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CHEMICAL ENGINEERING EDUCATION IN JAPAN AND THE UNITED STATES

*A Perspective**

PART 2

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GRADUATE EDUCATION in Japan and the United States differs significantly due to cultural/ societal factors. The most obvious difference is the disparate importance of the Masters and PhD degrees in the two countries. In the U.S., many universities allow the student to pursue the Doctoral degree without first obtaining the MS, but there is no fixed period for either degree. In the case of the PhD in particular, the primary requirement for graduation is generally perceived as "satisfying one's adviser." In Japan, there is a fixed duration of two years for the Master's and three additional years for the Doctoral degree. These fixed durations are important because, in contrast to U.S. practice, Japanese companies strongly prefer to hire all their new graduates at the same time of the year in order to facilitate group training. In the U.S., the Masters Degree, although seen as a useful extension of undergraduate work, is not particularly prestigious. In Japan, on the other hand, the Masters Degree students who unlike their U.S. counterparts generally have three solid years of research experience (counting the undergraduate senior year), are welcomed by Japanese industry as having the correct mix of broad and specific knowledge. This is due, at least partly, to the myopic specialization that is expected of doctoral students in Japan, evidenced by the differences in graduate course requirements. Most U.S. graduate schools have a formal minor requirement which necessitates passing several courses outside the major department. In Japan, the general atmosphere does not encourage such forays into new knowledge at the graduate level. In fact, graduate courses are kept as free of work as possible, in order to maximize the time available for research. The focus on one narrow area is reinforced by the fact that the graduate school almost exclusively retains its own undergraduates, who simply remain in the same lab in which they complete their undergraduate Thesis Project (the type of crossover from other disciplines that occurs in the U.S. is very rare). Doctoral students

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generally elect an academic career, continuing at the institution of their graduation*. Eventually, some of these "research fellows" move into vacated slots for assistant professors, while others stagnate or move out to industry. At the national schools, which are the primary research universities, each assistant professor slot is tied to a senior professorial slot in an administrative unit known as a *koza*. The realm of investigation of the *koza* is quite sharply defined, and hence assistant professors are not free to do research in any realm of choice, as they are in the U.S. In fact, the assistant professor is usually "mentored" by the senior professor throughout a significant part of his career. The creation of new *kozas* is overseen by the Ministry of Education, with each *koza* receiving an identical amount of funding from the government. Room for individual initiative under the Japanese system is much less than in the American system, in which schools prefer to bring in "new blood" from other institutions.

Japanese graduate students put in essentially six days of lab work per week, spending less than around 15% of their time on coursework. Although the gruelling lab routine leaves little time for pursuit of outside interests, the Japanese graduate school is not an unpleasant social experience. The members of the lab group, who are usually crowded into small laboratories, share a strong sense of camaraderie, enhanced through interactions such as drinking parties and summer trips to resort areas (it is very uncommon for Japanese graduate students to be married). This constant fellowship provides an outlet for stress and facilitates research discussions and mutual assistance among students. Formal research meetings involving the entire group are frequent, and except for the very newest members of the group (the undergraduate seniors), suggestions and observations may be made by anyone, in the best scientific tradition. In the U.S., the quality of the graduate school experience is probably less uniform. For a small but significant percentage of students, it turns out to be a nightmare, due to factors such as capricious advisers, an unsympathetic bureaucracy, and an overload of teaching duties. Considerable dissatisfaction also results from the fact that the student could be earning a much larger income in private industry. In contrast, graduate students in Japan generally receive *no* financial support and have minimal teaching duties, continuing for the most part to live at home or at the expense of their parents*. In addition, the relatively low starting salaries at all levels and the high degree of respect for graduate students by society largely eliminate the psychological handicaps suffered by graduate students in the U.S., where social status is primarily determined by income. A substantial fraction of an American graduate student's time is spent on coursework and teaching duties. In research, U.S. graduate students tend to work independently of others and also tend to work in "spurts," alternating between feverish and relatively relaxed periods. In addition, U.S. students are accustomed to enjoying a broader spectrum of social activities (*e.g.*, clubs, religious groups) than their Japanese counterparts. In Japan, peer pressure to conform to the standard work hours of the lab, mentioned in Part 1, is quite intense. Through close supervision, gossip, and innuendo, an atmosphere is created in which shirking is very unfavorably regarded, and in an extreme case a member might be ostracized by the group. Because of these differences in work habits and other cultural and language differences, it is rather hard for a foreign student to be successfully assimilated into a Japanese laboratory. Foreign students are generally incapable of fully taking part in the regular group activities, both professional and social, and many suffer from feelings of isolation (almost all foreign students are accepted on a case-by-case basis, and hence are present in far fewer numbers than on U.S. campuses). From personal observation, I would recommend that any student who wishes to experience working in a Japanese laboratory should at least have a rudimentary knowledge of spoken Japanese, be willing to work long hours, and be outgoing enough to participate in group activities. Being unmarried is preferable. While I would not rule out the possibility of a valuable experience for a female student, she should be prepared to deal amicably with a likely all-male environment and a strongly male-oriented culture.

In contrast Japanese students in American universities generally seem to adjust very well. There is a tendency, as in the case of other foreign nationals, to

*There are signs that this situation is beginning to change, with doctoral degrees now in strong demand at some major companies.

*A few scholarships, mostly in the form of repayable loans, are available for the economically disadvantaged.

socialize with other Japanese and form support networks. This sometimes results in less interaction with American students than is desirable. However, the large numbers of Japanese students, faculty, and company personnel* who participate in the U.S. educational system ensure that Japan has an opportunity to learn from and absorb the strongest parts of the American system. Unfortunately, the reverse is not true; the number of American engineering students and faculty who participate in some form of educational experience overseas, particularly in Japan, is too small.

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CONCLUSIONS

In both Part 1 and Part 2 of this paper, I have attempted to convey the *flavor* of receiving a scientific education in the social cultures of Japan and the United States. It should be clear that cultural factors loom very large in determining the educational experience, and hence, what is good in each system cannot necessarily or even desirably be transported to the other country. For example, American companies will undoubtedly continue to expect graduates who can plunge straight into their duties, while Japanese companies will prefer to shape and mold the roles of their employees. Nevertheless, it should benefit researchers, university administrators, science policymakers, and company managers in both the U.S. and Japan to have an awareness of these educational and cultural differences and to try and distill the best possible experience out of each system.

The Japanese educational system turns out large numbers of relatively uniform, highly trained, and rather idealistic graduates. Especially at the MS level, these graduates combine a fairly broad, though shallow, technical background with expertise in a specific area and a good understanding of research methods. They are hardworking and, equally important, experienced at getting things to work. These qualities make them suited to and easily assimilated into the predominantly applied research programs at Japanese companies. Furthermore, in contrast with the U.S., Japanese companies have no clearly defined technical and managerial ladders, and it is uncommon for employees to remain in an exclusively technical role throughout their careers. Thus, in the course of employment, the best of these graduates eventually occupy key managerial roles in Japanese corporations. (It has been estimated that around half of the directors of major industrial companies have an engineering background [1]). In the U.S., many managers who have BS or MS degrees in engineering have little or no experience in research. It is worth mentioning that there is no specific slanting of curricula in Japan towards manufacturing issues, in which Japan is often ascribed an almost mystical prowess by U.S. observers. However, it is difficult to overemphasize the importance of the research experience gained by Japanese Bachelor's and Master's students in instilling a feeling for scientific methodology and "doing things right," which is surely applicable to endeavors besides research. It is also plausible that the fundamental respect for and understanding of the research and development process (including staying abreast of the foreign scientific literature) on the part of Japanese technical managers has played a significant part in Japan's successes in adaptation and refinement of foreign technology, enabling competition with the U.S. in numerous technical fields.

On the other hand, it must be observed that the qualities of Japan's technical graduates are obedience and persistence, rather than independence and inquiry. Thus, one can point to numerous factors in Japan's educational system which will limit its stated goal of mobilizing the creative process. Among these are the lack of emphasis on originality, the often stifling level of supervision of projects at the lower degree levels, the tendency to overspecialize at the PhD and faculty level, and the lack of mobility between and within universities. While there is definitely a trade-off between advanced study in major and non-major fields and getting data for one's research project, the balance will have to be shifted somewhat if Japan is to produce graduates with multidisciplinary capability. Indeed, the multidisciplinary capability of American PhD students is probably one of the strongest features of the American educational system, which has translated to leadership advantages in non-traditional areas such as materials, biotechnology, and computers. However, one must never underestimate the Japanese capability for a focused re-

*Many Japanese companies and governmental agencies such as MITI send their employees to foreign universities to acquire a "broad perspective" as well as research and language skills, often with an MS degree as the formal objective. This is a prestigious assignment, and is rooted in Japan's long-standing tradition of learning from overseas.

sponse in such areas, once the basic work has been done and the potential is apparent.

Another area in which the Japanese system should seek improvements is in requiring more rigor in coursework; a system in which "getting by" is sufficient is detrimental to creativity. Last, but not least, the rigidity of the current *koza* system and its restrictions on initiative of younger investigators would seem to be in need of reevaluation in the light of Japan's desire to become a leader in new technologies.

In the United States, at the undergraduate level, the most transparent problem is the lack of significant research (or other practical hands-on) experience for the majority of the graduating class of engineers. Lab courses cannot make up for this failure. This results in an inadequate understanding of the scientific method of problem-solving on the part of Bachelors graduates, many of whom eventually go on to careers in technical management. In addition, at a time when the U.S. is struggling to maintain its technological position in several areas, it simply does not make sense to graduate engineers with little or no sense of what it means to do research. In the author's view, *at minimum*, a one-semester course equivalent (3 credits) of research should be a graduation requirement for the Bachelor's degree. In addition, the complexity and diversity of expertise that is required today would seem to point to a need for a greater number of courses, in both technical and non-technical fields. For example, in an age of international competition, there should be a requirement to demonstrate at least rudimentary proficiency in a foreign language.

There should also be some opportunities for discussion of broad social issues and how engineers and scientists can contribute to their resolution. The current adversarial relationship between technical problem solvers and people who perceive problems needs to be improved drastically. One possibility might be a requirement for attending seminars by visiting industrial personnel, regulatory officials, and representatives of responsible environmentalist organizations. A better understanding of the contributions of science and engineering to our national security and well-being would hopefully be an additional factor for student motivation, as it is in the Asian cultures of Taiwan, Korea, China, and Japan.

The ability to achieve such diverse objectives and still produce graduates of acceptable "drop-in" capability for American industry obviously requires better support from the basic educational system. Currently, the freshman year and part of the sophomore year in the U.S. are spent in acquiring a level of knowledge possessed by graduating high school seniors in Japan. The compression of a rigorous engineering curriculum into the remaining two years is undoubtedly responsible for "burnout," as well as the fairly general perception that engineers do not receive a well-rounded education, which in turn means that the least able graduates are unable to find jobs. Unemployment among graduating seniors, which has recently been as high as 20% [2], is one of the major issues confronting the profession in the United States. In contrast, in Japan, engineering graduates from prestigious schools are considered eminently employable in non-technical positions, and some go to work for trading companies or enter civil service.

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Concerning Japanese excellence in manufacturing, it is evident that this must be attributed to factors other than course requirements. However, in the U.S., manufacturing is currently acknowledged to be of relatively low prestige by many industrial managers. In order to partially rectify this situation, one solution would be for engineering schools to offer a "manufacturing specialty" option consisting of a focused group of courses in areas such as statistics, process control, engineering economics, and quality assurance, which are basic to manufacturing technology. This is neither excessive nor unrealistic, in view of the fact that some schools currently offer "options" or "emphases" in topics such as applied mathematics, biology, food science, microelectronics, and pollution control. By recognizing the value of this type of option through hiring practices, industry could stimulate a greater awareness of the importance of manufacturing among Bachelor's students.

At the graduate level in the U.S., attempts to streamline the PhD program should be implemented. While going to a fixed-duration system like that of Japan may not be appropriate, conscious efforts to enhance productive progress and shorten the duration of research projects so that a PhD is achievable in four years would be beneficial in encouraging pursuit of this degree by people whose objective is an industrial career. In attempting to streamline the degree, the broad interdisciplinary aspects of graduate study in the United States, a fundamental strength, should not be compromised, and perhaps could even be encouraged. For example, a student might be asked to submit a short proposal on extensions of his research to another field, which would be appended to his thesis with appropriate keywords for location by researchers who might otherwise never examine his or her work. For the MS degree, on the other hand, coursework is overemphasized, and a greater emphasis on research contributions would be desirable.

Both Japan and the United States have serious issues of access to higher education in technical fields for women and minorities. While the situation for women in the U.S. has improved significantly in recent years, in Japan the attitude toward women in technical and supervisory positions remains highly prejudicial. As the percentage of women in these positions in the U.S. continues to grow, discomfort will be experienced in cross-national dealings, *e.g.*, joint ventures. While change will be slow, it is to be hoped that Japan will eventually take its place among the leading societies in this regard. In the U.S., continuing efforts must be made not only to attract minorities and women into the scientific and engineering professions, but to deal with the fundamental causes underlying reduced participation by these groups.

In summary, although some would argue that each system serves the unique needs of its country adequately, comparing the systems of engineering education in Japan and the United States offers food for thought on possible improvements to each. While a significant number of Japanese students and faculty spend some time within the U.S. educational system, it is unfortunate that a much smaller number of Americans participate in the Japanese experience. It is to be hoped that in the future, more American students and faculty will view first-hand the workings of Japanese education. To stimulate this, it would be desirable for engineering departments of major universities to develop student and faculty exchange programs and to incorporate courses in Japanese language and technical Japanese into their curricula. In Japan, the focus for the future must be on stimulating creativity, while in the United States the educational system does not appear to wholly meet needs for research management capability and solution of pressing social concerns, including industrial competitiveness. In particular, concrete measures directed at increasing the prestige of manufacturing among engineering graduates may be warranted. While the job market for scientists and engineers frequently appears to be supersaturated, *stable* growth in scientific and engineering enrollments with production of good-quality graduates can be expected to benefit the nation in the long term. Both countries still face some very real issues of access and fairness. In the U.S., there is a clear need for professional societies to assist in monitoring statistics relating to women and minority enrollments. Finally, the nation's corporations can do their part by taking an active interest in education, promoting stable hiring policies, and maintaining affirmative action goals.

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interacting with high-quality students prior to graduation. The students benefit by interactions with industrial sponsors and by working on industrially-relevant research.

CONCLUSIONS

Thermodynamics and fluid properties research is a thriving activity at Georgia Tech. Although based mainly in the School of Chemical Engineering, there are joint projects with the Schools of Chemistry, Mechanical Engineering, and Applied Biology. There is also significant industrial participation via the Fluid Properties Research Institute. It is obvious from some of the work described that the need for thermophysical properties and for fundamental understanding of molecular behavior which determines these properties, will continue to grow as new technologies emerge and established technologies change.

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