The Education of Mechanical Engineers for the 21st Century*

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The education of mechanical engineers must be viewed from several perspectives: the contextual basis in which engineering is practiced; the curricular framework, its foundations and educational outcomes; and the developmental path for engineering education in the next century. The basis of the current educational paradigm is examined and its suitability for the next century is critically discussed in light of the demands that will be placed on mechanical engineers over the next generation. Several features of the education of mechanical engineers are discussed to suggest options that both Japan and the United States may exercise. Possibilities for international collaboration in undergraduate and graduate education, precompetitive R&D, and technology transfer are suggested.

Key Words : Engineering Education, Curriculum, International Engineering Education

Introduction

Engineering education in the next century will be developed in a contextual framework shaped not only by educational and professional matters but also by national and international politics, economics, and policies. Evidence assembled over the past fifteen years suggests that policies in a wide variety of areas determine the business model of either an industry or a nation, and in turn, the business model has a pervasive influence on how engineering schools develop educational programs and how they educate future entrants to the field. To name a few policy areas: R&D tax credits, worker training, technology development (e. g., the support of cutting edge technology and technology transfer strategies), small business assistance, support of basic scientific research, investment in new technology for business development, import/

export policies, mathematical and scientific preparation of college entrants, federal support of science, engineering and technology (SE&T) education, and investment in infrastructure.

Given this enlarged universe of forces and influences, it is worthwhile to consider the development of mechanical engineering in the historical context. The field dates from the end of the Dark Ages of Western Europe (1500) when expansion of experimental science was pervasive, the pumping of water was perfected, and the innovations of Newcomen and Watt in steam power were widely applied by 1750. The industrial Revolution (1750-1850) saw a further growth of mechanical technologies and the pervasive influence of steam power on transportation, manufacturing, and agriculture. It was in this period when the technology-based corporate organization had its genesis, albeit within the framework of the technical and manufacturing crafts. It was also during this period that the first engineering schools were established in Europe and the US, even though they were little more than schools for training practitioners in state-of-the-art technology. Mechanical engineering was imbedded within schools of either civil or military engineering. It emerged as a separate discipline in the 50 years prior to the turn of the century with the widespread development of machinery of all kinds, more powerful

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energy conversion devices, and more efficient transportation technologies.

During the next hundred years, mechanical engineering began to encompass a larger number of technical and empirically based activities. These included manufacturing engineering, industrial engineering, aeronautical engineering and electric power production and distribution. The period 1850–1950 was one of significant and great change insofar as the theoretical underpinnings of modern mechanical engineering are concerned. The educational process shifted from that of imparting knowledge via shop-based experiences and current manufacturing and design practices to knowledge of a more theoretical kind. The latter required more mathematics, basic sciences (particularly physics), and mechanics than had characterized engineering education the generation before. This change was led by a limited number of engineering educators who built on the traditions of the early engineering schools of the eastern US and the impetus given by the Morrill Act of 1870, which established the Land Grant public universities with their mission of teaching coupled to research and technology transfer. The Land Grant universities also directed post-secondary education toward either a practical or professional end, and they supported admissions policies that provided a means to social and economic advancement for the children of ordinary citizens.

A different educational developmental pattern emerged in Japan. The Edo Period (Tokugawa Shogunate) that was established in 1600 gave way to the Meiji Period (Meiji Restoration) in 1868. The Edo Period was characterized by the seclusion of Japan from world affairs largely through the restriction of international trade and, thus, exposure to western technologies and science. The last decades of the 19th Century brought a shift in political power from Edo to Kyoto, the unifying emergence of the Emperor, a change in the civil code of laws, a restructuring of the social class system, and a tremendous investment in the infrastructure of trade, communications, transportation and education. In education, the goal of universal literacy alongside the scholarly discipline imparted from classical learning created the basis for the fulfillment of the Restoration and the development of the nation in almost every sphere. The period was also a turning point owing to Japan's use of foreign study missions that were sent to the US and Europe to observe the industrial system, governmental institutions, business methods, the organization of trade, and the educational system. The result was an emulation of Western practices in economic, scientific, educational and technical activities. Gradually, a revitalized and reformulated world view emer-

ged by the beginning of the 20th Century. Within this transformation, engineering education was also transformed to support development of the modern industrial state based on technology and science.

By the beginning of the 20th Century, the gradual decline of the "shop-based" engineer and the emergence of the "school-based" engineer was the major conceptual shift. Additionally, the apprenticeship system of the US fell into decline, and the large corporation became the organizational paradigm. The mechanical engineer of the period was more likely to be an employee of such a corporation than a proprietor of small company or an independently registered professional providing engineering services. The practice of mechanical engineering lay within the framework of manufacturing, product development and design activities that were segmented with respect to task and function. This appears to have been the case in both Japan and the US.

The larger shift that occurred over the last 200 years was a result of the forces that brought on and perpetuated the industrial revolution along with a change in the organizing principles of society. The period was characterized by a rapid diffusion and adaptation of technical, and scientific advance without regard to geography or national boundaries—the transnationalization of innovation. Generally, innovations based on a basic design were made within the same conceptual and theoretical framework; that is, a technique was extended to greater maximum utility by small innovative steps using a core technology, e.g., the steam engine. Many of the advances in the mechanic arts, mechanical technology, and industrial processes employing mechanical devices followed this type of evolutionary path from 1850 to 1950. This process of technological advance and a focus on machinery has formed the contemporary intellectual framework of mechanical engineering.

What has occurred over the last fifty years in the development of technology, however, has been something quite different both in content and form, and this sort of developmental path will characterize the future of engineering as we know it and impact engineering education in a profound way. It is that knowledge from disparate sources forms the basis of an entirely new technology. For example, the development of the computer began in the 17th Century with the development of the binary system to represent quantity, or a number. Babbage realized that gears could be made to perform arithmetic operations and developed early mechanical calculators in the 19th Century. Conceptual leaps followed when Russell and Whitehead showed that any concept could be represented rigorously in mathematical form, and

Neuman derived the idea that all information is the same when quantified. In 1914, De Forest invented the audio tube that converts electronic pulses to sound waves, and about 1944 the device was applied to switch signals from zero to unity. In 1945 the first experimental computer using vacuum tubes was operated at the University of Pennsylvania. In 1947, the transistor was invented, and soon thereafter the first integrated circuit was developed. By 1985, computers based on integrated circuits had become commodity items with a very short product life cycle. They have also been readily adapted as tools in engineering, science, communications, finance, manufacturing, and education. Their future applicability and utility now rests upon the development of software and operating systems, which represents yet another area where innovative advances occur within a different conceptual framework.

What will characterize the future of engineering is just this type of knowledge combined from different fields and its portability. We will move from the discipline focus and organization which we know and understand well to a multiplicity of knowledges as a requirement for engineering practice. The systemization of knowledge and technique that characterizes all fields of engineering will remain valid as an operating framework, but the challenge faced by the engineering schools will be to provide the basis for a new type of engineer and engineering in the next generation.

While both the US and Japan enjoy robust and productive systems of engineering education that share several educational foundations and professional goals, both find themselves at roughly the same point with respect to the future. The two systems of engineering education are being asked to redefine themselves to support the advancement of high technology economies and industrial systems based more on innovation and the application of knowledge than on adding value to natural resources through processing and production-based manufacturing. In this framework, the knowledge content of new products and services will become the resource that adds value, and technological and scientific advances coupled to innovation will form the foundation for continued success of the national economy. Engineering will be the essential, critical link between the knowledge base and new products and services.

The Current Curriculum

Shifts that have taken place in both the practice of engineering and the role of the engineering have lead to a broadly based examination of the outcomes of engineering education. In the US numerous reports have called for curricular reform, the development of

specialized (professional) masters degree programs, career-long post-collegiate education, and stronger links between graduate study and research and the needs of industry. Reformulating the curriculum has been seen as a necessary first step to produce engineers with a greater degree of flexibility, a larger world view, a sense for the integration of knowledge across disciplines, an orientation toward innovation, and especially for mechanical engineers an orientation toward the product development.

Recommendations in this vein have also recently appeared in Japan. Elements of the vision include establishing more flexible undergraduate curricula to serve an expanding high technology economy, allowing undergraduates to embark on professionally oriented studies at an earlier point in their undergraduate careers, strengthening of graduate curricula, developing a system of access for post-graduate students who desire to return to university study after some years in industry, and improving support for graduate research in the universities. The over arching goal is to improve the innovative potential of the engineer and thus of Japanese industry.

From 1890 to 1970, the education of mechanical engineers in the US was driven largely by the needs of production-oriented manufacturing. Scientific advances and technological innovations also played a part, e.g., nuclear energy, engineered materials, and information technologies. The trend continued toward an emphasis on science, mathematics and engineering sciences in the undergraduate curriculum, and this had the effect of a reduced emphasis on engineering design, manufacturing technologies, and hands-on laboratory experience. The US system also adopted an elective system that allowed a degree of specialization that was not allowed in the Japanese system up to the present time.

While Japanese and US curricular structures emerged that reflected both their industrial and larger societal cultures, they have been remarkably similar. Generally, the four-year curriculum comprises a two-year period of foundation studies in basic science and mathematics followed by a two-year period focusing on engineering sciences and mechanical engineering technologies. Studies have begun to appear in the US on integrating the curriculum and providing an early focus on engineering, but with several notable exceptions, the curricular structure retains the two-plus-two structure and a degree of disassociation of the may focal areas of the discipline. Tables 1 to 4 provide a brief comparative summary of both systems as of the late 1980s and early 1990s.

Curricular content and form are framed and accredited in the US by the Accreditation Board for

Engineering and Technology (ABET) for approximately 300 colleges offering engineering degrees. The ABET criteria set minimum requirements on the content of the curriculum as a whole (Table 1) and also specific criteria within disciplines. ABET also sets guidelines on faculty composition, laboratory and

computing experience, and related educational support. While the guidelines have evolved over the years, they have reinforced the educational paradigm that merged from 1950 to 1975—a strong grounding in

Table 1 Overall curricular content for US engineering education in 1990 after criteria established by the Accreditation Board for Engineering and Technology (Reyes-Guerra, 1989)

Mathematics and basic sciences.	1 Year
Engineering sciences.	1 Year
Engineering design.	0.5 Year
Humanities.	0.5 Year

Table 3 Typical four-year Japanese engineering curriculum of 1990 (Frey, 1991). Units of credit are semesters hours. Course are offered in three to four hour units, and a laboratory is usually offered by each major professor

Humanities	24-48	(21 %-31 %)
Physical Education	4	(3 %)
Foreign Language	6-16	(5 %-10 %)
Specialized Subjects	76-88	(71 %-56 %)
Total	124-156 Semester hours	

Table 2 Typical mechanical engineering curriculum of 1990 based on the fifteen-week semester system (Reyes-Guerra, 1989). Units of credit are semester hours. One semester hour of credit generally corresponds to one hour of in-class instruction, except for laboratory courses. Courses of instruction are generally offered in three or four semester hour units.

	Humanities	Mathematics & Science	Engineering & Engineering Science	Other
First Year	6	18	0	10
Second Year	3	18	10	0
Third Year	6	0	28	0
Fourth Year	6	0	25	0
Total	21 (16 %)	36 (28 %)	63 (48 %)	10 (8 %)
Grand Total	130			
Laboratory	28(22 %)			
Engineering				
Electives	18(14 %)			

Note : As of 1995, curricula of major engineering schools required from 120-140 sem. hrs.

Table 4 Overall characteristics of the Japanese and US systems of engineering Education (Latorre, Hatamura and Ohashi, 1994)

	United States	Japan
Entrance	Self selecting ;national exams (SAT, ACT) usually in the fall ; fall admission.	National exams in Jan/Feb. ; April admission.
Academic Year	30 weeks ; summer optional ; two semesters or three quarters.	40 weeks ; two 6 month terms.
Graduation	Upon completion of requirements.	Once a year in March
Courses	3-4 contact hours per week per professor ; total : 12-16 hours.	1.5 contact hours per week per 2-3 professors ; total 18-20 hours.
Laboratory Work	1 - 2 per department ; greater emphasis on analysis.*	One affiliated with each full professor.
Faculty	9-month salary supplemented by research in the summer.	12-month salary base.
Research Perspective	Follows funding priorities.	Long range under senior professor's guidance.

*The situation has begun to change in the US with a shift toward more laboratory experience. Many US universities have begun to invest in computer-aided design facilities and thus increase students' exposure to modern methods of analysis and computation ; in most mechanical engineering programs, computer-based graphics is commonplace.

basic and engineering sciences with a focus on design in the fourth year, the so called "capstone" experience in design. Programs have focused on educational inputs, have maintained barriers between disciplines, and have produced graduates who need more laboratory and group experiences in order to function well in a dynamic professional setting. These same programs have also continued to supply engineers to the workforce and to graduate and professional schools who are very well educated in modeling and analysis and who are generally adept at state-of-the-art, computer-based graphic design techniques. Those with work experience as undergraduates, e.g., through a cooperative program in industry, also bring with them a familiarity with the industrial environment. This is the exception and not the rule.

The shifting emphasis within US curricula is illustrated in Table 5, where mechanical engineering curricula over a 35 year period are compared. Significant changes to be noted are an increased emphasis on humanities and social sciences, a reduction by two-thirds in the time allocated to laboratory work, and an increase in the technical electives at the expense of prescribed subject matter accompanied by a decline in the number of courses and in the breath in the curriculum. While the nominal subject emphasis as measured by the percentage of the curriculum in mathematics/physical science and engineering/engineering science has not changed all that much, within individual courses the subject matter has tended to reflect more fundamental topics than state-of-the-art technology. The reduction of laboratory contact has taken place in the design-manufacturing area.

Japanese engineering programs are not accredited in the same manner as in the US, and curricula are based largely on faculty expertise and interests, new technology development, and employment opportunities for graduates. The Ministry of Education sets the overall guidelines, but these do not have the kind of influence on the curriculum as do the ABET guidelines which promote very similar engineering programs across the US. Of the 535 universities and colleges in Japan offering engineering courses in 1994, 143 had faculties engineering and 128 had graduate schools in engineering. The engineering education system is highly stratified with the very few national universities being highly desired both for educational reasons and the potential for long-term career prospects. Most of the faculties of engineering are in the private schools of engineering and within the ten national universities. Conversely, most US engineering schools are contained within the public universities, and the public universities produce the majority of engineering graduates. Graduate programs in

Table 5 Mechanical engineering curricula at Colorado State University of 1987-89 and 1953-55 (Kulacki and Vlachos, 1995)

	1987-89	1953-55
Humanities	19(14 %)	11.3 (8 %)
Mathematics/Science	37(28 %)	36 (26 %)
Engineering/Engineering Science	71(53 %)	77 (55 %)
Other	6(5 %)	15.7(11 %)
Total Semester Hours	133(83 %)	140 (61 %)
Laboratory Experience	28(17 %)	91.4(39 %)
Engineering Electives	8(13.5 %)	10 (7 %)
Total Contact Hours	161	231.4

Note : Laboratory instruction is in addition to lectures and adds to the contact time in both cases.

engineering very widely in the US in productivity and research activity, but most of the engineering schools offer graduate degrees.

Although detailed analysis of Japanese curricula are difficult to obtain because of the variability of programs across the nation, some reports have appeared recently that begin to provide a critical analysis of the strengths and weaknesses of contemporary curricular philosophies. If one generalization is possible, it is that the educational culture that has grown up around the entrance examination and the selection process for admission have produced both desirable and undesirable effects. The examination process assures the university system that top quality students will be admitted to the engineering schools of the first rank, and this filtering process in turn assures future employers and graduate schools of a supply of raw talent for top quality appointments. The criticism of this approach is that the examination system tends to de-emphasize those attributes that are becoming more important to the success of Japanese industry and society, specifically, cross-disciplinary thinking and creativity. As Frey (1991) has put it,

"These exams also fundamentally affect not only what is learned, but how Japanese engineers apply this knowledge in their careers. The examination system has led to an emphasis on factual knowledge, drill, and memorization-rather than on analysis and critical thinking.

"Japanese universities.....want to know how much has actually been learned and how well information and theory can be applied to problem solving. Emphasis is on mastery of facts, control of details, and practiced skill in application of mathematical and scientific principles."

In the US, a similar concern is expressed not because of the matriculation process but because the curriculum is viewed as a flawed educational device. This viewpoint has lead to a serious reconsideration

of the aims, assumptions and outcomes of engineering education. The resulting national discussion has engaged universities, the federal government and industry for about the past ten years. It appears that the same discussion has begun in Japan with the release of several high-level reports from the Ministry of Education on the future of engineering education. In the US, the National Science foundation has taken the lead in raising issues and encouraging the discussion.

In both countries, concern is expressed over the downstream impact of engineering curricula that do not graduate students who are able to cope with the practice of engineering in a highly complex and dynamic environment. Industry in the US desires new hires who are able to bring to the workplace immediately useful skills to a greater degree than in the past. This demand reflects an industrial culture in which on-the-job-training is not pervasive and deeply imbedded as in Japan. Most US employers, however, continue to give good marks to the engineering schools and their students for basic scientific background, knowledge of engineering sciences, mathematical/computational ability, and facility with contemporary computer-aided engineering techniques.

Japanese industry and the Ministry of Education express concerns over the long-range viability of engineering education to keep the economy competitive through innovation and creative use of engineering and basic science. There has also been a realization that trans-disciplinary engineering, will become more the rule than the exception, and for mechanical engineering this means a shift from engineering focused on power-driven devices to highly integrated systems in which several technologies dynamically interact through high-level digital control devices.

The Future of The Curriculum

The foregoing places the education of mechanical engineers in a much larger context than is usually done. Both Japan and the US, as the world's leading economic powers, are vitally dependent on both the quality of their engineering and the abilities of their engineers. How engineers are educated and how they are employed will matter greatly to nations in which SE&T drives the economy. For Japan and the US, there is no alternative national developmental strategy because they have moved too far from the point where low valued added products can sustain their standard of living and their international competitiveness.

My belief is that engineering practice in the first half of the next century will be influenced by an enlarged set of concerns and opportunities. These will

Table 6 Social, economic and technological periods, or social surges-periods marked by paradigm shifts in society (Drucker, 1990)

Commercial Revolution, 1650-1725 : Expansion of trade following development of ocean going freighters ; Papin steam engine in 1680, and Newcomen's engine in 1712.

First Industrial Revolution, 1750-1850 : Expansion of innovation in mechanical devices, energy conversion technologies and transportation technology. Rise of the large business enterprise and the employee society.

Second Industrial Revolution, 1870-1970 : SE & T based businesses, beginning of the atomic age, information age, and genesis of the information paradigm (computers and information processing).

Third Industrial Revolution, 1970 : Information paradigm matures. Biotechnology era begins. Impacts on society are as yet unknown.

include a stronger link between scientific discovery and technical application, a global information infrastructure that will remove almost all barriers to communication and the sharing of ideas, the regionalization and globalization of markets for engineering services, an expanding global reach of key industries, an increased demand for traditional energy resources, and an increased concern for the capacity of the environment to support a much larger world population, i. e., global sustainability.

Mechanical engineering will be practiced in an era that, perhaps, will be totally different than any other (Table 6). The mechanical age that provided the basis for education and practice as we know it today has given way to an era that is more concerned with information (quality and quantity) and its management and high valued added products. It is also an era in which the biosciences and engineered materials will eventually have as much impact on society as did the steam engine in First Industrial Revolution. Both influences will change the foundations of mechanical engineering practice and mechanical engineering education.

In Japan and the US, the early signs of change in the engineering are indicated in the way engineering education is being viewed by the Ministry of Education and ABET. The Ministry of Education has addressed a number of critical issues for engineering education in its 1994 study report, and it is instructive to summarize several of them identified by the study team :

- An expanded role for engineers in society due to the widespread and growing use of technology.
- Interdisciplinary education to replace the current vertical educational system.
- National support for research and the future role to be played by educational institutions in

research.

- Developing a workforce for an era of heightened internationalism.
- University education aimed at improving the creativity of the workforce and providing for the continuing education of researchers and technicians.

Each of these topics forms the basis for policy development and the implementation of educational objectives at the university level. The attributes of the graduates are implicit for each topic. Similar studies and reports in the US have arrived at the same general set of issues and areas for action.

However, in the US, ABET has proposed modified accreditation criteria that reflect the larger role of the engineer in society and the development of globally oriented high technology industries. The proposed accreditation criteria for the year 2001 stipulate that engineering programs are to demonstrate that their graduates have the following attributes:

- An ability to apply knowledge of mathematics, science and engineering.
- An ability to design and conduct experiments, as well as to analyze interpret data.
- An ability to design a system, component, or process to meet desired needs.
- An ability to function on multi-disciplinary teams.
- An ability to identify, formulate, and solve engineering problems.
- An ability to communicate effectively.
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
- The broad education necessary to understand the impact of engineering solution in a global and societal context.

Underlying these program outcomes are overall educational requirements that are not very different from those outlined in Table 1. However, the proposed requirements combine studies in engineering science and design as appropriate for the specific field of study. Assessment tools pertinent for each of the outcomes have not yet been proposed by ABET, and this element of the proposed accreditation framework will probably be the most problematic given the tendency of US engineering schools to resist burdensome outcomes assessments.

What is at work in both Japan and the US is a sense that mechanical engineering education is at the threshold of an era where the utility and long-term viability of graduates in a transnational economy can only be assured by a different sort of educational experience and preparation. The dilemma is that the both educational communities and their related pro-

fessional societies and governmental agencies must either move swiftly toward this different future or be overtaken by larger economic and societal changes. If the latter occurs, a generation-long chaotic situation could develop for engineering education. Because Japanese engineering schools do not operate under national accreditation guidelines, they may be better positioned at the time to react nimbly and to reformulate their engineering educational system and its goals.

In the broadest sense, mechanical engineering education needs to be reoriented toward the innovative process and innovations (the two are different). The practice of engineering certainly embodies both of these key outcomes of engineering activity. However, the trend toward reductionism in undergraduate education, a great dependence on analysis in all phases of engineering education, the elective system to support specialization in the US, and a gradual movement away from collaborative-integrating learning have produced graduates who are deemed inadequately prepared for the demands of the future. A call for a redirection of educational goals and objectives has been the result, along with a restructuring of the curriculum. I should mention that a reformation of the curriculum in mechanical engineering, actually began 25 years ago with a critical examination of the design, experience received by students. The result has been incremental change in overall content, curricular structure and accreditation guidelines.

The task ahead in curriculum development is daunting given the rapidly changing demands on mechanical engineers. An expansion of the elective system will probably not work, nor will the introduction of a limited number of "tracks" at the undergraduate level, say, to reflect the needs of particular industry sectors or technologies. What is needed is a comprehensive restructuring that views undergraduate education as the foundation for employment as well as advanced study in either graduate school or industry. The educational process must be directed toward a fully integrated experience, in which students would receive a holistic education. The major outcome would be an engineer at the baccalaureate level who views engineering as a comprehensive, integrating process for which the tools and the knowledge base change as solutions develop. Such an engineer would view the definition of a problem as the most important part of an assignment. To some extent the form of the curriculum and its content would reflect this kind of overarching outcome. Table 7 presents a listing of the components of a holistic engineering education.

Table 7 Complementary outcomes of a holistic engineering education (Bordogna, 1995). The left-hand column characterizes the outcomes of the present curriculum

Vertical (In-depth) Thinking	Lateral (Functional) Thinking
Abstract Learning	Experiential Learning
Reductionism	Integration
Develop Order	Correlate Chaos
Understand Certainty	Synthesis
Research	Design/Process/Manufacture
Solve Problems	Formulate Problems
Develop Ideas	Implement Ideas
Independence	Teamwork
Techno-Scientific Base	Societal Context
Engineering Science	Functional Core Engineering

Three broadly defined elements must be considered in the kind of educational redesign contemplated here:

- The reconfiguration of the essential components of the undergraduate curriculum.
- The role and purpose of graduate and professional education at the masters level.
- A reformation of the role of the faculty.

The recent paper by Kulacki and Vlachos (1995) provides an extended discussion of the first two points. Briefly, each of these major components comprises the following.

Curricular Reconfiguration

The goal is to provide an integrated educational program with greater emphasis on humanities in a curriculum containing a reduced number of semester hours (Kulacki and Vlachos, 1995). Specific objectives are,

- Reduce total semester hour requirements to 120 to 123.
- Increase the content of the humanities and social sciences.
- Increase quality and quantity of laboratory experiences.
- Assure active participation of students in design across the curriculum.

Implementing these objectives will not be easy. Both in Japan and the US, a reduction in the number of courses would accompany the 120 semester hour constraint, and faculties of engineering and science are generally reluctant to yield "academic turf" to new theories of education. However, the objective could be accomplished by reducing technical electives and skill courses, improving articulation in the engineering sciences and mathematics courses, and teaching engineering knowledge and some engineering science within the framework of design, e.g., just-in-

time methods.

Humanities and social sciences would be redefined for engineering students to provide for them an in-depth study of one or two topical areas. With this approach, students would receive advanced level instruction that they would not normally get if a distribution of courses would be required. Typical course concentrations could be in history, economics, political science, and literature. A study plan would be developed by the student to achieve coherence through an appropriate sequence of courses throughout the four years of study. A humanities requirement on the order of 25 to 30 percent of the total semester hour requirement would be possible without harming the core engineering subjects and educational objectives.

Laboratory courses impact hands-on learning and experience that cannot be obtained via either demonstrations in the lecture or computer simulation. While laboratory experiences are extensive in the Japanese system, improvement is needed in the US system. The reconfigured curriculum would include a laboratory in either science or engineering each semester. Early experience would focus on learning how to conduct experiments, use of hardware and software, and linking laboratory projects to design. Enriching the curriculum would be accomplished by including a laboratory practicum in several of the engineering science courses, linking formal instruction in design to laboratory experience, and requiring open-ended experiments as part of the third and fourth year laboratory courses.

Design experiences could be enhanced in a variety of ways, and changes to the curriculum represent fundamentally different challenges in Japan and the US. Nevertheless, an increased emphasis on design could be easily obtained by requiring a course each semester in design. This annual design course would be enhanced with independent studies projects and a senior thesis as a requirement for graduation.

Graduate and Professional Education

With a constrained and highly articulated undergraduate curriculum, the role and purposes of graduate education at the masters level takes on added importance. Future developmental patterns and likely outcomes appear to be different in Japan and the US.

Given the established role of private companies in Japan in the training of its SE&T workforce and the traditionally low rate of enrollment in full time graduate studies, several concurrent shifts would be necessary if a robust, professionally oriented post graduate education system is desired. Factors that to be considered include:

- Acceptance by companies of university-trained masters degree holders.
- A redesign of company training programs and internal mentoring practices.
- Management of applied research conducted for industry by universities versus that conducted in the national laboratories.
- National support of graduate education and research in the universities.
- Graduate admissions policies at the universities.
- Curricular content and structure, outcomes guidelines, and portability of degrees.

In the US, full time graduate education is primarily supported by the universities and the national government through various educational development initiatives. Additionally, corporations tend to provide advanced education through employee benefits programs, i. e., post graduate training is not subsumed fully within corporate development and personnel practices. Consequently, the necessity for masters level education is not universally accepted, and the purposes and value of an additional two years of study are viewed differently across various industry sectors. The tendency of engineers in the US to change employers several times during a career and to pursue graduate study on a part time basis are also factors in how much post graduate education is internalized within corporations.

Nevertheless, several reports have appeared recently that recommend a rethinking of the role and purpose of the masters degree and its relation to current and future undergraduate curriculum designs. The role of the degree with respect to doctoral level education is also a factor. (For example see Kualcki and Vlachos, 1995, and Rathbone et al., 1995)

If a broadly based restructuring of masters degree programs is implemented in the US, the primary curricular change will be a reorientation of the program toward specialization within mechanical engineering, i. e., systems dynamics and control, mechatronics, energy conversion, heat transfer engineering, materials processing, etc. This makes sense pedagogically because graduate curricula can respond more quickly to rapidly changing demands of the field than can undergraduate programs. Additionally undergraduate curricula are already overburdened with respect to content and need to be limited in scope and objectives if graduate education is to have meaning for practicing engineers and their employers.

Additional features of future masters programs within the US context might include:

- A required design project supervised by a combined industry-university panel.
- Required courses in management, finance, market-

ing, etc. for students who will not pursue studies for the doctorate.

- Accreditation by ABET.
- Granting of some form of professional license, say, following the Canadian model of registration.

For both Japan and the US, focused national efforts are needed to better define this element of the overall educational system. The stakeholders include professional societies, universities, and the national governments.

Reformulating the Role of the Faculty

If broadly based reforms of undergraduate and masters level education are implemented by the early years of the next century, the role of the faculty must also be reconsidered. While the conditions of faculty appointment and the duties of the faculty are quite different in Japan and US, a number of similar themes and issues would emerge. Ultimately, a redefinition of the role of the faculty would have an influence on graduate education and the operational framework for the conduct of research at the national laboratories and in universities. If we consider the elements of a holistic engineering education that are presented in Table 7 as being operative underlying principles, it appears that the following transformation in the duties and roles of the faculty will take place:

For individual faculty members, their roles will shift from:

- From mentor of an individual to a facilitator of groups of students and researchers
- From technical expert working individually to a member of team organized around a problem.
- From a teacher transmitting facts and data of a sub-discipline to a member of a team-based approach to teaching that also imparts engineering judgment to students.
- From an individual scholar working in a sub-discipline to solve problems to a collaborator in a trans-disciplinary team working to both define and solve problems.

For a department or college faculty as a whole, the following transformations might be expected:

- From a collection of experts that work in sub-discipline groups with respect to teaching and research to a flexible organizational structure that contains clusters of individuals to optimize teaching effectiveness and research quality.
- From an organization with no professional unity to an organization with a unifying professional framework.
- From an organization with varying types of technical, professional, and commercial relations with industry to an organization that promotes strong ties to industry (for the US system) and industry

and government laboratories (for the Japanese system).

Each of these topics derives further discussion and elaboration, and they would naturally arise in the process of curricular reform at the undergraduate and masters levels. They are naturally linked together, and this makes the entire area of reform in engineering education particularly challenging.

Conclusion

Both Japan and the US are at a critical turning point in the development of their engineering education systems. Both systems share many similarities, and each can benefit from the other's past experiences and current planning efforts. It would appear that the industrial and economic vitality of either country could be enhanced through collaboration and knowledge sharing in the development of their respective engineering educational systems. Additionally key policy questions are on the agendas of each nation for the investments that need to be made in higher education overall and specifically in those programs that preserve and advance the SE&T workforce.

Overarching issues for both countries appear to include the cultural basis for engineering education and learning; the cultural basis for employment policies and the social responsibilities of employers of engineers; the role of the faculty in the learning process; and research support, especially with respect to graduate and professional education.

Let me suggest two initiatives for the next five years that would have the effect of improving collaboration between the two countries in the development of their engineering education systems and their R&D enterprise. Each of them will naturally bridge educational, professional, and cultural issues

Japan-US Engineering Education Commission

The purpose of the Commission will be to provide a forum for policy and program development, a common basis for curriculum development, a vehicle for collaborative analysis of engineering trends and data, and an integrating capability for the activities of academia and various branches of government in both countries that influence engineering education. As an example, the Commission can provide an international platform for sharing best practices in education and research and long range planning activities for the identification of precompetitive R&D of interest to both countries. An immediate objective of the Commission could be to organize an international workshop on mechanical engineering education for the Pacific Rim countries before the year 2000 under the theme of knowledge sharing for curriculum development.

For the long run, the Commission would focus on cross cultural issues for trans-national educational development and engineering practice. Under this goal a forum for interaction of all stakeholders in the educational process could be continuously maintained for the benefit of engineering education in both nations. Naturally the work of the Commission would encompass all fields of engineering.

Japan-US International Graduate Center

This center would be established for advanced studies in the various branches of engineering, applied science and technology. Students would be awarded posts at the center for the purpose of either obtaining a masters degree or limited advanced studies in, say, a subdiscipline of mechanical engineering. Initiatives of the Center might also include programs management of technology, cross cultural studies for engineers, technology policy research, and distance education. Technically based research activities would need to be carried out in member universities and government laboratories in both nations, but long-term research on generic topics of importance to both nations could be initiated, e.g., interfacial engineering, low temperature heat exchange processes, and advanced robot technology. A collaborative planning process will be needed to bring this type of center into being, but I believe the benefits to both nations would be well worth the effort. With sufficient support from industry and government, the Center could form the basis of an multinational, regional graduate university of applied science and technology for the Pacific Rim (Hopp, 1995).

To close, let me say that many engineering educators and leading industrialists in Japan and the US have commented at various times about the path that engineering education and engineering should follow in the future. Comments by Julius Stratton in 1958 seem to have anticipated our current situation:

"First, may I remind you that engineering is itself many things, a vast domain of many lands. It includes the highly skilled art of the modern technician; it encompasses managerial occupations requiring a consummate knowledge of human behavior; and it has been pushed forward now into areas of systems design-with its array of problems that can be mastered only by the most sophisticated methods of modern science and mathematics.

"Every part of this extended domain contains elements essential to the industrial life of the nation. Our great professional societies, such as the institutes of mechanical and electrical engineers, choose to group these activities together in a few large categories. But the fact is that within any one of these traditional branches there is a vast range of

professional qualifications. The term 'electrical engineer' no longer describes adequately the occupation..... [and] at the same time the electrical field is fusing into the mechanical, and it becomes increasingly difficult to distinguish one profession from the other.

"But now in addition, let us also recognize that henceforth the vanguard of engineering, the great creative genius of the profession, will march forward hand in hand with science. The research engineer of the future may be concerned with the anatomy of a component or the physiology of [biological] systems. His interest may center on materials, fluid flow, combustion, or information theory. Whatever it may be, it is unlikely that in these areas he will make important contributions without the benefit of a superb training in physics, chemistry and mathematics..... [But] for all the common ground, engineering is not and never will be science. There is inherent in the profession a whole set of attitudes and concepts completely foreign to pure science. The engineer must have a feel for materials, a concern for cost, an understanding of the factors of size and weight, an appreciation of the problems of maintenance and replacement, and, above all, an unfailing sense of responsibility toward his client and public good."

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