories: A-Not important, B-Weak, not a program concern, C – Weak, D- Sufficient, E-Strong, F-Strong, needs more emphasis.

Table A7. Industry assessment of recent BSME graduates. A-Not important, B-Weak, not a program concern, C – Weak, D- Sufficient, E-Strong, F-Strong, needs more emphasis. Values are percent response. (Spring 2010. N = 600)

<table>
<thead>
<tr>
<th>Skills</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical experience</td>
<td>2</td>
<td>12</td>
<td>55</td>
<td>23</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Communication (oral, written)</td>
<td>0</td>
<td>4</td>
<td>53</td>
<td>29</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Overall systems perspective</td>
<td>2</td>
<td>14</td>
<td>45</td>
<td>32</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Engineering Codes and Standards</td>
<td>9</td>
<td>27</td>
<td>45</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Problem solving &amp; critical thinking (analysis)</td>
<td>1</td>
<td>3</td>
<td>35</td>
<td>42</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Project management</td>
<td>11</td>
<td>28</td>
<td>34</td>
<td>23</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Design (product creation)</td>
<td>2</td>
<td>8</td>
<td>31</td>
<td>46</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Experiments (laboratory procedures)</td>
<td>10</td>
<td>6</td>
<td>30</td>
<td>44</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Business processes</td>
<td>15</td>
<td>34</td>
<td>29</td>
<td>18</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Leadership</td>
<td>6</td>
<td>19</td>
<td>27</td>
<td>40</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Interpersonal/teamwork</td>
<td>0</td>
<td>3</td>
<td>24</td>
<td>50</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Technical fundamentals (traditional ME sub-disciplines)</td>
<td>1</td>
<td>1</td>
<td>19</td>
<td>53</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>New ME applications</td>
<td>21</td>
<td>15</td>
<td>14</td>
<td>41</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Computer modeling/analysis (software tools)</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>44</td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td>Information processing (electronic communication)</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>43</td>
<td>41</td>
<td>2</td>
</tr>
</tbody>
</table>

The industrial respondents were asked to assess recent BSME graduates according to the performance categories developed in the 2009 surveys. Responses are tabulated in the Table A7 ranked by category. The top weaknesses are practical experience, communication, and systems perspectives.

Representative comments relating to practical experience include:

School prepares students for the ideal world, not always the same as the real world.’
Shortage of engineers with hands on experience in building things
How to actually build it is becoming a lost art in this country
Too much reliance on computer analysis with little or no ability to perform order of magnitude analysis without the computer.

Question No. 2. Overall, do you feel the undergraduate ME curriculum needs greater breadth or depth?

Responses are evenly split between breadth and depth: 29% for greater breadth; 40% for the current curricular balance of topics, and 31% for greater breadth. Relative to various skills, respondents indicated an interest in more depth in technical fundamentals, project management, problem solving, and mathematics and physical sciences. There is
interest in more breadth in new ME applications, communications, engineering codes and standards, and social sciences.

**Question No. 3. What is the current preference of your firm in hiring recent mechanical engineering graduates?**

A bachelor’s degree is preferred by 45%, a master’s degree by 20%, and 35% express no general preference. The main reasons that respondents gave for the hiring of master’s degree graduates are technical depth (90%), maturity (77%), and technical breadth (68%).

**Question No. 4. In the foreseeable future, in order to accomplish their assignments and for your company to prosper, do you think mechanical engineers will need a greater amount of post-BSME coursework or training than is currently customary?**

Both the industrial and academic responses indicated a greater amount of post BSME coursework or training: 58% for more training/education, 25% not for more training/education, and 16% not sure. A larger percentage of the academic responses to this question opt for more training as well (79%), with 9% saying no, and 12% not sure.

**Question No. 5. An initial attempt is being made in the United States to increase the educational requirements from a BS degree to a BS degree plus the equivalent of 30 semester hours (this could be a masters degree) to obtain a professional engineer’s license. Do you agree with proceeding in this direction over the next 5-10 years?**

There is very low industrial support for the requirement of a master’s degree for ME professional registration: 21% agreeing or strongly agreeing, 58% disagreeing or strongly disagreeing, and 20% neutral on the question. By comparison, academic responses are 53% agreeing or strongly agreeing, 34% disagreeing or strongly disagreeing, and 14% neutral on the question.

A representative comment sums up the industrial viewpoint:

I believe a BS+30 requirement for licensure as a PE would be bad for the engineering profession. The overwhelming majority of sub-standard engineering work that I have encountered was the result of engineers failing to properly apply basic concepts or failing to limit themselves to areas where they had adequate expertise.’
Spring 2010 Academic Survey

**Question No. 1.** Consider the skill sets below, please indicate your assessment of your undergraduate program according to the following categories: A-Not important, B-Weak, not a program concern, C – Weak, D- Sufficient, E-Strong, F-Strong, needs more emphasis.

Table A8: Academic rating of student skill sets. A-Not important, B-Weak, not a program concern, C – Weak, D- Sufficient, E-Strong, F-Strong, needs more emphasis. (Spring 2010. N = 84)

<table>
<thead>
<tr>
<th>Skill Sets</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical fundamentals (traditional ME sub-disciplines)</td>
<td>0%</td>
<td>0%</td>
<td>3%</td>
<td>32%</td>
<td>58%</td>
<td>6%</td>
</tr>
<tr>
<td>Problem solving &amp; critical thinking (analysis)</td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
<td>31%</td>
<td>48%</td>
<td>14%</td>
</tr>
<tr>
<td>Design (product creation)</td>
<td>0%</td>
<td>2%</td>
<td>15%</td>
<td>28%</td>
<td>45%</td>
<td>11%</td>
</tr>
<tr>
<td>Interpersonal/teamwork</td>
<td>0%</td>
<td>0%</td>
<td>9%</td>
<td>43%</td>
<td>43%</td>
<td>5%</td>
</tr>
<tr>
<td>Mathematics</td>
<td>0%</td>
<td>0%</td>
<td>12%</td>
<td>40%</td>
<td>43%</td>
<td>5%</td>
</tr>
<tr>
<td>Communication (oral, written)</td>
<td>0%</td>
<td>0%</td>
<td>22%</td>
<td>25%</td>
<td>40%</td>
<td>14%</td>
</tr>
<tr>
<td>Physical sciences</td>
<td>0%</td>
<td>2%</td>
<td>6%</td>
<td>51%</td>
<td>38%</td>
<td>3%</td>
</tr>
<tr>
<td>Information processing (electronic communication)</td>
<td>3%</td>
<td>5%</td>
<td>12%</td>
<td>45%</td>
<td>34%</td>
<td>2%</td>
</tr>
<tr>
<td>Computer modeling/analysis (software tools)</td>
<td>0%</td>
<td>2%</td>
<td>12%</td>
<td>43%</td>
<td>34%</td>
<td>9%</td>
</tr>
<tr>
<td>Social sciences</td>
<td>0%</td>
<td>3%</td>
<td>5%</td>
<td>60%</td>
<td>31%</td>
<td>2%</td>
</tr>
<tr>
<td>Liberal arts</td>
<td>0%</td>
<td>5%</td>
<td>5%</td>
<td>57%</td>
<td>31%</td>
<td>2%</td>
</tr>
<tr>
<td>Experiments (laboratory procedures)</td>
<td>0%</td>
<td>0%</td>
<td>9%</td>
<td>54%</td>
<td>28%</td>
<td>9%</td>
</tr>
<tr>
<td>Statistics</td>
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<td>0%</td>
<td>29%</td>
<td>46%</td>
<td>22%</td>
<td>3%</td>
</tr>
<tr>
<td>Practical experience (how devices are made/work)</td>
<td>0%</td>
<td>2%</td>
<td>34%</td>
<td>42%</td>
<td>18%</td>
<td>5%</td>
</tr>
<tr>
<td>Leadership</td>
<td>0%</td>
<td>9%</td>
<td>35%</td>
<td>28%</td>
<td>18%</td>
<td>8%</td>
</tr>
<tr>
<td>Project management</td>
<td>0%</td>
<td>12%</td>
<td>29%</td>
<td>43%</td>
<td>12%</td>
<td>3%</td>
</tr>
<tr>
<td>Overall systems perspective</td>
<td>0%</td>
<td>5%</td>
<td>46%</td>
<td>29%</td>
<td>12%</td>
<td>6%</td>
</tr>
<tr>
<td>Innovation</td>
<td>2%</td>
<td>2%</td>
<td>35%</td>
<td>40%</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td>Life sciences</td>
<td>5%</td>
<td>9%</td>
<td>35%</td>
<td>38%</td>
<td>11%</td>
<td>0%</td>
</tr>
<tr>
<td>Business processes</td>
<td>5%</td>
<td>25%</td>
<td>37%</td>
<td>18%</td>
<td>11%</td>
<td>2%</td>
</tr>
<tr>
<td>Entrepreneurship (as different from Business Processes)</td>
<td>5%</td>
<td>14%</td>
<td>43%</td>
<td>18%</td>
<td>11%</td>
<td>6%</td>
</tr>
<tr>
<td>New ME applications – bio, nano, info,...</td>
<td>3%</td>
<td>17%</td>
<td>40%</td>
<td>34%</td>
<td>5%</td>
<td>2%</td>
</tr>
<tr>
<td>NAE “Grand Challenges”</td>
<td>15%</td>
<td>22%</td>
<td>42%</td>
<td>15%</td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td>Engineering Codes and Standards</td>
<td>6%</td>
<td>23%</td>
<td>37%</td>
<td>31%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Sustainable Technologies</td>
<td>2%</td>
<td>6%</td>
<td>45%</td>
<td>31%</td>
<td>0%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Responses are tabulated in Table A8 in which the skill sets are ranked. Topics that are rated strong are technical fundamentals, problem solving, and design. There is a fair amount of agreement between industry and academia on strengths: technical fundamentals, teamwork, and design. The three weakest topics are systems, entrepreneurship, and sustainable technologies. There is a difference of opinion in the weaknesses, as the top industry weaknesses such as practical experience are ranked fifth and overall systems perspectives are ranked sixth by the academic respondents.

**Question No. 2.** Is it important to the professional success of graduates that mechanical engineering curricula emphasize emerging technologies?

A majority of respondents agree with the statement: 62% agree/strongly agree, 9% disagree/strongly disagree, and 28% neutral on the question.
Question No. 3. In your assessment of your undergraduate program do you think more courses and credits are required?

About 36% of the respondents agreed with the statement, 52% thought current courses and degree credits are about right, and 13% feel that fewer courses and credits are needed.

Question No. 4. Do you foresee major curriculum change in your department over the five year period 2010-2015?

About 69% agree that major change is probable or highly likely, and 31% feel that changes are not likely. The importance of sustainable technologies, entrepreneurship, new ME applications (bio-, nano-, info-), and innovation are the four most cited reasons. Seventy-five percent of respondents indicate the changes will be done through more efficient curriculum planning, 43% though instructional technologies, 28% through additional required courses, and 12% through reduced electives.

Question No. 4. Should ME programs require all students to have more design/build or other practical engineering experience prior to graduation?

About 82% the respondents agreed with the statement; 81% indicated that they can accomplish this by increased/expanded hands on design/build experiences (to varying degrees in the curriculum), 56% through increased co-op or internship experiences, and 44% through increased laboratory experiences.

The reliance on the senior year capstone design experience is however pervasive” “Our major practical experience is provided by a yearlong capstone in which the design and fabrication of a functioning device is required.”

Question No. 5. Do you support a broader four-year engineering curriculum that will prepare a student more generally for entry-level engineering practice?

Forty-eight percent of respondents agree/strongly agree, 22% disagree/strongly disagree, and 31% are neutral on the question.

Question No. 6. Do you support a broader four-year baccalaureate in mechanical engineering, with a 5th year Professional Master's degree as the preferred preparation for entry-level engineering practice in the future?

Forty-nine percent of respondents agree/strongly agree, 34% disagree/strongly disagree, and 17% are neutral on the question.
Question No. 7. Do you support a broader four-year baccalaureate in mechanical engineering, with a 5th year traditional Master of Science as the preferred preparation for entry-level engineering practice in the future?

Thirty-four percent of respondents agree/strongly agree, 47% disagree/strongly disagree, and 19% are neutral on the equation.

Question No. 8. Do you support a focused four-year baccalaureate in mechanical engineering, which will prepare a student for entry-level engineering practice?

Twenty-nine percent agree/strongly agree, 34% disagree/strongly disagree, and 36% are neutral on the question.

Question No. 9. Do you support a five-year baccalaureate in mechanical engineering, which will prepare a student for entry-level engineering practice?

Fourteen percent agree/strongly agree, 69% disagree/strongly disagree, and 16% are neutral on the question.

Generally, the responses indicate the strongest support is for a broader four year curriculum, and to a lesser extent support for a broader four year curriculum with a professional master’s degree as the preferred preparation for entry-level engineering practice in the future. There is not strong academic support for either a five year Bachelor’s Degree or a traditional MS degree as the preferred preparation for entry-level engineering practice in the future.
Appendix B. The Summer 2010 ASEE Distinguished Lecture and Workshop

This appendix contains responses to a survey distributed to those in attendance at the Distinguished Lecture at the Annual Conference of the American Society for Engineering Education (ASEE) in June 2010. The audience numbered 137 representing some 60 engineering schools. Not all questions in the survey were answered. Thus, in the tabulation below, the number of responses to the several questions is indicated in parentheses.

**Question No. 1. Most Mechanical Engineering Department Heads feel that there is a need for substantial curricula change. Select your choice of the most compelling reason for substantial curricula change?**

(a) The increasing body of knowledge (23)
(b) The outsourcing of engineering work to other countries at one fifth the cost—thus the need for more emphasis in design and innovation (5)
(c) The current state of the nation/world and the NAE Grand Challenges (69)
   - meeting current industry needs/society needs effectively
   - as well as demands from industry
   - diversity/change of today’s, social media
   - and ethical obligation. Engineers have the knowledge to address the technical areas
(d) Competition from universities abroad who are graduating more engineers in programs that are increasing in quality (and there is a trend for those programs to gain ABET accreditation) (15)
   - a great example of this is occurring at a high school level in Pittsburgh. The Pittsburgh Science and Technology School in Oakland, PA was started in 2009 as a result of education research at Carnegie Melon Univ. There is not enough space to write about the curriculum of this school here. However I highly recommend looking into this school’s science curriculum
(e) No compelling reasons for change (1)
(f) Other (25)
   - curriculum doesn’t meet needs of students
   - I’m not convinced substantial curricula change is what is needed – perhaps substantial delivery change to address the underrepresented groups who aren’t choosing engineering
   - students do not retain or use facts we currently teach during the 4 years
   - to produce “real” engineer
   - business demands it
   - attract more diverse students to profession which is expanding rapidly
   - Much change is needed b/c of the need to graduate well-trained, effective engineers
   - need to match curricula with changing needs of students/employers
- easier said than done
- we are stuck with Cold War/Sputnik eng science curricula which also de-emphasized socio-political/teamwork/etc
- better prepare our students for the future – including technical and other skills
- not providing skills needed for our information – international rich world
- students are not being prepared for higher level thinking and synthesis that most BS grads require to do within a few years of graduation
- need for sustainable world (society, community, nations)
- The need to provide leaders who know how technology works and will solve large scale problems
- attracting more diverse students (race, gender, personality, thinking style)
- need for more professional skills, leadership
- the problem our student need to solve aren’t technical solely. They need additional professional skill sets
- most current are not consistent with what is known about deep learning
- program should become multi-disciplinary
- make unrealistic assumptions about teenagers and ignore data on how people learn- change must proceed slowly – fast change has been demonstrated by the Obama administration to provide disaster

**Question No. 2.** Many studies (NAE, etc.) and the recent ASME industry survey data have indicated a need for substantially more practice-based-learning in the curriculum. How should the engineering education community respond? Select all that apply.

(a) Hire more tenure track faculty with industry/engineering practice experience (62)
- tenure for teaching as well as industry experience, why only tenure for research?
- but don’t expect them to fit the mold of traditional academics
(b) Utilize more lecturers and professors of practice with strong industrial experience and an ability to teach, not necessarily PhD's. (70)
- does this create “second class” faculty?
- and faculty engaged with industry is as needed base industry internship for faculty
- give them professorships; not just adjuncts. Utilize benefit package too.
- make sure they have the opportunity and expectation of developing quality teaching skills
(c) Retain our current faculty profiles but replace content with practice-based learning experiences. (39)
(d) Encourage more co-op or internship experience (66)
- this tends to lengthen the time to degree and can increase cost to students
(e) Given that enrollments in engineering are increasing (particularly mechanical) and budgets are often being cut, we are not able to implement such change. (3)
(f) Other (8)
- embrace incentives for pros other than research
- at this time support ET programs. Utilize ET faculty, courses, facilities
- don’t necessarily need to replace content, but need to teach content in a different (project-based, design-focused) way. Is faculty training available for these types of pedagogical approaches?
- provide leadership training/education for faculty, chair, deans to understand why these changes are needed
- change academic reward system to more strongly value time intensive practice based teaching
- stronger requirement for programs to have a close connection between industry needs and curriculum in the accreditation process
- send PhDs into work place each summer to get back to the “real world” worth real issues. They forget how to the real world operates or never knew
- reward faculty with industrial experiences. Law does. Medicine does. Engineering hires folks with a lot of years of industry, with PhDs as assistant professor. (UGH!). call them professors perhaps without tenure but certainly tenure track
- reengineer the curriculum in parallel with other efforts to increase participation of practitioners
- reduction in pure math/science – replace with interested activities
- change reward system to encourage faculty to do this
- go for an integral and deep change in our concepts about teaching and leadership. Marginal change will not help at all.
- eliminate tenure
- rewarding faculty for practical experience
- Use project-enhanced-learning methods in courses to enhance (not replace) content learning
- paradox: faculty are hired based on specifics, very specialized knowledge and mastery and their ability to generate funds via grants for universities who are experiencing identity crisis as the locations in our nation that will drive new knowledge rather than educate, hence these faculty have little expertise to lead instructional design that will lead to systems level awareness and problem solving capability
- encourage co-curricular activities that are practice based
- see Engage project at engageengineering.org; practice learning must be relevant to today’s students
- use co-curriculum project experiences: competition projects, internships
- add multi-disciplinary opportunities

Question No. 3. Mechanical Engineering Technology and Mechanical Engineering have co-existed since the 1970s, although recent trends have seen some Engineering Technology programs convert to Engineering programs. Is there a place for engineering technology in the engineering education spectrum? If so, what should it look like as an educational experience?

(a) Engineering technology’s applied focus could serve as the first two years of a four-year engineering degree (e.g., two year ET plus two year Engineering program). (25)
(b) In a CDIO style implementation, e.g., Conceive-Design-Implement-Operate, engineering technology’s role would be to place emphasis on Implement-Operate content (25)

(c) Four-year engineering technology programs should be ABET-accredited under the same criteria as engineering programs but retain the applied engineering learning in their curricula (31)

(d) There is no need to change engineering technology programs (7)

(e) Only two year engineering technology programs should remain as engineering technology programs but all four-year technology programs would convert to practice based engineering programs. (36)

(f) Other (7)

- encourage ME programs, to adopt hands-on approaches from ET
- more practice/hands on in all engineering areas as a teaching style and strategy. Kids aren’t getting it at home or in HS
- create a set of common courses such as design with joint ME and MET teams
- increased and better articulation between community college, 2 yr and 4 yr MET programs
- we need to maintain the ET option as it typically attracts a different type of learner. Maybe the ET programs are better suited to prepare grads for immediate employment and better meets what industry wants in an employee. Engineering programs need to move away from the intense theory to the more applied
- similar to “C” above but 1. emphasize industry experience (not PhD) for ET faculty and 2. emphasize that engineering is primarily prep for graduate school
- ET program already address many of this issues such as practice based programming. They do need to strengthen in innovation
- clarify what is engineering technology and what is other technology.
Question No. 4. There appears to be little debate (recent ASME academic and industry surveys) that a different education is going to be needed for our engineering graduates to be successful and globally competent. There is growing debate on how what this should be accomplished. Pick one of the following ideas as the one you feel would be most successful.

a. A five-year baccalaureate engineering degree (6)
b. A four-year BS degree followed by a one year professional masters degree (41)
   - this is commonly supported by companies that pay for employee courses related to their positions
c. A four-year BS degree followed by the typical master of science degree (typically a two year program) (8)
d. A four-year general engineering (not discipline specific) BS degree (with greater breadth and more practice orientation) followed by discipline-specific masters degree in engineering (30)
   - multi-discipline (or allow freely): design (across discipline), bio eng, environmental/chemical/manufacturing engineering
   - 4yr degree and increased coop, internships and industry training
   - a four year BS with some content changes with a strong emphasis on co-op as well as a strong emphasis on a study abroad exp
e. Continue current style and content of BS degree programs but put more emphasis on life-long learning (31)
   - I think that we need to place more emphasis on this criterion – which might mean a reduction in specific content. Maybe industry could take on responsibility of specific training (they do this in most cases any way)
   - but change the content to be relevant, include everyday examples and include leadership/communication/team skills throughout
f. Other (8)
   - 4-5 yrs BS with project based portfolio and career specific for 3yr level course options
   - globally based projects
   - BS degree plus 5 yrs work experience and then MS in leadership
   - radical alteration of 4 yrs program so that professional skills as integrated within content courses and much of content is dropped as not relevant
   - repayment of financial loans by going to EWB, Peace Corps, like doctors in low income areas
   - first – eliminate industry exemption for licensure, requiring the EIT license to call yourself an engineer and practice engineer at all. Second – require continuing Ed for EIT’s to cover additional “soft” topics, such as leadership, etc (and ethics). Third – consider raising the number of PhDs required every year. Right now many states require 15 PhDs/yr which is the equivalent of a credit hour course/yr. I recommend doubling the requirement to 30 PhDs/yr
   - I do not believe that a 5-yr program is possible in the current economic environment. The cost is too great.
- a completely new way of framing engineering education. We urgently need radical innovation in engineering education, not only in mechanical education but in all specialization
- engineering scientists should follow path in “d” above, but most engineers should be in ET and follow path “e”
- change BS programs to include less content, more practice and other skills that are in demand
- many programs have reduced the value of the MS degree through an emphasis on the PhD. The MS is very valuable
- let the market decide what they want. If industry wants more master’s students they will hire more. Also, more technical content doesn’t seem to be what the students need as per the Seering Study at MIT
- Integrate global issues across curriculum. If faculty learn global issues, it is really not difficult to make small changes with integration of global issues
- a streamlined BS curriculum with greater flexibility followed by a professional MS and a traditional MS so that there are multiple pathways to move forward
- 4 yr BS and industry placement internship (12 mos) or 4 yr BS with co-op (total 12 month placement)
- 4 yr BS degree + class that will transfer to the MS degree. Maybe 5 classes + co-op
- word is richer in variety than indicated by any single answer
- there’s need to change how we teach, who we teach more than to change what we teach. If an additional year is added to a process that is our 25% efficient way (MIT study) what kind of positive yield are we going to get by the 5th year? Change how more than what.

**Question No. 5.** *The need to develop communication and leadership skills in our students is often cited as necessary for their success in the future. How should this be accomplished in a four year curriculum? Pick one.*

a. Much more integration of these topics into engineering courses (93)
- this is important. Professors need to spend more time evaluating the communication component
- if possible mimic environment in industry, with teams, briefings and presentations
b. More stand-alone courses in these subjects within the curricula (10)
c. There is no room for these subjects in a four-year engineering curriculum
d. Make better use of the university’s general education requirements (18)
e. Other (5)
- more use of programs from ASME
- multiple opportunity for integration at minor expense of 1-2 existing topics
- combination of efforts (a/b/d) and emphasis in service learning, co-curricular activities
- integration across curriculum, not just in eng. This may be difficult in larger
university with more “silos”
- what does industry really need?
- no more room needed
- bring technical communication expertise into engineering courses and programs
- how do you measure leadership? Be careful, leadership is different from management. Some literature indicates leadership is natural + not taught
- the existing load of non-technical courses and also integration into engineering courses is sufficient
- check out existing leadership and other campuses and institutions run my WEP + MEP programs. We are already doing this in many places but there is no integration into curriculum. Would be easy to do

Question No. 6 How do we make room for such content? Pick one.
f. Eliminate the second course in any engineering topic sequence, e.g., the second thermo course (19)
g. Reduce content coverage in many or most of the engineering courses to make room for these subjects (50)
h. Add credit hours to the program (12)
- scrutinize each course, take out what is no longer needed to make room. Create more project based courses.
- add an optional track or club with leadership and communication foci
i. Other (16)
- teach in a different way – e.g. team based learning
- you don’t have to reduce content, it can be integrated into courses w/o sacrifice if done well
- transform portions of course assignments to have more communication/leadership components
- work with industry to get their participation and help make this happen
- integrate these aspects into existing course work – if required increase credits slightly
- much material can be learned outside of class. (project-based leaning for example) – can also reduce math/science or integrate activities. Why do courses stand alone and not integrated with same skills
- revamp current activities (assignments, lab reports) to better align with communication skills needed in industry
- Integrate soft topics into all engineering courses. For example, we can add team design projects (that also require oral and written communication) into traditional engineering science classes (such as dynamics)
- eliminate gen-education courses in communication (if English departments teaches technical writing as poorly as they do at my institution (did not mention which institution)
- students are willing to do offline asynchronous work, use this to provide opportunities for communication activity
- combine f & g
- look at co-curriculum activities or additional opportunities for communication
and leadership skills development
- as stated above, there is no need for additional non-technical courses
- reduce the non-technical courses
- False assumptions, you don’t have to reduce content to this engineering.
Professors don’t cover math and science but hold students accountable for using it. Ditto for writing and speaking

**Question No. 7. How do we measure performance? Please comment.**
- look to business schools and liberal arts to learn from them
- industry satisfaction with graduates
- project based leadership
- internship with employer feedback
- do a pilot test class by class
- surveys: student at graduation/3 yrs out/10 yrs out
- we can all recognize good communication and all faculty should feel empowered to evaluate communication. Leadership is harder
- - by how employable our graduates are after a 4 year degree
- Learning performance: that improve if we mix technical and emotional intelligence pedagogical goals and level of retention there of welfare of students during their studies
- Content transformation, impact and task completion
- Set appropriate rubrics. Measure according to rubrics
- Use students portfolio or peer evaluation
- Design – presentation (outcome based assessment)
- To have an interview with students before they graduate
- If this comment comes from industry, then industry should have a voice in the measurement process
- Combine courses and add new ones, i.e., statistics + dynamics, engineering design + engineering freshman seminar. Also 50 minute classes should be changed to 80 minutes. Many high schools (at least in Pittsburgh) are using 80 minute class time to incorporate lecture and active hands-on experience and communication and leadership skills
- By looking at what the product or output of the student is relative to the intended
- Focus on systems level awareness and drill down on specifics as needed to guide the access of well established knowledge
- Can be integrated with appropriate teaching of learning attributes
- Move to measure potential upon graduation ra2ther than curriculum based content assessment
- Real life feedback from industry partnerships and feedback from the industry participants
- Design curricula to include these outcomes international with engineering outcomes needed
- Develop rubric which evaluates speaking & listening, writing & reading, presentation (tables & graphs) & interpretation
- Industry satisfaction
- Continue to survey industry of university graduates to measure progress. See how we impact the world’s most difficult problems. Are we progressing?
- Add a realizable factor – use industry evaluations of students. Combine team and individual grades – especially communication, brainstorming.
- More writing assignments, team projects

Additional Comments:
- Higher level objectives such as leadership and innovation. Should be an integral and natural part of all classes. If taught separate it will remain separate. Facts taught can remain same in core classes but the way they are taught and assessed should focus on the higher level objectives (PBL, problem ref, hands-on)
- think about developing AP courses in high school to gain experience, education and credit
- Don’t reduce technical content too much. While students may retain only 25% of specific materials there is a foundation of “technical literacy” that engineers need. Best to integrate soft skills into technical courses while making technical courses more grounded in practice
- See Olin College example – 4 yr BS, socially connected with design and hands on activity every semester. Apprenticeship model is good. Consider maintaining faculty – BS graduate engineer for 3 yr period after graduation
- I would suggest removing or substituting unnecessary courses with something more useful. I would also negotiate with university requirements and substitute them with courses that are essential
- We need to change to organizational structure and constraints of the typical P&T structure of engineering programs in order to promote real change
- Lifelong learning is a key solution strategy in a rapidly exchanging world. How to promote this should become a key subject of engineering education research
- All engineering departments need to have the guts to eliminate the deepness of the curriculum and to remove 20-25% of the traditional material. Then you fill in with a grand challenge problem, solved in teams and presented to industry and faculty panels. It’s time to rise above the science part and incorporate the practice part that so many of our grads in real life. This is how you create engineering future
- A design spine is critical in all of the above questions. PBL and design can be the context in which to learn content, communication, teaming, management and critical thinking. This is the best option. If requires little more than a faculty who are willing to implement a new instructional approach
- I’ve been at large publics (Michigan State, VirginiaTech, Univ of Utah). I’m now at a very small private liberal arts university (Seattle Pacific). We do a much better job at integrating leadership, communication, practical experience, and multidisciplinary problems in the curriculum, than what I saw at the R1s. Example: we started a new general engineering program with an emphasis on appropriate and sustainable engineering. The core courses are all
problem based. Internships are required. Design projects are interdisciplinary and many include business students. Students are required to take social/environmental (policy electives, leadership is integrated into curriculum (e.g. students read a book on leadership in sophomore circuits’ class). Perhaps look at liberal arts institutions as a model

- What was presented and trying to do today seems to be similar to what we are doing in academic now. It seems that V2030 is lacking a paradigm shift. It’s missing that “leap forward” concept/idea.

- Total revamp of curriculum is needed. Combine calculus with physics and solve engineering problems. More communication and leadership can be integrated into all engineering courses. Same with ethics and global concepts. Why a lot of 3 hr courses? Combine topics and meet hour or two everyday

- Leadership and innovation require higher order skills which should be emphasized. However these higher order skills also require levels of intellectual and emotional maturity that undergraduate students are still acquiring. There is a danger that we educators will merely add content in innovation and leadership. We need to recognize that leadership and innovation don’t fit with statistics, machine design, heat transfer. We need to address the human development of our students. We need to teach those aspects of professionalism that they avoid and that faculty is probably unable to teach because they (faculty) lack those skills.

- Real & meaningful partnership between industry and academia in developing effective modules to engineering education

- Are there 2 different groups of engineers: practicing and academic?

- Don’t need to reduce, just integrate communication into every class, example: students present and discuss their work at every class. Possibly faculty need communication skills so that can teach it

- Get industry at the table to have a conversation about expectations

- There is a high probability that global climate change will be the dominant issue in 2030 and its consequences. One possibility is the destruction of civilization as we know it. Education should be dealing with this possibility. ASME has its head in the sand on this issue. The head of the environmental division appears to be a climate change skeptic.

- At our institution engineers transfer to technology when they fail in the engineering program. How could options a or c on #3 even work in that case?

- Reward system should foster industry experience instead of theoretical research and publishing. Our main problem in the US is remedial education in K-12 of our public schools. Graduates of US public schools are deficient in math, English, and most of all the ability to study.
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