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VISION 2030: THE FUTURE FOR MECHANICAL ENGINEERING EDUCATION WITH A FOCUS ON HEAT TRANSFER AND THERMODYNAMICS

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ABSTRACT

The role and scope of the engineering practice is transforming rapidly. What mechanical engineers do, and how they do it, both in thermal and mechanical systems, is changing due to meeting global challenges, expansion of the disciplinary boundaries, and rapid technological innovation. In this paper, we suggest changes in mechanical engineering education to prepare students to work successfully in this challenging environment. The ASME's Vision 2030 Task Force identified key areas of knowledge, skills and abilities needed for mechanical engineering graduates to be successful in a global economy. The task force recommends strengthening the following seven 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, attracting a more diverse student body, increased faculty expertise in professional practice and strengthening post-graduate education for practitioners. A partnership between industry, professional societies, government, and academia is needed to successfully implement these recommendations and develop the full potential of mechanical engineering graduates.

INTRODUCTION

This paper documents the recent findings of the ASME Vision 2030 Task Force, charged with looking at the future for mechanical engineering education. Change normally occurs when there is a compelling need, and this is particularly true with engineering education. There have been many studies, for example, see [1-7], over the years focusing on engineering education that have suggested change, but few of their recommendations have had impact, unless 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 societal need. The Grand Challenges, articulated by the National Academies, clearly express societal needs. But what is fundamentally different now than five years ago or thirty years ago, during the first energy crisis? Perhaps differences are great, with a growing need for alternative clean energy sources, significant food and fresh water shortages 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 concern for the environment. Couple all of these with financial collapse of many institutions, and the financial stress that many governments are experiencing and we have the need for pervasive and comprehensive societal 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 suggests that, as Simon Ramo, National Academy of Engineering, said, *"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."*[8] Hallmarks of needed change will be not only be 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 challenges facing this planet for the benefit of all.

The fate of the world should be left 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. Engineers must lead in their communities, in local, state and federal governments, and engineering must lead towards a sustainable world. There are no second chances for many in the world, now is the time for action. What does this call for engineering leadership mean for what, and the way, we teach our students? Our students 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 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 paper presents new information about the status and long-term outlook for mechanical engineering education, with data from industry engineering supervisors, academic department heads and faculty, and practicing early career engineers. Special focus and recommendations will be made for education in the thermal sciences.

THE SUPPORTING DATA

An assessment of recent engineering education literature, multiple surveys of stakeholders, including mechanical engineering department heads, industrial engineering 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. These perspectives, from industrial and academic stakeholders and constituencies, were critical to the formation of recommendations.

Via pilot surveys, the Task Force identified key areas of knowledge, skills and abilities needed for mechanical engineering and mechanical engineering technology graduates to be successful in a global economy, whether working in small companies or large. Focusing on these key skills, the task force then developed and conducted extensive surveys in 2009 and 2010 of three key stakeholder groups in ME and MET: department heads, industry supervisors, and early career engineers, to assess the strengths and weaknesses of mechanical engineering education graduates. Responses were received from academic leaders at more than 80 institutions, from more than 1,400 engineering managers, and more than 600 early career engineers with less than ten years of practice. Complete data sets are given in the Vision 2030 report [9], and overall summaries are given in [10, 11].

To help develop Vision 2030 recommendations for academia, it was important to understand the current needs of industry. Thus, the extensive survey efforts outline above. Sample data from these surveys are shown below in Figures 1 and 2 and both reinforce mechanical engineering traditional strengths as well as point to areas that need to be strengthened. In addition to technical knowledge, the role of the mechanical engineering graduate in addressing "grand challenges" of sustainable engineering, energy, and human health requires educational change to achieve new areas of impact. To develop and implement creative solutions, mechanical engineering graduates must possess leadership and innovation skills, in addition to their technical fundamentals.

STRENGTHS

Figure 1 shows a comparison of how the industry supervisors (n=647), the educators (n=42), and the early career mechanical engineers (those that answered the strengths question, n~590) rated the 15 areas as a strength (e.g., "strong" on the scale above) of the graduates. Note the wide disparity of opinion between the industry supervisors and the academic leaders in many of these areas. This should serve a reality check for many academic programs. For example, problem solving and critical thinking were rated as a strength by 48% of department heads but only 14% of industry supervisors. Interpersonal teamwork was rated as strength by 51% and 43% of early career engineers and academic department heads, respectively; but by only 20% of the industry supervisors.

There was agreement about graduate capabilities in some areas, with computer modeling/analysis and new technical fundamentals showing reasonable agreement (albeit low as a strength in the later case). More often, the early career engineers and the academic leaders showed a relative level of agreement, with the industry supervisors showing less agreement.

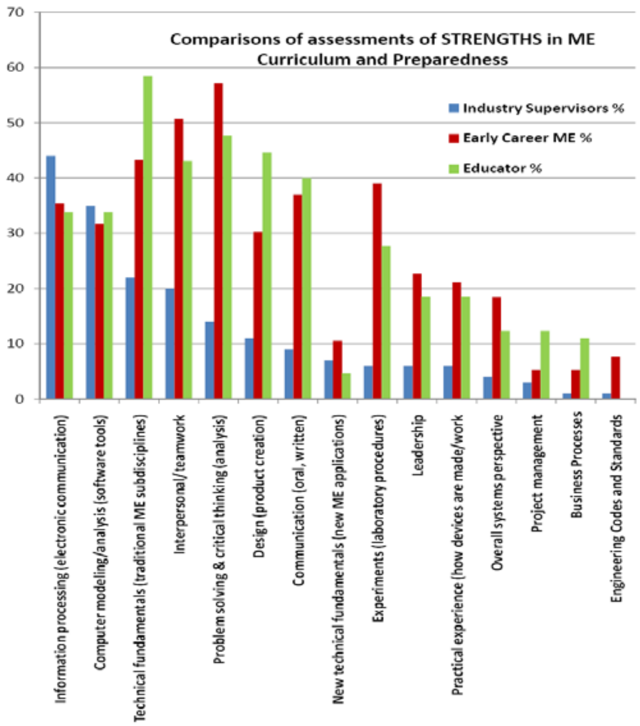

Figure 1 Comparison of Strengths in ME Curriculum

WEAKNESSES

Figure 2 shows a comparison of those industry supervisors rating the 15 areas as a weakness (e.g., "weak—needs strengthening" on the scale above) of the recent graduates. Again, note the disparity of opinion between the industry supervisors and the academic leaders in some of these areas. There was general agreement about lack of capability of graduates in some areas, with project management and business processes showing perception of weakness in reasonable agreement at the 30% level. The industry supervisors' four strongest (highest percentage) perceptions of weakness were practical experience—how devices are made or work (59%), communication (oral and written—52%), engineering codes and standards (47%) and having a systems perspective (45%). These were matched by early career engineers' perception of their greatest weakness in two areas: practical experience (42%) and engineering codes and standards (54%). The other two high percentage weaknesses as rated by early career engineers were project management (35%) and business processes (34%). (In addition, their data portrays a sense that overall systems perspective education was weak, echoing their supervisor's impression, with 31% indicating this rating level.)

The engineering educators had only one of their four strongest perceptions of weakness aligned with the industry supervisors and the early career engineers (engineering codes and standards at 37%). Only one other area aligned with industrial supervisors (overall systems perspective at 46%). In addition, academia and early career engineers agreed on another common weakness, business processes (37%). The fourth top academic perceived weakness was new technical fundamentals/new mechanical engineering applications (40%).

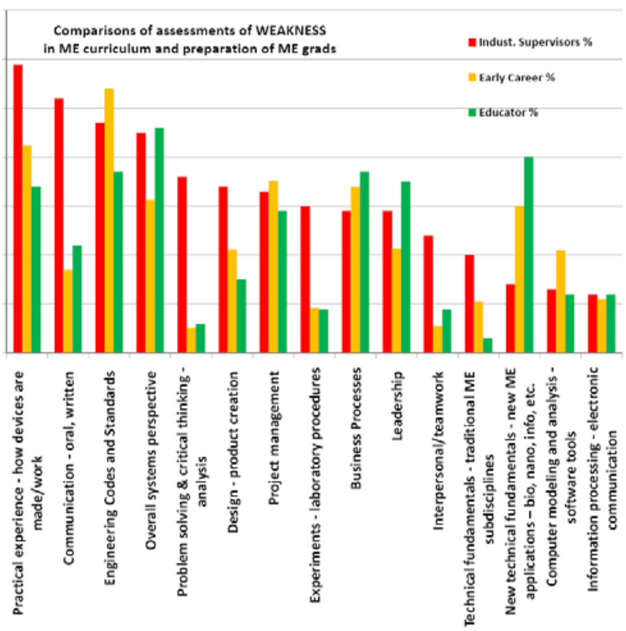

Figure 2 Comparison of Weaknesses in ME Curriculum

AGGREGATED DATA - ECEs

When survey responses were aggregated, two factors emerged where differences of opinion were significant: communication skills and the practical experience of early career engineers (ECEs).

We asked industry managers, academician and the early engineer cohort to rate preparation and skill level in communications (generally defined). Figure 3 reveals the first of mismatches we find. Industry managers are nearly equally divided on this question, which identifies possibly the adjustment the ECEs need to make in the business setting and most likely some deficiency in their preparation for practice. Academicians and ECEs themselves, on the other hand, strongly feel "sufficient to strong" in this skill set. Whether this comparison reveals either an inherent weakness in the undergraduate degree program or a predisposition held within industry on new college graduates remains a question for future discussion and research.

In concert with communication skills, knowledge of how devices are made and work (generally included under the rubric of practical experience) differences in the viewpoints again surfaced. Figure 4 illustrates a general weakness here, and the ECEs themselves parallel this assessment. Without a context, this result should be viewed only in the most general light, but it is indicative of the strong theoretical focus of most current mechanical engineering undergraduate programs. Early career engineers were a bit less negative on this question even though34% considered their practical experience a weakness.

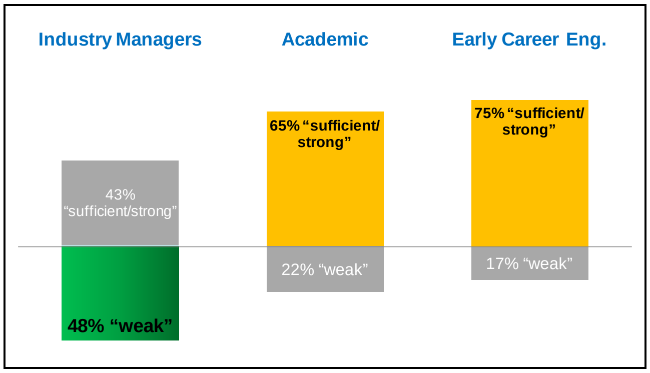

Figure 3. Difference between industry, academics and early career engineers on communication skills. (ASME, Vision 2030 Surveys, 2010-2011)

In parallel with this question, we asked whether ECEs possessed the necessary systems perspective in their engineering work, and we find surprisingly good agreement across stakeholder groups. Industry leaders answered positively at a rate of 44% and academics at a rate of 46%. The ECE's were less positive, answering at a rate of 31%. Note that all positive response rates ware less than half of the sample. Thus there appears to be a compelling need to address this skill area via pervasive curricular reform

What our recent surveys and those of the past two years have shown is that ECEs and academics view their strengths to generally include problem solving, technical fundamentals, and teamwork. All of these areas consistently registered more than a 40% positive response. Greatest weaknesses identified by ECEs are knowledge of codes and standards and practical experience. Both of these areas registered more than a 40% response rate. Closely following were weaknesses identified with project management, business processes and an overall systems perspective. We view these latter categories of knowledge as those that are inherently involve maturation and experience in engineering practice and business processes. They are decidedly within the realm of the professional aspects of ECE skill set. It is problematic whether undergraduate engineering programs can provide the necessary training to reduce currently identified knowledge deficits, and to this point, our survey of industry suggests that engineering education should include a practical component.

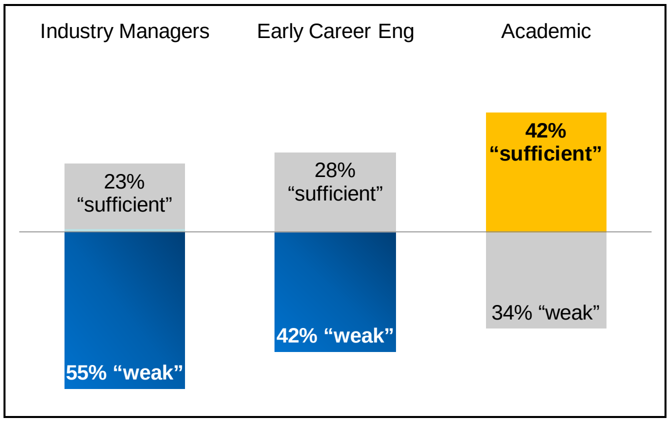

Figure 4. Differences in viewpoint on ECE's practical experience between industry managers, early career engineers and academics. (ASME Vision 2030 Surveys, 2010-2011)

RECOMMENDATIONS

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 increasingly diverse practice of mechanical engineering. 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, increased faculty expertise in professional practice, and focusing on post-graduate education for specialization. These are discussed in general and with specific recommendations for mechanical engineering education in the thermal sciences.

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.

Mechanical engineering is critical to solving the world's environmental challenges based on the thermal sciences. Mechanical engineers design heating, cooling, ventilation systems through energy generation and conversion in the built environment—green building design, energy management, and operations. They are important contributors to air, ground and water pollution abatement technologies. Mechanical engineering students should be challenged and involved in thermal sciences early in their academic career by asking them to think about, and take on projects involving thermal science aspects of such problems, ideally in a way that is appropriate in their regional context.

Curricular Flexibility-- 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 include thermal sciences or related topics.

For those programs that are ABET accredited, either within the USA or internationally, the ASME has begun a process to modify the mechanical engineering program criteria to enable more flexibility. The significant change working through the process is that the program criteria will no longer require both thermal and mechanical competencies, but preparation for professional work in one or the other, with exposure to the area not emphasized.

Practice-based engineering -- 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. To strengthen the practical experience component of graduate's skill sets, a significant 'practical experience' component should be added to curricula. A proven, successful approach, Sheppard et al. [6] 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.

Mechanical engineering has always emphasized efficiency in energy systems, whether it is in rotating machinery, automobiles, or power plants. The principles and practical aspects of efficiency should continue to be emphasized in thermal science courses, e.g., thermodynamics and heat transfer, and in technical elective courses. A basic understanding of carbon capture and processing will likely be needed to allow for more efficient technologies to be developed. Mechanical engineers should know how to appropriately apply sensors for effective energy management for multiple user levels. The use of current codes and standards, from ASME or other organizations that promulgate them, should be embedded in thermal science courses. Involving students in energy use audits of both residential and industrial sites can be meaningful to both the client as well as the students involved in the audits, helping the students understand the role of thermal sciences in a very real and practical way [12].

Professional Skills -- We recommend the development of professional skills in the engineering graduate to produce engineering leadership characteristics required for implementing thermal science-based engineering solutions to help solve the complex challenges facing companies, regions and planet. Professional skills such as a complex thermal system-level perspective, inter-disciplinary teamwork with others not well versed in thermal sciences, 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 thermal science technical topics.

New Balance of Faculty Skills -- Employing more faculty with significant industry experience in thermal sciences 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 related to thermal sciences, project management and business processes, use and understanding of thermal science related codes and standards in different contexts, could impart a greater, and more authentic, sense of the world of mechanical engineering practice as related to thermal sciences to students. Too often student projects are related to mechanical devices, e.g., cars or robots, since they are easier to build and experience. Faculty with industrial background in thermal sciences can better enable and support projects that have a thermo-fluids focus.

Diversity -- The mechanical engineering profession and its academic programs have one of the lowest percentages 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. Reinforcing connection of engineering to contextual real-world solutions that help people and society, a message shown to increase student retention and diversity, can be done via thermal sciences as these subjects are key to solving many such problems. 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.

Post graduate education -- 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 with a focus on thermal sciences provides opportunity for graduates and practitioners to meet such a need by increasing their understanding of the more complex aspects of thermal science topics.

DISCUSSION

These recommendations are broader than those of past engineering curricular reform efforts, where the debate focussed on the mix of math, science, engineering analysis and design knowledge. 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. The mechanical engineering profession must ensure that its solutions are implemented in viable economic, social, and environmental terms. This responsibility implies a richer professional framework in engineering education than presently exists.

What is now critical is the acquisition of skills such as problem formulation/solution, innovation, and the leadership ability of all of our students. This skill mix will be needed for engineers to be successful in engineering practice and to support societies' drive for a sustainable future. 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 where 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. In particular, looking at such changes from a thermal sciences perspective has not occurred on a wide scale.

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, ASME is seeking modifications to the ABET general criteria and program criteria for mechanical engineering as noted above. This implies that ME Departments develop stronger course sequences in the thermal sciences, such as a thermal science-focused design spine. To help address the significant growth some mechanical engineering programs are experiencing, a debate about whether the ABET ME Program Criteria should address a minimum faculty size/student ratio to ensure program quality in design and encourage an increase in the proportion of "practice-experienced" faculty within programs should occur.

Successful implementation of a broader and 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.

CONCLUSION

Substantive changes will be required in the traditional mechanical engineering curriculum to allow for strengthening the areas 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.

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