CHEMICAL ENGINEERING EDUCATION IN JAPAN AND THE UNITED STATES

*A Perspective**
PART 1

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RECENTLY, CONCERN AND interest in the United States about Japanese technological and managerial "excellence" has been very high, as evidenced by numerous books and articles [1]. It is plausible that Japan's success in commercial technological development is intimately related to the Japanese educational system [2]. Hence, it is of interest to compare the university training of scientific personnel in each country, to see how strengths are nurtured. As one who has experienced an undergraduate education in Japan (Tokyo Institute of Technology, 1976-1980) and a graduate education in the United States (University of Wisconsin, 1980-1986) in chemical engineering, I will attempt to distill my personal experiences and observations into such a comparison. In addition to curriculum content at the institutions I attended [3] I will focus on some of the broader societal and cultural factors determining the educational environment. Finally, I will discuss some advantages and disadvantages that each educational system appears to possess and attempt to infer where opportunity for learning from each other might exist.

THE ENTRANCE EXAMS

No discussion of undergraduate education in Japan would be complete without mention of the entrance examination system. In Japan both the private schools

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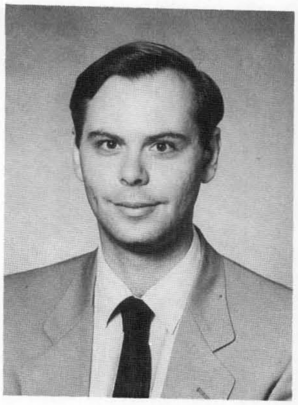

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as well as the prestigious national universities have their own entrance exams, and, in addition, there is currently a standard screening exam for all of the national universities. In Japan, it is widely recognized that career opportunities in most major companies are largely determined by the university to which the person gains admittance. For this reason, the competition to pass the extrance exams for prestigious universities such as Tokyo University, Kyoto University, Tokyo Institute of Technology or Waseda (the last a private school) is intense, with applicant ratios as high as five to one. Competition also begins early, as students endeavor to gain admittance to high schools which have good records of producing entrants to the prestigious universities. Many students essentially sacrifice their high school leisure time, attending preparatory schools (*Juku*) at which supplementary homework is given after their regular school day and on weekends. The level of the entrance exams varies widely, but for a prestigious university may be considered to be at roughly the college sophomore level in the U.S. in areas such as mathematics, physics, chemistry, and written language. While many of the

*The views expressed herein are the author's and not those of Exxon Corporation.

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exam problems are extremely complex, there is a tendency on the part of the students to study problem types by rote, using commercially available booklets of previously given exam problems. Students who fail their exams for a prestigious university on their first attempt often spend an additional year in preparatory school as *ronins* (wandering samurai) to get another chance to take the exams. This activity is generally supported monetarily by their parents.

UNDERGRADUATE EDUCATION

The highly competitive entrance exam system guarantees that the prestigious universities get the cream of the high school crop, at least in terms of motivation and stamina. In addition, the almost uniformly high quality of precollege education in Japan (the product of a highly standardized curriculum) means that the entering class possesses a significant head start in scientific knowledge over matriculating U.S. students. For this reason, no classes are offered in algebra or trigonometry, for example, in major Japanese universities (calculus is taken in high school). Nor is there a need for courses to develop written skills in the students' own language. However, from the foregoing description of the gruelling exam procedure, which looms over the students' entire high school experience, it is not surprising that undergraduate college is regarded in Japan as a time for rest and play by society as a whole [2]. This leads to a totally different attitude towards classes and coursework in the U.S. and Japan, which partially nullifies the starting advantage held by Japanese students. In contrast to U.S. practice, Japanese students generally receive very little homework, and what there is tends to be composed of rote problems, often similar to textbook examples. There is extensive plagiarism of homework solutions by perhaps one third of the class, so that differentiating grades on the basis of homework is almost meaningless. Class cutting is common, especially in the non-major courses, as is lack of attention (talking, *etc.*) to a degree that would be considered intolerable by American professors. While exams are more formal, students are rarely failed in courses. Indeed, for mediocre exams, points are sometimes added on for the purpose of allowing students to make the grade (the colloquial expression for this is *geta-hakase*—"putting on the clogs"). While in the U.S. this situation would be considered to reflect on the credibility of the institution, this is not the case in the Japanese cultural context, which does not place a high premium on individual achievement. It is important to remember that in Japan, seniority generally counts at least as much as performance in career advancement, and decision-making is collective rather than on the initiative of individuals. Since the basic "weeding out" process is the entrance examination, a person's performance in college is less important than the college attended in Japan. Furthermore, because Japanese companies expect that their employees will remain with them for the duration of their lives, they provide extensive formal and informal training for employees newly hired from college. The formal training stresses company unity rather than technical aspects, which are picked up later through mentor-pupil relationships similar to those which occur in graduate school. For example, in some companies, new employees are grouped in rural locations for programs of daily calisthenics and sports, as well as seminars and indoctrination. Typically, technical graduates then go through an apprenticeship period of several months, during which they are rotated through such diverse assignments as shift work or retail sales. By contrast, most U.S. firms emphasize "on-the-job training," with the assumption that sufficient mastery of basic skills in the relevant technical field has been attained. Despite this, in the United States, geographical, educational, and political factors necessitate that even good universities (especially state schools) accept large numbers of relatively poor students, who are eventually weeded out. In this process, students are deluged with homework, lab reports, and exams, and grading is generally rigorous, with high standards and at least some analytical thinking ability expected. Thus, the situation in the U.S. is just the reverse of that in Japan—a mediocre performance at a good school is not especially helpful for employment.

Another likely important factor in the difference in motivation between Japanese and U.S. undergraduates is the degree to which each group is self-supporting. Unlike the U.S., where it is the norm for university students to live away from home, in Japan, whether a student lives at home or not is generally determined by how far he must commute to attend school. Many students commute from as far as two hours distance, spending a significant fraction of that time standing in packed trains. Even when Japanese students do not live at home, it is common for their parents to pay all educational expenses, plus a fairly liberal allowance. Japanese university students often work as private tutors, earning as much as twenty dollars an hour (the pay frequently determined by the prestige of the student's university!). This money would normally be regarded as pocket-money, rather than as a contribution to educational expenses. These customs are, of course, linked to the still prevalent tradition of living with and supporting one's parents after the father's retirement. When this is contrasted to the situation of a typical American student, who works for long hours at a university co-op or fast-food restaurant to support his or her basic needs, one can easily see why the degree of seriousness towards undergraduate coursework is quite different.

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While the American student likewise regards undergraduate college as a time for play, it is also recognized as a time for personal and career development. Certainly, in both countries, the best students are highly motivated and conscientious. The contrast is that in Japan the top students study mostly on their own initiative. American students, on the other hand, are force-fed material and expected to become competent in it or fail, dependent on their innate ability. An unfortunate side effect of this approach is a tendency, noticeable to anyone who has been a teaching assistant in a class of seniors, for graduating American engineers who dislike their field. The aspirations of most seniors, including the best performers, are to move away from technical work into management as quickly as possible, and a career as a research scientist or engineer is frequently not even considered. Going on to graduate school is relatively unpopular, although the poor job market in recent years appears to be leading some seniors with bad employment prospects to consider it favorably. In the U.S. in 1986, the percentage of graduating chemical engineering seniors continuing directly to graduate school was 16% [4], probably including a significant number of MBAs. However, the ratio of graduating Master's and PhD students to Bachelors in 1986 was 31%. Apart from yearly enrollment trends [4], this is at least partially due to students returning from industry, and students who enter graduate school in chemical engineering from other fields (particularly chemistry). In contrast, in engineering departments of prestigious universities in Japan, it is common for more than 50% of the graduating class to continue directly to graduate school in the same department. It is also rare for Japanese engineering students to voice an interest in management while still in school. This is probably due as much to the societal respect for the profession of engineering as to the inevitability of slow career advancement under the lifetime employment system.

UNDERGRADUATE CURRICULA

It is interesting to examine undergraduate curricula for chemical engineers in Japan and the U.S. In Japan, as in the U.S., the undergraduate degree (Bachelor of Engineering) requires four years of study. At Tokyo Institute of Technology, the school operates on a two-term system, the first term from April to September (with a two-month summer vacation) and the second from October to March (with a winter break). At Tokyo, the freshman year consists of basic courses in the natural sciences (including lab courses), social sciences, humanities, and languages. It is worth stressing that Japanese students in all engineering fields are required to take language courses, even though they arrive at the university with six years of English study completed. At Tokyo Institute of Technology, there is a *de facto* requirement for four English courses, as well as three courses in another language (German, French, or Russian). In addition, the first year includes an overview of areas in the major field presented by different faculty members. At Wisconsin, as at other institutions, the first year mix is much narrower, consisting of natural science "catch-up" courses (calculus, general chemistry, and freshman English) with only three elective credits available.

In the sophomore year, the student at each institution begins to take a significant number of courses in the major area. Table 1 contrasts the required courses in the *major field* for the Bachelor of Science Degree in Chemical Engineering at the University of Wisconsin with the Bachelor of Engineering Degree at Tokyo Institute of Technology, as of 1987 [3]. It is evident from this list that there is considerable overlap in the "core" courses which constitute the degree. Indeed, the differences between the curricula of the departments are probably due more to departmental culture than national emphasis, *e.g.*, the requiring of transport phenomena-related courses at Wisconsin. However, the overall flavor and certainly the content of the courses at Wisconsin is more mathematical and analytical, whereas the accent at Tokyo tends towards the chemical and empirical. The U.S. curriculum relies heavily upon the chemistry department for chemistry instruction, which is not the case at Tokyo. In fact, it is usual for Japanese departments to provide almost all their own instruction, with ties between departments (even those as closely related as chemistry and chemical engineering) being almost non-existent. Although the same number of lab courses appears in the table, Tokyo Institute of Technology has a *de facto* requirement for additional freshman labs in chemistry and physics. Furthermore, the Japanese lab courses involve at least ten hours per week of actual lab work (three days per week). Thus, the Japanese student's exposure to lab work, prior to the senior year, is already higher than that of the average U.S. undergraduate (Wisconsin requires more lab work than many U.S. schools). One should also note the presence of courses intended to familiarize the student with the scientific literature. This type of instruction, coupled with the extensive training in foreign languages, ensures that the Japanese graduate can make full use of the U.S. technical literature, whereas the converse is certainly not true. Although Wisconsin is a rarity in offering a course in technical Japanese [5], there is no foreign language requirement for graduation, and many U.S. Bachelors graduate without taking a single language course. In addition to the courses listed in the table, the graduate at Tokyo must take several other departmental courses in areas of interest as a graduation requirement. These include titles such as Catalyst Chemistry, Separations Science, Environmental Chemical Engineering and Theory of Instrumental Analysis. Typically these courses are overviews, requiring even less assigned work than the "core" courses. At Tokyo Institute of Technology, course requirements are basically completed by the end of the junior year, which is feasible due to the relatively low workloads (the usual courseload is eight to ten per semester). While the number of courses required for graduation is around sixty-five at Tokyo (approximately half in the major field), compared to about forty at Wisconsin, the Japanese engineering undergraduate enjoys a surprising amount of freedom in shaping his or her education. By contrast, American students are very constrained in their ability to broaden their background by the pressures of the required courses in and outside of the department, which constitute around 75% of the credits required for graduation. Examination of the curricula for the University of Minnesota and the University of California at Berkeley revealed similar trends.

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TABLE 1
Major Courses Required for ChE Degree

University of Wisconsin	Tokyo Institute of Technology
Physical Chemistry Lab[c]	ChE Lab I (Phys. Chem.)
Intro. Org. Chem. Lab[c]	ChE Lab II (Org. Chem.)
Operations and Process Lab	ChE Lab III (Unit Ops.)
	ChE Lab IV (Org. Chem.)
	ChE Colloquium I[l]
	ChE Colloquium II[l]
Transport Phenomena Lab	
	Special Lectures in Appl. Chem.[r]
Intro. Organic Chem.[c]	Indust. Organic Chem. I[r]
	and 12 among the following 15
Intermed. Organic Chem.[c]	Indust. Organic Chem. II
	Indust. Organic Chem. III
	Funds. of Chem. Eng.
Physical Chemistry[c]	Indust. Phys. Chemistry I
	Indust. Phys. Chemistry II
Transport Phenomena	
Chem. Process Calcs.	ChE Stoichiometry
Thermodynamics	ChE Thermodynamics
Momen. and Heat Trans. Ops.	Mechanical Operations
	Heat Transfer Operations
Mass Transfer Operations	Mass Transfer Operations
Chem. Kinetics and Rctr. Design	Reaction Engineering
Algebraic Lang. Programming[cs]	ChE Information Proc.
Process Design	ChE Equipment Design
Proc. Dynamics and Control	
and 1 of following 2	
Chemical Engineering Materials	Materials Science
Polymer Science and Technology	Fund. of Bioengineering

*At Tokyo, other courses in the natural sciences, humanities, foreign languages and physical education are required for graduation, as well as thesis research. At UW, there are several required courses in math, general chemistry and physics as well as a 15-credit liberal studies requirement. However, there is no specific requirement for foreign language physical education, or research.
[c]Given by Chemistry Department
[cs]Given by Computer Science Department
[l]Literature survey course
[r]Recommended

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THE SENIOR YEAR

Although the first three years of the Japanese undergraduate experience are relatively undemanding by U.S. standards, this changes completely in the senior year, which is devoted almost entirely to the student's undergraduate Thesis Project. At the beginning of this year, the student joins one of the department's research laboratories and begins to work full time as a junior researcher, receiving training and guidance from the senior members of the lab. Usually, there is a mentor-pupil relationship with a specific graduate student or research associate, and the undergraduate is expected to do data-gathering and follow-up work under this person's supervision, rather than work on something completely original. Nevertheless, after a year of work, most students produce a fairly good quality thesis, and the student gives a defense to the assembled faculty. The most important consequence of this training is that the student is directly exposed to research practice and the scientific method. This gives the average Bachelor's graduate a healthy respect both for graduate school and for research as a career. Another significant benefit is that the student generally acquires hands-on experience with several analytical and experimental techniques as well as with building equipment. In addition, from a more Japanese viewpoint, the student becomes conditioned to a rigorous work schedule, similar to that in Japanese companies. Typical hours of work are 9:30 AM to 9:30 PM, the maximum feasible in view of the long commuting times (students in lodgings close by often work later). The whole lab also works on Saturdays, until at least late afternoon*. While the Chemical Engineering Department at UW offers elective credits for working on undergraduate research projects, there is no stated or unstated requirement to participate in research. Relatively few students choose to elect research credits, especially since the junior and senior years consist of very rigorous and time-consuming major courses. Interestingly, a recent article suggests that participation of undergraduates in research is encouraged more at certain liberal arts colleges, which produce a significant number of publications coauthored by undergraduates, than at the major research universities [6]. On the other hand, motivated U.S. students can and do acquire significant practical experience through summer jobs and co-op programs. This is rarely the case in Japan, where companies feel no incentive whatsoever to train short-term employees.

*Needless to say, these statements are based on my own experience in Prof. Nobuo Ishikawa's fine laboratory. However, my interactions with graduates from other universities suggest that my experience was typical for undergraduates in technical fields.

THE SOCIETAL VIEW

To digress for a moment, an important benefit of receiving an engineering or scientific training in Japan is its social status. The Japanese public sees engineering and technology as having conferred great economic benefits to society, and the cynical negativism towards technology that is common in the U.S. and Western Europe is almost nonexistent. While respect for teachers is a trait of Japanese society as a whole, professors in the sciences and engineering enjoy particular respect, perhaps symbolized by their frequent portrayal as heroes in children's TV cartoons. Consistent with this, the relationship between professors, engineers, and social activists (*e.g.*, environmentalists) is rather less adversarial and more easygoing in Japan. Despite close ties between industry and universities, professors are generally not viewed as partisan in environmental issues, but rather as mediators. The general respect for the scientific professions rubs off onto industrial professionals, graduate students, and even undergraduates of prestigious universities. Interestingly, this is true despite two major "technological" events that have left a profound impression on the psyche of both Japanese scientific personnel and the public at large: the dropping of the atomic bomb and the tragic Minamata pollution case. These events are generally blamed on military personnel and greedy businessmen, respectively, with scientific and technical personnel escaping relatively unscathed. In fact, in the university, it is recognized that environmental problems are the responsibility of engineers to solve, rather than problems to be avoided or covered up. Thus, while there is little formal training in environmental or safety issues, such issues (*e.g.*, Minamata) are frequently and openly mentioned by professors in Japan. This is in sharp contrast to the U.S., where engineering is generally not perceived idealistically, even by its practitioners. Classes in the U.S. are usually devoid of commentary on sociotechnical issues, being wholly composed of the technical nitty-gritty. It is ironic that U.S. companies are forced by regulatory agencies and the public to be very attentive to such issues.

One area in which Japanese technical education is sorely lacking is the presence of women. At Tokyo Institute of Technology in 1976, for example, out of approximately 120 matriculating students in applied chemistry fields there were no women; in some years since then there have been two or three. This is not due to formal restrictions, which are unnecessary, since at the present time women do not enjoy career opportunities in technical or managerial roles comparable with males in Japanese firms. Naturally, this and other social pressures (*e.g.*, prejudice against married women working outside the home) strongly discourage women from pursuing technical careers. The highly ingrained cultural factors barring the participation of women in the professional work force in Japan are not likely to diminish rapidly, despite recent legislation directing equal pay for equal work for men and women by the Japanese government. The same is true for the members of Japan's small minority groups (people of Korean descent, Ainus and inhabitants of former "outcast" villages), *i.e.*, while there are no formal restrictions on their participation in university education, their career opportunities are severely limited.

The United States is far ahead of Japan in bringing women into the scientific and technical mainstream. Thus, women have increased their share of doctorates in science and engineering fields from under 10% in 1970 to more than 25% in 1985 [7]. Although women continue to be underrepresented in engineering, earning 6% of the doctoral degrees, the percentage of women bachelors graduates in engineering is higher (around 30% at Wisconsin in 1986), so that continued improvement in women's representation in the profession may be anticipated. On the other hand, the situation for minorities in the U.S. has improved less rapidly, and must be viewed as a fundamental fairness issue [8]. Recent statistics show, for example, that blacks constitute only 2.6% of graduating scientists and engineers at the bachelors level, and only 1.1% of PhD's [7]. Unfortunately, the highly politicized debate on the status of American education in 1986 gave relatively little attention to the issue of minority participation. Although to rectify the current situation much needs to be done by society as a whole, universities should not waver in their attempts to draw and retain more women and minority students into science and engineering programs [8]. If one takes into account the fact that the U.S. actually graduates fewer engineers per capita than either Japan, our major trading competitor, or the Soviet Union, our main ideological competitor [9], it is clear that enhanced participation by these groups is not only requisite, but also that it need not cause "reverse discrimination" issues.

EDITOR'S NOTE: This comparison of U. S. and Japanese chemical engineering education will continue in the next issue of Chemical Engineering Education with Dr. Floyd's discussion of graduate education in both countries.

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