Appendix B

Mathematics and Science Education in Japan, Great Britain, and the Soviet Union

During recent years, a steady stream of international comparisons of elementary and secondary education has painted an increasingly bleak picture of the deficiencies of American mathematics and science education. Depressing comparisons with teaching practices in Japan, Taiwan, Hong Kong, and South Korea have been seized on by many of those pressing for the United States to address its crumbling competitiveness. The source of competitive advantage is often referred to as "human resources" or "human capital''—skilled, talented, and flexible workers. For example, a recent commentary noted that international comparisons of mathematics education " . . . typically depict Korean 10-year-olds working out the Four-Color-Map Problem in their heads while Americans of the same age struggle to do double-digit multiplication without removing their socks. "[1]

Problems in Making International Comparisons

While international comparisons do point to significant differences in mathematics and science course offerings, curricula, and teaching, it is important to bear in mind two major problems in any sort of policy-oriented comparisons among cultures and countries:

- developing a sufficiently accurate explanation of the ***causes*** of observed differences, which are very often rooted in what are, to the outsider, opaque cultural and social differences in the roles of families, business, the State, law, and education; and hence
- determining what aspects of other systems could readily be ***appropriated and transferred*** across cultures and societies, and which would be foolish or even counterproductive to consider transferring.

For example, the United States could adopt a national curriculum, but such a move would be resisted strongly by many policymakers. Such a move would threaten the fragile compacts between national and local autonomy stipulated in the Federal as well as State constitutions. Further, a "national curriculum" would likely consist of little more than a lowest common denominator of topics defined by special interest groups and argued out line by line in highly partisan congressional debates. Rather than providing models to be emulated, the ultimate value of doing international comparisons may be to provide a kind of "mirror" in which to examine and better understand the reasons for well-entrenched, culturally rooted American educational practices and policies.

On an analytical level, it is difficult to make sound international comparisons in education unless studies are designed to compare "like with like" and to collect enough data to build a picture of overall educational capacity—teachers, students, and schools—in each country. In considering the high school students' exposure to mathematics and science, for example, it is important to note that the American school system is designed to retain all students to age 18 (and actually succeeds in enrolling about three-quarters of this group), whereas schools in other countries typically enroll a much more select group of students in the 14- to 18-year-old range.

These caveats aside, it is generally agreed that the American education system devotes relatively less time to mathematics and science education compared with other countries; estimates are that American students spend only one-third to one-half as much time on learning science as their peers in Japan, China, the U. S. S. R., the Federal Republic of Germany, and the German Democratic Republic.' Significant differences in the mathematical progress of children in selected cities in the United States, Taiwan, and the People's Republic of China **have** been found from the elementary grades. Japanese kindergarten children already surpass American children in their understanding of mathematical concepts.[3] It is evident that differences are across the entire educational system of each nation.

Japan

The country with which commentators most enjoy making international comparisons of mathematics and science education is Japan.' Japanese children study

'Edward B. Fiske, "Behind Americans' problems With Math, A Question of Social Attitudes, " New *York Times,* June 15, 1988, p. B8.

[2]F. James Rutherford et al., *Science Education in Global Perspective: Lessons From Five Countries* (Washington, DC: American Association for the Advancement of Science, 1985).

'Harold W. Stevenson et al., "Mathematics Achievement of Chinese, Japanese, and American Children, " *Science, vol.* 231, Feb. 14, 1986, pp. 693-699.

'The following is based largely on William K. Cummings, "Japan's Science and Engineering Pipeline: Structure, Policies, and Trends, " OTA confar more mathematics and science than American children, and more of them emerge from schools with a greater degree of scientific and technological literacy than do American children. Japanese institutions of higher education can draw from an exceptionally well-qualified crop of students. In addition, many go on to science and engineering majors; it is estimated that, in proportion to its population, Japan produces as many scientists and twice as many engineers as does the United States.

Japanese education resides within the cultural milieu of Japan. A well-known recent study explored the importance of families in mathematics education. While Japanese families considered poor performance in mathematics to be a consequence of lack of effort, American families more often attributed success to innate ability, despite poor teaching.[5]

Japanese students typically attend school for **240** days per year (compared with 190 in the United States), because they work a half day on Saturdays. It is believed that they spend a greater proportion of class time on academic activities. [6]

In elementary schools, the science curriculum includes matter and energy, living things and their environments, and the Earth and the universe. These themes are often reinforced by educational television programs broadcast by the Japan Broadcasting Association and coordinated with the curriculum.[7] Students often go on field trips with their school. It is widely reported that Japanese mathematics and science curricula demand more from their students than those in the United States: Japanese students simply cover more ground. Although Japanese and American elementary school students spend a similar amount of time on mathematics and science, from six to eight periods per week, the time is far more intensively used in Japanese schools.

Research data suggest that there is less variation among students in mathematics and science learning than in the United States. In part that is because Japanese elementary schools are not grouped or tracked by ability, and the use of mixed-ability cooperative learning groups, or *han*, is very common. But it is also due to the assumption that everyone can and must be competent in these subjects. A recent book notes that:

> It is simply taken for granted . . . that every child must attain at the very minimum "functional mathematics," that is, the ability to perform mathematical calculations in order to accomplish requirements successfully at home or work.[8]

Japanese lower secondary schools, which cover grades seven to nine, are similar to American junior high schools, but have few or no electives, Students are required to wear uniforms and adopt a more serious and disciplined approach to work than they had in elementary schools, There is still no sorting by ability, although the use of cooperative learning groups is rare. Upon completion of lower secondary schools, at the end of ninth grade, all students have taken some elementary geometry, trigonometry, algebra, and probability and statistics. They have devoted between 6 to 8 out of 30 weekly class periods to mathematics and science. In science, students take a variety of general science topics, including biology, chemistry, physics, and earth science. Teachers specialize in a subject area and teach only that area. The pressure to get into a good upper secondary school leads students in lower secondary schools to be highly competitive and neurotic, and the consequent pressure to succeed is often cited as a cause of teenage suicide. Many students attend out-of-school *juku*, which are coaching lessons that prepare them for examinations for entry to upper secondary schools, mostly concentrating on English and mathematics.

The final **3** years of school, upper secondary school, are quite different from the preceding 9. Entry to this level is on the basis of lower secondary school records and common entrance examinations administered by the local prefecture; schools can be highly selective, and there is considerable variation in the courses that students take. Attendance at upper secondary schools is voluntary, and tuition is charged. About **90** percent of young people attend them. Typically, several upper secondary schools serve students within a given neighborhood and there is a clear ranking of prestige among them. Some upper secondary schools specialize in academic-preparatory programs and other vocational programs; only about 30 percent offer both programs. [9] While the post-war reforms at first embraced

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tractor report, October 1987 See also U.S. Study of Education in Japan, *Japanese Education Today*, OR *87-500* (Washington, DC: U.S. Department of Education, January 1987); John Walsh, "U.S.-Japan Study Aim Is Education Reform," *Science, vol. 235*, Jan 16, 1987, pp. 274-275; Debra Viadero, "Japan and U.S. Release Assessments of Each Other's Education Systems," *Education Week*, Jan. 14, 1987, pp. 9, 19; Willard J. Jacobson et al., *Analyses and Comparisons of Science Curricula in Japan and the United States, Second IEA Science Study* (New York, NY, Columbia University Teacher's College, 1986); and Wayne Riddle, Congressional Research Service. "Public Secondary Education Systems in England, France, Japan, the Soviet Union, the United States, and West Germany: A Comparative Analysis," EPW 84-770, Issue Brief, 1984, pp. 16-21,

[5] Stevenson et al., op. cit., footnote 3, p. 697; U.S. Study of Education in Japan, op. cit, footnote 4, p 3.

[6] The amount of time spent on a subject is one, somewhat crude, indicator of the amount of learning in that subject. But the amount of learning also depends on the efficiency of that learning, which depends in part on the quality of teaching methods employed and, in the elementary years, the links with other subjects Learning in mathematics and science by elementary, school children depends in part on their reading and writing abilities.

[7] Tomoyuki Nogami et al, "Science Education in Japan—A Comparison With the U.S," mimeo prepared for the National Science Teachers Association 35th National Convent Ion, Mar. *27, 1987*, pp. *2-3*

[8] Benjamin Duke, *The Japanese School: Lessons for Industrial America* (Westport, CT: Praeger Special Studies, 1986), p. 82.

[9] U S. Study of Education in Japan, op cit., footnote 4, p. 41.

the neighborhood comprehensive high school principle, parents often lobbied officials to send their children to the better neighborhood schools and upper secondary schools now are definitely not equal.

Within Japanese upper secondary schools, students select a given course of classes, and it is very difficult to change course or take classes outside those specified for that course. There are few or no electives. Typically, academic-general and vocational-specialized courses are offered, although both often have common coursework in the first year. Within the academic-general course there is often a branch at the end of the first year of upper secondary school, at which point those planning science and engineering majors are separated from those planning arts majors. Students are often further sorted by ability levels within each course. About two-thirds of the students take academic-general courses, one-quarter take vocational courses, and the remainder enter specialized colleges of technology or training schools, or enter the work force directly.

Those planning science and engineering majors take a total of 102 credits over 3 years, of which 18 are in mathematics and 16 are in science; these credits include calculus, physics, chemistry, and biology. In grade 10, students spend 10 out of 34 hours per week in mathematics and science courses, rising to 14 and 18 hours in grades 11 and 12, respectively. In grade 12, the science-bound take 5 hours per week of integral and differential calculus as well as both physics and chemistry. In total, one-half of those in academic high schools are in science courses. Nevertheless, the core courses required for both the arts and the vocational-specialized courses are sufficiently demanding in mathematics and science that some students who have taken these courses can still compete for entry to college science and engineering programs. The uniformity of classes means that Japanese students have no equivalent of the advanced placement examirlations, and must all start with freshman mathematics science programs at college. The upper secondary school curriculum is very demanding, and some students fall behind and lose interest. The net effect is that, while the proportion of 22-year-olds that receive baccalaureates in the United States and Japan is about the same (23 to 24 percent), about one-quarter of these in Japan are in natural science and engineering as compared to 15 percent in the United States.

Japanese public upper secondary schools are complemented by a number of private upper secondary schools, in part because only a limited number of public schools were built after the war and the education in lower grades was emphasized. About one-quarter of upper secondary schools are private. While some of these schools are highly selective, others enroll those who failed to qualify for the limited number of places in the public sector. Public schools generally carry more prestige.

For the college-bound, the upper secondary years are extremely demanding as students prepare to take college entrance tests, In the Japanese system, there is well-defined ranking of higher education institutions and a student's decision to enroll in a particular institution will have, through contacts with students and professors, a great effect on his or her later career, job prospects, and life. The college education that students receive is relatively unchallenging. The great competition to enroll in the "right" university has created pressure for a very intensive academic curriculum and the extensive use of examinations to sort and prepare students for college entrance in the upper secondary school years. Students often take both the nationally administered First Stage Standardized Achievement Examination and examinations set by the particular university to which they are applying, These examinations test only factual recall and include no testing of skills with experiments and the process of construction of new scientific knowledge. In preparing for the examinations, students often enroll in *yobiko* which are similar to the *juku* at lower secondary level.

In many ways, it is ironic that the Japanese school system does so well in mathematics and science whereas the American system has problems, because Japan's schools were reorganized along American lines. The ultimate aim was to democratize and demilitarize Japan during the post-war American occupation. Japan's schools have also made good use of curricula and instructional material developed in America. Japanese schools are run by about 50 prefectural-level school boards and 500 local school boards which, unlike many of their American counterparts, are filled by people appointed from above rather than elected. The national Ministry of Education, Science, and Culture (monbusho) prescribes curricula, approves textbooks, provides guidance and funding, and regulates private schools. The prefectural boards of education appoint a prefectural superintendent of education, operate those schools which are established by the prefectures (primarily upper secondary schools), license and appoint teachers, and provide guidance and funding to municipalities. Municipal boards operate municipal schools, choose which textbooks to use from those approved by monbusho, and make recommendations about the appointment and dismissal of teachers to the prefectural board.

The cost of education is shared by the various tiers of government and, at later stages, by parents directly, The Japanese government pays about half of the cost, including some subsidies to private schools. Special budget equalizing regulations direct the central government to augment the spending of poorer districts up to a minimum level; there still remains a 60 percent variation in average per pupil expenditure among school districts. There is a uniform national pay scale for teachers, with a modest starting salary and steady annual increments that can triple a teacher's income after 20 years of service. Overall salaries are competitive with other occupations, and teaching is an attractive job; there are normally at least enough applicants for teaching positions, even in mathematics and sciences. Teaching remains one of the limited number of professional occupations that are readily available to women, but most teach only in elementary schools; only 18 percent of teachers in upper secondary schools are female. Most teachers have degrees in single academic disciplines other than education, although substantial numbers have no degree at all. Each prefecture and large city has an education center for its teachers, which provides inservice training and conducts educational research.

Curricula, in principle, are controlled by local school boards, but the central Ministry of Education sets standards in a "National Course of Study" and approves textbooks. In practice, it is believed that there is considerable uniformity of curricula. Curricula emphasize mastery of key subjects, such as mathematics and science, and make few concessions to individual learning styles, predilections, and idiosyncrasies. It is a belief in Japanese culture that creativity is only possible once fundamentals are mastered.

Just as Americans admire the uniformity and excellence of the Japanese system, many Japanese are searching for ways to make their system less monolithic and competitive, and more respectful of individual creativity, particularly as the country is now stressing the development of a basic research capability.[10] Japanese students are schooled to master factual material rather than analysis, investigation, or critical thinking. Teacher lectures from textbooks are very common, although considerable use is also made of laboratory work in science.[11] Similar programs of educational reform analysis and activity exist in Japan and the United States; the United States program is often taken as a model.[12] The Prime Minister's National Council on Education Reform called in September 1987 for the school system to put more emphasis on diversity and creativity, but the council has been split by internal controversy over the shape of possible reforms. It is believed that these calls may lead some prefectures to combine lower and upper secondary schools and to put a reduced emphasis on examination-based sorting.[13]

Great Britain

Most observers of Great Britain's system of mathematics and science education have concluded that it is very good for those who plan college study in science and engineering, but comparatively weak for the rest.[14] Students, by international standards, specialize at a very early age, and are offered few opportunities to shift interests. Preparation for examinations, which are externally set and assessed, is the dominant activity for those college-bound, Enrollment in higher education institutions is restricted both by financial mechanisms and fairly strict entry requirements, and the proportion of British 18- to 22-year-olds that enroll in college may be the smallest in any developed nation.

Like the United States, comparatively little science is taught in British elementary schools and there are few teachers qualified or motivated in the subjects. The emphasis instead is on mathematics. Most students begin science classes in one or more of the fields of physics, chemistry, and biology in the sixth grade, and continue them to the end of eighth grade. In grades 9 and 10, students choose a limited menu of courses to specialize in for the purposes of taking nationally administered school-leaving examinations (now known as the General Certificate of Secondary Education) at the end of 10th grade. Those college-bound in science and engineering might take six to eight subject exams, of which three or four are in mathematics and science subjects. Enrollment in grades 11 and 12 is voluntary, and is normally restricted to those preparing for nationally administered college entrance examinations (known as Advanced-level, or A-level) examinations. At this stage, students normally specialize in only two or three subjects, which tend to be related to each other, although proposals have often been made to expand this number in the interests of giving college students a "broader education. " In these grades, the science- and engineering-bound can take only mathematics and science subjects, if they choose.

Entry to colleges and universities in Great Britain is granted on the basis of grades and the number of passes awarded in the A-level examinations, and most

[10] The Japanese parallel to the U.S. Study of Education report is Japanese Study Group, Japan-United States Cooperative Study on Education, "Educational Reforms in Japan, " mimeo, January 1987, which studied aspects of U.S. educational reform that might translate to Japan, especially the transition between secondary and higher education.

[11] U.S. Study of Education in Japan, op. cit., footnote 4, p. 34.

[12] Ibid., pp. 63-67; and Walsh, op. cit., footnote 4.

[13] David Swinbanks, "Reform Urged for 'Hellish' Japanese Education System, " *Nature*, vol. 326, Apr. 16, 1987, p. 634.

[14] See Joan Brown et al., *Science in Schools* (Philadelphia, PA: Open University Press, 1986).

institutions make offers to students conditional upon their achievement of certain grades. A minimum of two passes in two subjects at A-level is normally required, and entitles the student to free tuition and access to a grant program for living expenses while at the university.

The Soviet Union

In many ways, the mathematics and science education system in the Soviet Union is similar to the American and British systems.[15] Each is a very uneven system, geared primarily to training those who will become professional scientists and engineers. The bulk of the school population learns relatively little and is left largely alienated from science and engineering. The extremes in the Soviet Union, however, are quite distinct. The layer of top quality students, which ranks internationally with the best, is very thin; there is a steep drop-off below that level.

The education system in the Soviet Union, like that in the United States, Great Britain, and Japan, is undergoing reforms. The impetus for these reforms is the new national desire to improve the efficiency of industry.

Soviet elementary and secondary education is split into three phases:

- primary or elementary education, grades 1-3
- "incomplete" secondary education, grades **4-8;** and
- "complete" secondary education, grades 9 and 10.

Most students complete eighth grade, normally achieved at age 15, and then choose among several different paths. Some continue in general education secondary schools and are most likely to enter higher education, while others enter the work force but continue their secondary education via evening or correspondence courses. Higher education is open to students from each of these routes, but most college students come from those who enrolled full time in general education secondary schools. A third path after eighth grade is to enroll in a technical or vocational school. These schools are primarily intended to train future skilled workers and technicians. For the most talented students, there are a number of specialized schools, often residential, some of which specialize in mathematics and science,

Entry to higher education in the Soviet Union is competitive, with an approximate oversupply of secondary school graduates of between two and three times the number of higher education places available. Admission to higher education institutions is primarily by means of examinations. Political considerations are often important, and students who participate in extracurricular social service activity, such as agricultural work, are often given some preference in admissions and award of stipends. Although only about 20 percent of students go on to higher education, about half of these are in science and engineering, with the effect that a larger proportion of each birth cohort graduates in sciences and engineering than in the United States.

Reforms in progress include a requirement for students to begin full-time education a year earlier, at age **6** rather than age **7.** The extra year will allow time for study of additional subjects such as labor education and computer science. At the moment, computers are very rarely used in classrooms, but their use has become a national priority. All students will have required courses in information science, but it is likely that many of these classes will be taught without hardware. To improve the skills of the work force, all students in general secondary education learn manual labor skills, even those who go on to higher education. The current phase of curriculum reform is designed to introduce less demanding, but more comprehensive, curricula in many subjects, including mathematics and science. This last step is ironic, because the intensity of the traditional mathematics and science curriculum is often praised by American commentators. More money is being allocated to education; teachers' salaries are being increased and merit pay arrangements are being introduced.

Under the reforms, closer links are being forged with both higher education institutions and local firms and enterprises. All schools are being paired with neighborhood factories and businesses: enterprises will be required to provide financial and material assistance to schools and hope to receive better trained workers, Many higher education institutions are signing agreements with secondary schools, under which college faculty will assist in secondary school teaching. Students will be given access to research facilities at colleges, and the colleges will admit a specified number of students to higher education. Research laboratories are also being encouraged to participate in such agreements. So far, 30 of about 900 higher education institutions have signed agreements of this kind. While reforms of this kind should improve the quality of education of future scientists and engineers, they will force students to specialize at a younger age, often 15 or 16, than has been the case.

As a further part of the Soviet reform program, more students will be encouraged to enter technically oriented vocational programs in grades **9** and 10 rather

"The following is based on Harley Balzer, "Soviet Science and Engineering Education and Work Force Policies: Recent Trends," OTA contractor report, September 1987.

than general education secondary programs. Although the training these students receive is supposed to be equivalent to that in general education secondary programs, this step will probably reduce the already oversubscribed pool of qualified high school graduates planning to enter higher education. College entry standards have also been tightened during the last **8** years, except in fields such as computer science, and biology, which have been targeted for expansion.

Conclusions

While mathematics and science education in other countries contains many features to be admired, including the commitment to these subjects, the emphasis on academic learning, and the geographical equalization of learning opportunities, each system contains some features that disturb many American educators. They include unswerving allegiance to the mastery of facts rather than creativity and individual expression and the extensive use of lectures. Other unappealing features are the limited number of women teaching in upper secondary schools, the central control over many aspects of teaching, and the teaching of science and technology literacy to a select few rather than the full cohort of students. Above all, many other countries have a greater degree of centralization in educational decisionmaking than exists in the United States. Schools and school districts need to identify practices that are transferable, but also need to be extremely cautious of the cultural and social assumptions underlying some of these practices.