AC 2011-2804: VISION 2030 CREATING THE FUTURE OF MECHANICAL ENGINEERING EDUCATION

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Vision 2030 – Creating the Future of Mechanical Engineering Education

Introduction

In July 2008, the ASME Center for Education formed an engineering education task force, subsequently entitled ASME Vision 2030. The committee was composed of representatives from industry and education, including both engineering and engineering technology educators. The constituents of mechanical engineering education were assumed to be 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. The 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" was defined to include the endeavors of both mechanical engineering and the mechanical engineering technology graduates. Also, the term "mechanical engineering education" was defined to include the education of mechanical engineering and mechanical engineering technology students at both the undergraduate and graduate levels.

The Vision 2030 Task Force is still actively pursuing 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 adoption of recommendations for mechanical engineering education curricula, with the goal of providing graduates with improved expertise for successful professional practice.

The Case for Change

The role and scope of the mechanical engineering profession has been transforming. Both what mechanical engineers do and how they do it are changing owing to the expansion of the discipline's boundaries, increased need to attend to global issues, increased professional and diversity expectations, and rapid technological innovation. These important factors impact the mechanical engineering profession and serve as motivators for significant change within mechanical engineering education. As stated by Simon Ramo, "…the ability to harmonize science and technology activity with societal demand will assume vastly increased importance. Either the engineering profession will broaden greatly or the society will suffer because the matching will be too haphazard."[1] While some may argue that the educational system in the U.S. remains the envy of the world, others are not as sanguine. Massive investments are being made in many countries, both in Asia and the Middle East, in higher education. Multinational corporations have the ability to source their engineering expertise worldwide. If the mechanical engineering profession within the United States is to remain viable, it will depend on the ability of U.S.-based mechanical engineers to provide continued value and expertise to industry and government.

Innovation and leadership. Innovation and leadership will be critical factors for the U.S. industrial base to maintain success of the U.S. economy while finding sustainable resolutions of the challenges facing our planet. As the economies of other nations become more sophisticated and developed, the U.S. economy will depend more on the creative power of its engineering workforce and an efficient process of bringing new ideas to market. However, global cooperation will be required to resolve the challenges facing our planet. Creative invention by mechanical engineering and mechanical engineering technology graduates is essential to innovation, but so is leadership. The implementation of invention to become innovation requires leadership. Increased numbers of engineers in leadership roles in public and private sectors are needed now more than ever.

Global issues. The ASME 2028 Global Summit[3] identified a number of critical uncertainties that global societies face. Critical challenges facing the engineering profession 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.

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 engineering profession is to respond effectively to these global challenges.

With the advent of organizations involving students in venues beyond their academic home, such as Engineers for a Sustainable World, Engineers without Borders and others and the formulation of the National Academy of Science's 'Grand Challenges' facing the world[2]. 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 venue to apply their mechanical 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 the innovation process. Mechanical engineers and mechanical engineering technologists must occupy prominent roles toward sustainable economic futures. Students and graduates, along with industry and the public, must be educated to understand that sustainable, not unlimited, growth is central to viable long term solutions to both technical and economic problems.

Workforce redefinition. Workforce redefinition is a challenge for mechanical engineering as the process of product conceptualization, design, manufacturing, and service has both changed and dramatically increased in speed even as population demographics (both of college students and the population in general) have changed. The fraction of women and minorities in the mechanical engineering profession has remained very small and essentially constant (at about 15%) over the last thirty years. This is in spite of significant efforts by government, industry, and academia to increase the attractiveness of the mechanical engineering profession to women. At the same time, the medical and legal professions have dramatically increased the fraction of women within them to about 50%, or even greater. The current mechanical engineering educational process does not attract and retain enough women and minorities. Without achieving a critical mass of diverse talents and experiences, the relevancy of the mechanical engineering profession and its products will be increasingly at risk.

Previous engineering education studies. The National Academy of Engineering's *The Engineer of 2020*[4] envisions the future and attempts to predict the role engineers will play in the future. The guiding principles were that the pace of technology innovation will continue to be very rapid, the world will increasingly be globally connected, the social and business groups involved with technology innovation will be increasingly diverse and multidisciplinary, and that social, cultural, political forces will continue to shape technical innovation. The NAE's report *Educating the Engineer of 2020*[5] continues the themes presented in *The Engineer of 2020* . It notes the increasing complexity and scope of engineering systems in energy, environment, food, product development, and communications. It suggests an earlier and stronger introduction to engineering practice within undergraduate programs, with the students experiencing the iterative process of designing, analysis, building, and testing.

The report, *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education report*,[6] indicates that, despite the growing importance to society of engineering practice, the engineering profession still tends to be held in relatively low regard compared to other professions. The report also noted that industry tends to view engineers as disposable commodities, replaceable by less expensive offshore engineering services.

In response to polls showing that K–12 teachers and students generally have a poor understanding of what engineers do, a National Academy of Engineering (NAE) project, as reported in *Changing the Conversation*[7], identified, tested, and disseminated a small number of messages intended to improve public understanding of engineering. Most current messages are framed to emphasize the strong links between engineering and math and science—which many consider as discouraging potential students. These "old school" messages ignore other, more attractive, characteristics of engineering: creativity, teamwork, and communication. The recommended re-branding of engineering requires modifying and improving the engineering profession's appeal to different groups, especially minorities and young females.

The 2009 book from the Carnegie Foundation for the Advancement of Teaching titled, *Educating Engineers*[8] 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. The authors visited a variety of engineering programs to examine current educational practices in mechanical and electrical engineering. They found an emphasis on the acquisition of technical knowledge, distantly followed by preparation for professional practice. The authors argue for a "networked components" educational model where components of engineering science, laboratory work, and design activities interact with one another in an approximation of professional practice.

In summary, greater sophistication, often at the interface between basic science and engineering and at the systems level, influences engineering skills needed in the workforce. Both engineering research and very applied and hands-on engineering are needed within industry (as shown by survey data reported later in this paper). In addition, a critical need to reestablish world-class manufacturing in a number of industries within the U.S. points to a growing need for a redefined and larger mechanical engineering technology educational venue.

The reasons for re-thinking engineering education are compelling. Mechanical engineering and mechanical engineering technology program content and attendant populations have to respond to future workforce needs, either by resizing or restructuring. The responses of academic programs are expected to vary widely, due to the great diversity within engineering and engineering technology programs and the regions they serve across the nation.

The National Science Foundation (NSF) sponsored 5XME workshops in 2007[8] and in 2009[9] to explore necessary transformative change in mechanical engineering education and research in the U.S. The 2007 workshop report proposed that: the primary challenge for mechanical engineering education in the USA is to educate mechanical engineers that will provide five times the value added, as compared to the global competition, i.e., the "5XME." The general recommendations of the 2007 5XME workshop were that the bachelors degree should introduce engineering as a discipline, and be viewed as an extension of a traditional liberal arts degree; the bachelors degree should be viewed as the foundational stem upon which extensions for continued professional depth and transition to non-engineering career paths can be grafted; the masters 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 and innovation.

With an interest in implementation, the 2009 5XME workshop formulated a number of mechanical engineering curricular concepts: a professional (or design) “spine” offering engineering reasoning, engineering synthesis and other professional skills during all four years, the fundamental topics central to a mechanical engineering or mechanical engineering technology curricula are mechanics, thermal sciences, materials, design and manufacturing, and systems and controls, and that the curricula should be sufficiently flexible to prepare graduates for a wide variety of careers. One suggested curricula consisted of 25% basic math and science, 25% mechanical engineering principles, 25% social science and general education, and 25% problem solving and design.

Assessment of Current Mechanical Engineering Education

A number of surveys and sessions were used to provide focused input from constituents, including industry, government agencies, mechanical engineering and mechanical engineering technology program leaders and faculty. Some of the information gained from these surveys and face-to-face sessions is presented below. These inputs helped further document the perceived strengths and weaknesses in the various mechanical engineering education areas and graduate skill sets in engineering practice.

A survey was designed by ASME to assess the strengths and weaknesses of mechanical engineering graduates from the perspective of industrial managers and engineers. The form was web based, with questions about respondent’s industrial experience, educational background, hiring and supervisory responsibility, and asked open ended questions about recent hires in their companies. Initial responses were received from 381 engineers and managers with follow-up surveys resulting in over a 1000 respondents. The size of the companies represented ranged uniformly over five categories from small (1-230 employees) to very large (greater than 46800 employees). The range of industrial experience of responders was from about 1 year to over 30 years. As the amount of data received was large, only highlights are reported here. (As these and other ongoing survey data are digested, additional publications will disseminate them.)

The analysis of the responses was performed both by computer, a text-analysis program, and by the committee. A subset of the Vision 2030 committee then created 14 categories that best organized the responses. The strength and weakness responses were sorted into these categories. As the same characteristic could be listed as either a strengths or weaknesses, it was decided to use a net result in characterizing the results. For instance, ‘interpersonal skills’ was listed as a strength by 19% of the responses, and as a weakness by 10%, giving a net strength of 9%.

One question asked managers for the strengths and weaknesses of recent B.S. mechanical engineering hires in their company. As presented in the table below, the responses indicated that the top four strengths were electronic communication techniques (not necessarily quality!), technical fundamentals, computer modeling and analysis, and interpersonal/teamwork skills. The greatest three weaknesses were lack of practical experience – how devices are made and work, oral and written communication, and problem solving/critical thinking. These were the dominant response categories, with all other responses below the 5% level. Interestingly, new applications and leadership areas were not mentioned as a strength or weakness by the industrial respondents. As might be expected, responses for mechanical engineering technology graduates showed a net positive of 22% for a strength of graduates in the area of practical experience.

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

Another question asked the industry respondents if their company would prefer more breadth with respect to mechanical engineering education rather than depth? The responses were 48% desired more breadth, 29% more depth, and 22 % more breadth and depth. Representative comments included the following.

> Technical breadth is more important because engineering practice is multidisciplinary, and their engineers work on systems, not components.

Breadth across all disciplines is important for work on multifunctional projects.

Breadth provides a broader perspective on what it takes to get a project done and the collaboration needed across skill sets.

A Vision 2030 plenary session was held at the ASME Engineering Education conference at Hilton Head, South Carolina in March 2009. There were 85 department heads and engineering educators at the conference. At the plenary session, this group was asked to respond to a set of questions, some of which were unique to the academic setting while others probed topics asked of the industry respondents. For instance, the academics were asked for the missing components in the traditional mechanical engineering curricula to help prepare students for the 21st Century skills and industry was asked what skills and knowledge will be needed in graduates for their companies to be competitive in the 21st Century. These responses are shown below. Academic-based responses placed 'technical fundamentals – new ME applications' as the primary missing component, with 27% of the respondents. The next four priorities were 'interpersonal and teamwork,' 'overall systems perspective,' 'business processes and entrepreneurship,' and 'global issues and challenges.' Note that relative to 'missing components,' there were major differences between the engineering educators and the industrial respondents. Response incongruities can be highlighted by looking at the differences (either positive or negative) between the two groups. The primary missing component for the educators was 'new ME applications (bio, nano, etc.)' but this area (or its components) was not mentioned once by the industrial responders, resulting in a 27% difference for this category. The second largest divergence was practical experience, with a 14% variance.

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

In addition, educators were asked several questions that did not have a corresponding question in the industry survey. For instance, a question probing how the typical mechanical engineering education curriculum aligns with the grand challenges of energy, climate, water, quality of life and poverty was asked. Overall, respondents noted that the mechanical engineering profession, as it is the broadest of the engineering disciplines, can contribute to solving all the grand challenges. Respondents also noted that a general 'branding' issue' exists for the mechanical engineering profession, other disciplines have added names like 'environmental' or ‘bioengineering’ to their names, directly connecting them to the global challenges. Suggestions were made that the definition and statements of engineering problems given to students needs to be changed to put them in a ‘grand challenge’ context. The titles of mechanical engineering courses could be updated to reflect these issues. The issue of systems integration as a weakness of the typical mechanical engineering educational program was also raised. But, it should be noted that often mechanical engineering educational programs do not market themselves as connected to solutions to the grand challenges. Thus, change needs to be broader than just changing course titles or problem statements in classes with students already in the major if mechanical engineering is to change public perception, especially among prospective students and their families.

The academic group was asked how the practices of teaching should change in the coming decades. The responses indicated that many institutions are implementing project-based learning, in varying degrees, as this approach models how projects are done in industry. There was interest in assessing project breadth versus depth, and the resources (faculty, space, and laboratory) required with this approach. Many believe that their school’s senior capstone courses deliver project-based learning experiences. There was an interest in flexibility in the curriculum, so that students can take specialized courses such as entrepreneurship courses if they so desire. There was 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. Interestingly, department heads also mentioned that one of the larger barriers to change within the curriculum and pedagogical approach is faculty.

Another question was if the professional school model, similar to medicine, is a good idea? The academic participants were not in favor of a professional school model. There were questions raised about the lack of industry support, and the additional cost to the engineering student. There was also no desire to move to a five year bachelor’s program, including more credit hours, and more courses. The need to instill professionalism into students from the first day of classes was discussed.

While not a result of the Vision 2030 task force, the work done by Warren Seering and his survey information (as reported to during the 2009 5XME workshop[11]) of early career MIT mechanical engineering graduates sheds 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 skills/knowledge was obtained somewhere else. Such data argue for a change in what we do within mechanical engineering education.

Initial Recommendations

While data analysis and discussions are ongoing, the following thoughts present initial views of the Vision 2030 task force as ways to strengthen two aspects of undergraduate mechanical engineering education. While a perceived strength of mechanical engineering technology programs, the practical knowledge/experience of students graduating from mechanical engineering programs can be improved, at least in the eyes of industry. For all types of mechanical engineering education programs, the curricula should provide exposure to learning "professional skills."

To strengthen the professional experience component of the students' skill set, a significant portion of the curriculum needs to be dedicated to such activities. One way to accomplish this is for curricula to contain a design/build spine, where design courses are included in each of the freshmen, sophomore, and junior years, along with the more typical two semester senior capstone design course. In such a sequence, important elements of professional practice would be introduced, and then reinforced, in subsequent courses in the spine.

Professional skills such as problem solving, teamwork, leadership, entrepreneurship, innovation, and project management could be central features of the design spine. The problem solving component can incorporate problem formulation and judgment, e.g., a formalized design process. Rather than propose a course in leadership, or a course in innovation, these skills are better learned in the context of a structured experience in problem formulation - problem solving, ideally coupled with a design and build project.

The NAE Grand Challenges can be incorporated as elements into early design courses to help provide context and engineering background for students while they are in their science and mathematics courses. Such linkages aid in showing students that mechanical engineers are needed to provide leadership in the development of innovative and sustainable solutions to these challenges.

The yearlong senior capstone class provides a vehicle to focus on larger scale engineering problem formulation, and the design, construction, and operation of a piece of hardware or prototype. The two terms would allow for the generation and selection of design concepts, engineering analyses, detailed component design, fabrication, systems integration and assembly, prototyping and testing, application, and failure analysis of the project. During the year, students would prepare and follow a project plan, allocate resources and budget, write progress reports, and deliver design reviews to different audiences. Ideally these projects would be industry sponsored and involve industry mentors in addition to the faculty mentors. Such scenarios also allow for very relevant intellectual property discussions.

The mechanical engineering profession has one of the lowest percentages of women and, similar to all engineering fields, a low percentage of all underrepresented groups. To be able to attract underrepresented groups to mechanical engineering education, the message of the positive impact that the mechanical engineering profession has on improving the world should be communicated to prospective students and their families. In addition, this message should be infused into first-year engineering courses to help retain underrepresented groups.

Conclusions

Engineering's past history for 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 the engineering profession can, and should, do more. Hallmarks of these changes will hopefully be not only increased invention but also the implementation of that invention, or innovation. Successful innovation requires leadership, and, in perhaps a biased view, that leadership should come from engineers whom have the technical insight and ethical courage to solve the grand challenges facing this planet for the benefit of all her inhabitants. We can no longer leave our fate entirely in the hands of those that are often non-technically educated. Engineers must take leadership roles, not only on technical projects, but in society as well. Engineers must lead within their communities, local, state, and federal governments if the engineering profession is to lead towards a sustainable world. Human population has reached the point where there may be no second chances, now is the time for action. Now is the time for engineering leadership, our country needs it and our planet needs it.

What does this mean for what, and how, we teach our students? The group of engineering educators on the Vision 2030 task force believes our students need to lead not only technically but also socially, politically, and ethically. In addition to technical skills, our future engineers need to be given communication and people skills, business sense, a global perspective and an unparalleled understanding of our environment, to foster both compassion and passion for our planet. A broader view of ethical behavior needs to be infused into their education, where there are values beyond the bottom line, e.g., not unlimited growth but sustainable growth. Coupled with the importance of economic growth, graduates should possess an appreciation for the equitable distribution of that growth.

Acknowledgements

This project was funded by the ASME Foundation, whose support is gratefully acknowledged. Additional task force members contributed to the content of the reports from which this paper is drawn: Alice Agogino, University of California at Berkeley; Robert Laurenson, Boeing; Richard Smith, Renesselaer Polytechnic Institute; Cynthia Stong, Boeing; Galip Ulsoy, University of Michigan; Steve Wendel, Sinclair Community College; Lawrence Wolf, Oregon Institute of Technology; and Thomas Perry, ASME.

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