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New Mechanical Engineering 1991: The University of Tokyo Approach*

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The changes in Japanese industry have resulted in a new concept of what is mechanical engineering. Consequently the University of Tokyo has revised its mechanical engineering program to reflect this development. This paper presents an outline of the employment trends of recent graduates, a discussion of the wider scope of mechanical engineering employment, and an outline of the new mechanical engineering curriculum introduced in 1991.

INTRODUCTION

THIS paper updates references [1–3] on the developments in mechanical engineering at the University of Tokyo. Since the first graduation class in 1879, more than 5000 mechanical engineers have graduated from the University of Tokyo's mechanical engineering program. From this early stage of the Industrial Revolution, society required engineers who would be able to exploit coal and oil by using mechanical systems to obtain inexpensive powered machines. This evolved into the present engineering courses of machine dynamics, thermodynamics, fluid mechanics, solid mechanics and machine design.

Now with microprocessors and databases we are embarked on a new track beyond the development of muscle-substituting machines towards the development of information-driven machines (brain-substituting machines). These developments are causing a number of fundamental changes in education, research, industry and society [4].

As a contribution to understanding how these changes are being handled in the mechanical engineering program at the University of Tokyo, this paper discusses three areas:

1. Trends in mechanical engineering graduates employment.
2. Japanese students' perception of engineering.
3. Evolution in new mechanical engineering curriculum.

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† Professor and Chairman.

TRENDS IN MECHANICAL ENGINEERING EMPLOYMENT

Figure 1 shows a comparison of the number of science and engineering graduates in Japan and the U.S.A. per 100,000 population [5]. The U.S. numbers may seem slightly larger since computer

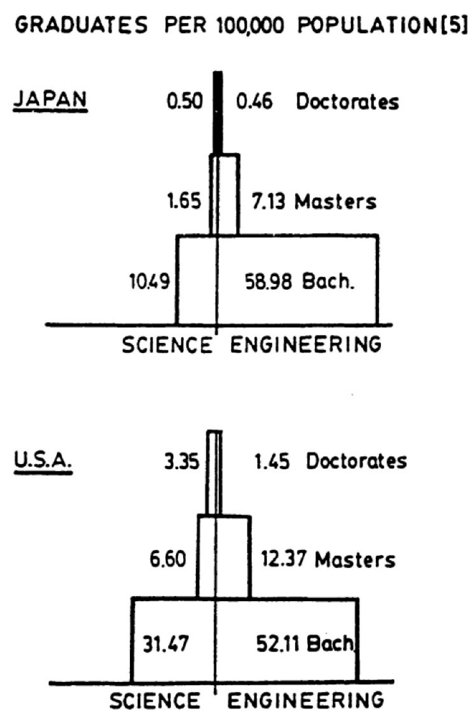

Fig. 1. Comparison of science and engineering graduates per 100,000 population in Japan and the U.S.A. Adapted from [5]. Note: U.S. statistics include computer science in engineering.

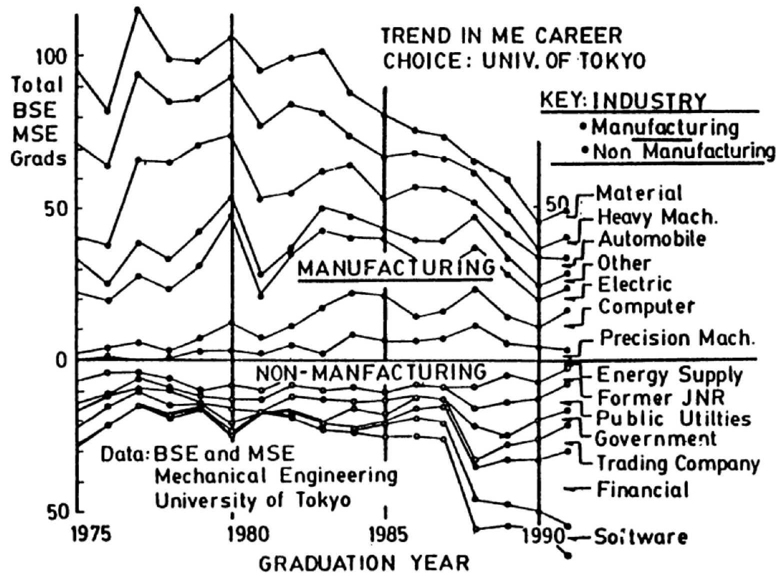

Fig. 2. Bachelor and Masters graduating in mechanical engineering, University of Tokyo, 1975–1991.

science majors are included with engineering. Nevertheless, Fig. 1 indicates a comparable engineering output in the U.S.A. and Japan.

In recent years there has been a shift in the employment pattern of the University of Tokyo's engineering graduates [6–8]. This is shown in Fig. 2. The shift from mechanical engineering graduates entering manufacturing to non-manufacturing-related jobs began in Japan around 1982. It has been attributed to the following reasons:

1. *Compensation*:
There are significant differences in compensation among industries. Students are choosing higher-paying companies, and these are often in non-manufacturing industries. Figure 3(a) and (b) illustrates this difference between banks and manufacturing industries [5, 8]. Figure 3(b) shows that as the productivity of manufacturing industries increased, the wage ratio, manufacturing to banks, actually dropped.
2. *Weakening of professional identification*: Students no longer choose their careers based on their major fields of study. This trend is much smaller when the students complete the master's degree before employment as shown for the University of Tokyo's mechanical engineering graduates in Fig. 4.
3. *Changes in recruitment policies*. Financial business firms are employing more engineering graduates than in the past. Historically, these businesses employed social science graduates, including graduates from law, economics and arts. Figure 5 illustrates that the banks are very selective in hiring the students from universities with higher SAT scores [5].
4. *Early student choice of Major*: The common university examination system in Japan has forced the standardization of high school education. Students make early decisions in their fields of specialization and department without full appreciation of the implication of their choice. As a result some students alter their career plans if their interests differ from the prescribed course of their engineering major.
5. *Role model*: Students plan their careers and lives based on their assessment of their parents who are mainly wage earners.

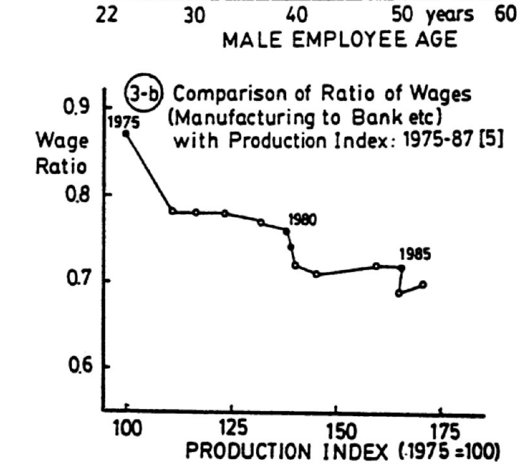

Fig. 3. Comparison of salaries for Japanese bank and manufacturing industries employing over 1000 employees [5, 8]. (a) Annual income versus age for 1986. Adapted from [8]. (b) Ratio of manufacturing/bank wage versus Production Index. Adapted from [5].

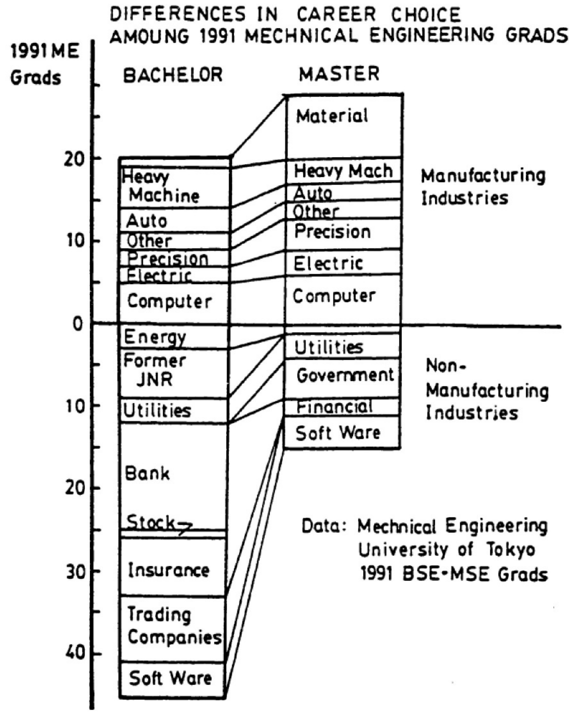

Fig. 4. Employment breakdown for 1991 BSE and MSE in mechanical engineering, University of Tokyo.

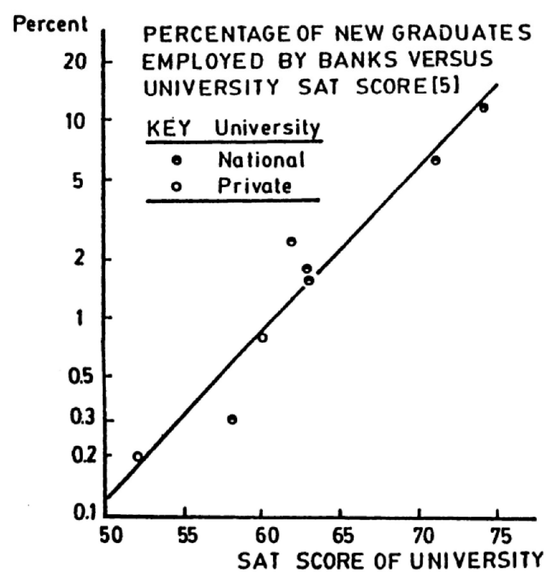

Fig. 5. Correlation of graduates employed by banks with SAT score of Japanese university. Adapted from [5].

The major shift in mechanical engineering employment began in 1982 (Fig. 2). This corresponds to the period when Japanese heavy industry faced problems with the high yen/dollar exchange and a reduction in its exports. The categories in Fig. 2 break down the mechanical engineering graduates into two main areas: non-manufacturing and manufacturing industries.

PERCEPTION OF ENGINEERS' WORK

There is also the broader issue of the number of students entering engineering. This has a far-reaching impact on the growth and the maintenance of the industrial base. Figure 6 shows the percentage of students who entered different faculties in Japan and the U.S.A. [8, 9]. In both the U.S.A. and Japan there has been a decline in the number of students entering engineering after 1985. To examine the broader trend, the entering classes of Japanese students were assigned to two categories in Fig. 7 [9].

1. Category S, which consists of the faculties of science, engineering, medicine, agriculture, pharmacy, etc.
2. Category L, which consists of law, economics, social science, literature, arts, pedagogy, etc.

Examining Fig. 7, it is clear in Japan that there is a decline in the entrance applicants into Category S and a corresponding increase in category L. In a survey of the entering freshmen class, the students were requested to rank on a positive and negative scale the impressions of what is the student situation for S and L. This is plotted in Fig. 8 [9]. Obviously, the attraction for L majors are the perception of more free time and soft work.

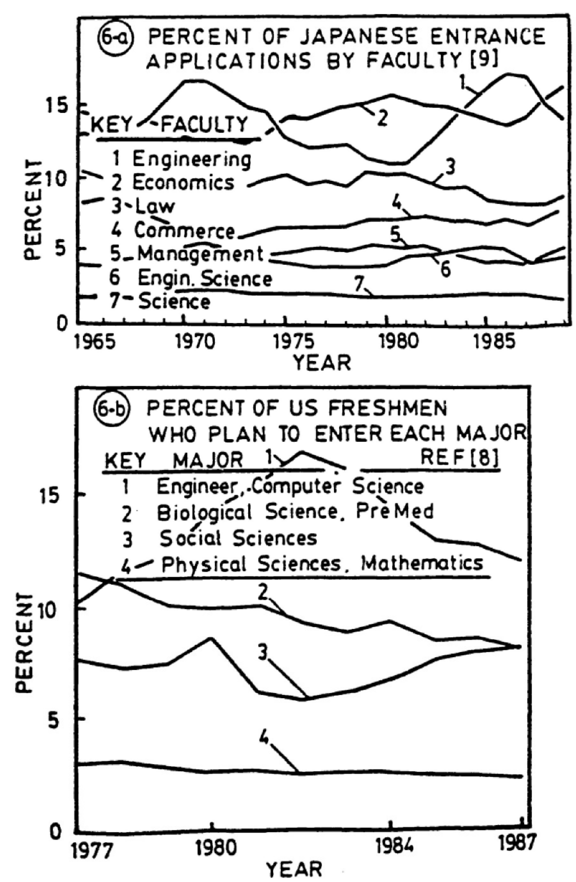

Fig. 6. Breakdown of university entrance applications to engineering and other majors [8, 9]. (a) Japan, 1965–1989 [9]. (b) U.S.A. 1977–1987. Adapted from [8].

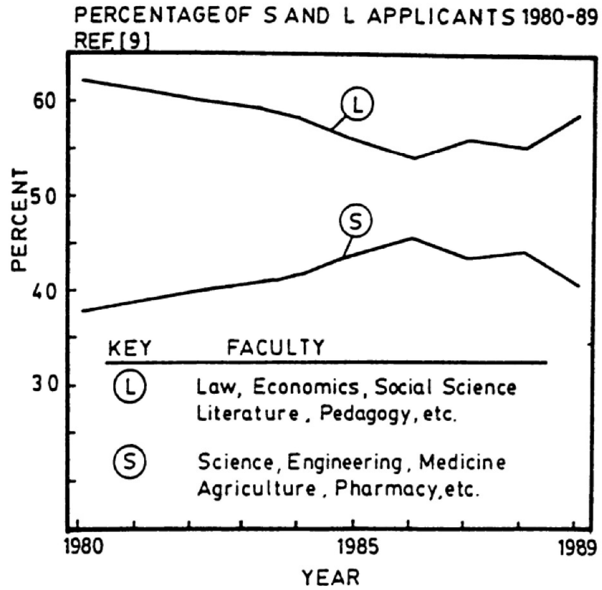

Fig. 7. Trends in Japanese university entrance applications, 1980–1989 [9]. S = science, engineering, medicine, agriculture, pharmacy, etc. L = law, economics, social science, literature, pedagogy, etc.

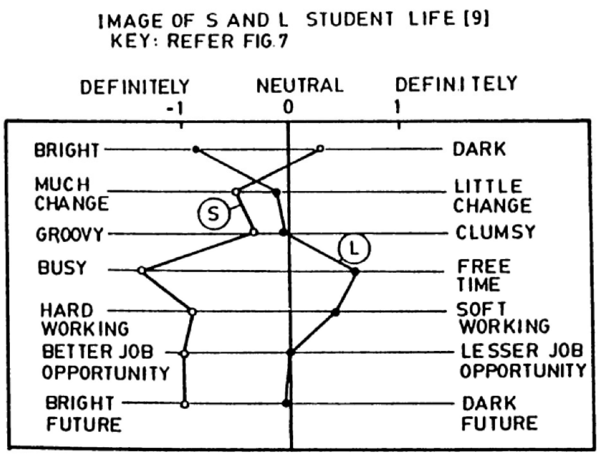

Fig. 8. Freshman student's image of student life [9].

An analogous survey was made on the image of a researcher and a banker to reveal the source of students' attraction to the banker's career. The results are plotted in Fig. 9 [5], which clearly indicates the perception of higher wages, higher social esteem and a more social and stable situation for the banker. This tendency of engineering graduates to join banks has been commented on by several persons [7]. 'The reason students are attracted to banking is that we care about people', said Nobutaka Yamamoto, Executive Vice-President of Sanwa Bank. 'We should be able to reform some areas involving our renumeration and working conditions', said President Kazushiye Min of Kubota Ltd. There is a consensus that, 'We have to strengthen our efforts this year to renew the manufacturing industry', as Yasuo Shinga, President of Sunimoto Metal Industries commented.

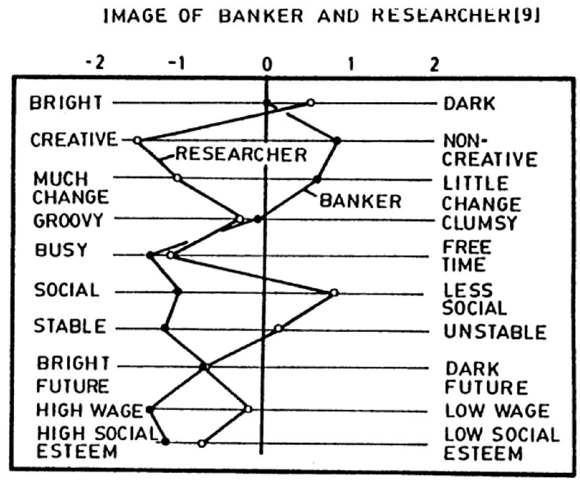

Fig. 9. Freshman student image of banking and research careers [9].

However, this trend is a logical development if we consider it from the viewpoint of the concept of replacing human intelligence with smart machines. To prepare the next generation of mechanical engineers for this expanding role, it is necessary to develop a new curriculum for mechanical engineering.

EVOLUTION OF A NEW MECHANICAL ENGINEERING CURRICULUM

In reference [2] the four courses of study in mechanical engineering at the University of Tokyo (1988–1990) were described. They included:

1. Mechanical science: scientific analysis of physical phenomena in mechanical engineering.
2. Energy systems: thermal and other flow machinery and the process of their operation.
3. Design and manufacturing: materials, CAD–CAM and techniques for production management.
4. Control, information and systems: mechatronics, robotics and computer control of machines.

The introduction of this curriculum in 1988–1990 was an intermediate step in a major revision of the mechanical engineering curriculum at the University of Tokyo. To understand the background for this revision, let us examine the automobile as representative of machine production. In a modern passenger car more than 200 sensors and 10 CPUs are installed to control the engine's fuel injection, exhaust emissions, automatic transmission, anti-skid brakes, active suspension, steering, air conditioning and the stereo system. A decade ago there were no CPUs installed in passenger cars. By adopting these sensors and CPUs a higher level of performance and functionality is achieved in our modern automobiles. Past machines were characterized by force, power and strength, while today information, intelligence and system integration are emerging as the key words for characterizing our modern information-driven machines. The frontier of mechanical engineering has now shifted from developing power-driven machines (muscle-substituting machines) to information-driven machines (brain-substituting machines).

Mechanical engineering has been a discipline whose framework is based on applied mechanics, which includes solid mechanics, fluid mechanics, thermodynamics and machine dynamics, all which are part of the natural sciences. The engineer uses the applied mechanics to analyze, predict and design the behavior of machines. In the past mechanics-oriented courses and design practice constituted the substance of mechanical engineering education. Also included were a number of courses which dealt with the state-of-the-art of individual machines such as internal combustion engines, pumps, compressors, turbines, electric motors and generators, ships, airplanes and automobiles.

With the growing importance of information-driven machines such as manufacturing robots, NC machines, energy-efficient automobiles, etc., new demands and requirements for mechanical engineers are emerging. These requirements focus on the development of 'artificial' science. 'Artificial' science, or emulative science, deals with the logic and methodology for the optimization of intelligent activities. It is the creation of human intelligence and is essential for the duplication by machines of intelligent activities such as sensing, data transfer and analysis, processing architecture, interface with CPUs and operating software. In this sense artificial science is the basis for brain-substituting machines.

The new mechanical engineering is symbolically shown in Fig. 10. The classical power-driven machine is now changing to an information-driven machine, based on artificial science.

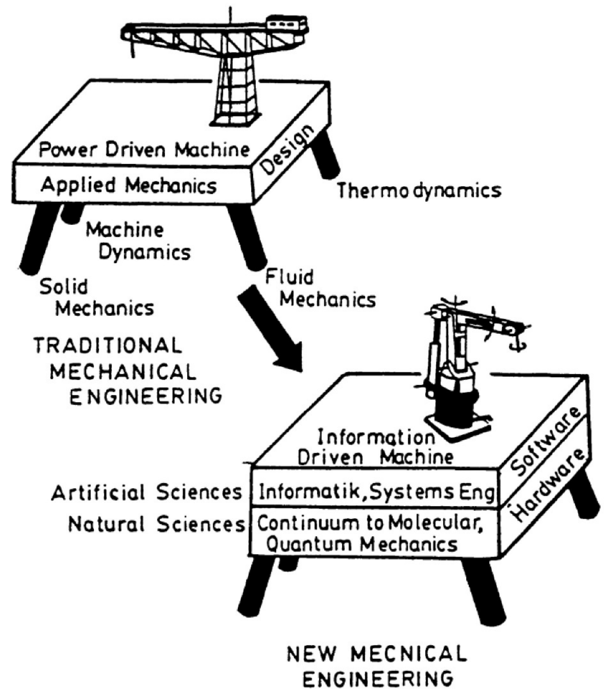

Fig. 10. Illustration of concept in traditional and new mechanical engineering.

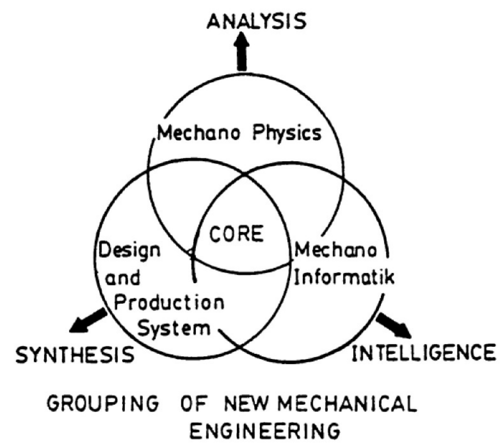

Fig. 11. New mechanical engineering course of study at the University of Tokyo.

NEW MECHANICAL ENGINEERING COURSE AND CURRICULUM

While the traditional 4-year mechanical engineering curriculum is based on the core of applied mechanics and design practice, the new mechanical engineering curriculum requires more than adding courses. The alternative approaches are:

- Introduce new educational courses of study.
- Drop and add specific courses.
- Extend the period of study past 4 years.
- Develop a narrower field of specialization.

The first approach was finally adopted. Figure 11 illustrates the core curriculum and the division of the mechanical engineering students into three groups.

1. Mechano-physics: analysis of physical phenomena as well as energy generation, conversion and its effective utilization.
2. Design and production: synthesis for creation of machines and systems.
3. Mechano-informatics: information and control to improve intelligence of machines and their coordination into user friendly objects.

The course of study are briefly outlined in Tables 1 and 3 for each year of study. As discussed earlier [3], the minimum period of study is eight semesters in 4 years for the BSE degree. At the University of Tokyo, the student's first three semesters are used to complete a course of general studies, and the following five semesters are used to complete the speciality courses such as mechanical engineering.

Table 1. New mechanical engineering courses 1991 at the University of Tokyo (second year)

Lecture	Course		
	Mechano-physics	Design production	Mechano-informatic
Fourth semester			
Mechano-molecular engineering	R	R	R
Solid mechanics	R	R	R
Fluid mechanics I	R	R	R
Applied thermodynamics	R	R	R
System dynamics	R	R	R
Mechanism and information	R	R	R
Software I	R	R	R
Introduction to ME	R	R	R
Engineering mathematics 1	R	R	R
Electrical and electronic engineering 1	R	R	R
Introduction to instrumentation	—	—	—
Metallography	—	—	—
Machine design practice 1	C	C	C
Mathematics and Dynamics Seminar	R	R	R

C, compulsory; R, strongly recommended; —, free elective.

Table 2. New mechanical engineering courses 1991 at the University of Tokyo (third year)

Lecture	Course		
	Mechano-physics	Design production	Mechano-informatic
Fifth semester			
Machine dynamics	R	R	R
Production technology	R	R	R
Machine design and element	R	R	R
Automatic control 1	R	R	R
Mechano-thermophysics	R	—	—
Structural systems engineering	R	—	R
Fluid mechanics 2	R	—	R
Heat transfer	R	—	R
Experiment and measurement	R	R	—
Mechatronics 1	R	—	R
Software 2	—	—	R
Numerical analysis	R	—	R
Engineering mathematics 2	R	—	R
Electrical and electronic engineering 2	R	—	R
Machine design practice 2	R	—	C
ME seminar 1	R	R	R
Experiment in ME 1	C	C	C
On-site factory practice	—	C	R
Sixth semester			
Mechano-solid physics	R	—	—
Strength design	R	—	R
Fluid mechanics 3	R	—	—
Energy systems engineering	R	R	—
Internal combustion engine	R	—	—
Vibration and waves	R	—	—
Mathematics for ME	R	—	—
Machine and aesthetics	R	—	—
Creation of machines	—	R	R
Informative production systems	—	R	—
CAD–CAM	—	R	R
Systems management	—	R	—
Automatic control 2	—	R	R
Mechatronics 2	—	—	R
Software 3	—	—	R
Information systems 1	—	—	R
Human interface	—	—	R
Computational mechanics 1	—	—	R
Electrical and electronic engineering 3	—	—	—
Engineering mathematics 3	—	—	—
Machine design practice 3	—	C	R
ME seminar 2	—	R	R
Experiment in ME 2	C	C	C
Experiment in electrical and electronic engineering	—	—	—

C, = compulsory; R, recommended; —, free elective.

Table 3. New mechanical engineering courses 1991 at the University of Tokyo (fourth year)

Lecture	Course		
	Mechano-physics	Design production	Mechano-informatic
Seventh semester			
Mechano-optophysics	—	—	—
Structural optimization design	—	—	—
Turbulence engineering	—	—	—
Combustion engineering	—	—	—
Energy-conversion machines	—	—	—
Tribology	—	R	—
Advanced manufacturing techniques	—	R	—
Overview of industries	—	R	—
Industrial systems	—	R	—
Design engineering	—	R	—
Automotive engineering	—	R	—
Automation	—	R	—
Vehicle dynamics	—	R	—
Robotics	—	—	R
Micro-intelligence machine	—	—	—
Advanced software	—	—	—
Signal and image processing	—	R	—
Information systems 2	—	—	R
Bio-systems engineering	—	—	R
Computational mechanics 2	—	—	—
ME seminar 3	—	—	—
Topics in ME	R	R	R
Graduation thesis 1/2	C	C	C
Eighth semester			
Function of bio-systems	—	—	—
Security engineering	—	R	—
Systems planning	—	R	—
Graduation thesis 2/2	C	C	C

C, compulsory; R, strongly recommended; —, free elective.

In examining Tables 1–3, the core curriculum is completed in the fourth and fifth semesters. This enables the mechanical engineering students in each group to study a number of strongly recommended courses (students must pass more than 75% of strongly recommended courses) in the remaining semesters before their graduation. This reduction in the compulsory courses and expansion of the student's freedom to select courses in other disciplines are considered an important element in this new mechanical engineering course. In a subsequent paper, a more detailed discussion of the courses and the student's interaction will be presented.

CONCLUDING REMARKS

The technological information revolution has created a number of fundamental changes in Japanese industry and now education. The role of mechanical engineering in developing machine-based heavy industry is now evolving into one of creating industries in high technology. This has become an important element in not only traditional engineering and manufacturing industries, but also in service industries, such as banks, trading companies and software manufacturers. The previous approach of a student following a mostly prescribed mechanical engineering curriculum was found to be too rigid for the present situation. Instead the new mechanical engineering curriculum features 25% core courses and 75% selective courses designed for each group of students. This reflects an unprecedented change in the formation of Japanese mechanical engineers. It is a development that engineering educators throughout the world will find interesting when evaluating the suitability of their present engineering curriculum to prepare engineers for the 21st century.

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