Session II
COMMUNICATION OF SCIENTIFIC KNOWLEDGE

COMMUNICATION

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1. Introduction

Scientific and technological ideas are exchanged, nationally and internationally, within a number of communities of interest, each of which is addressed toward a specific professional area of expertise.

Rapid progress in telecommunications and transportation services has fostered the growth of various communities of interest to national and international dimensions. However, there still exist some impediments to the exchange of ideas, particularly among international communities of interest. The language barrier is an example. The organizational barrier is another. In some organizations, international telephone or telex is still considered a luxury and international travel a part of tourism.

There are impediments of a different sort that hamper the exchange of ideas among diverse communities of interest. Large institutions tend to split into a number of smaller units that are directed toward narrower areas. Scientists and technologists are increasingly devoting themselves to one of these smaller communities of interest and are paying less attention to the activities of other communities. To be competent, a scientist or technologist cannot afford to spend time and effort to be a Pascal or a da Vinci. Thus, the exchange of scientific ideas between diverse scientific communities has become increasingly difficult, and the exchange of ideas between a scientific community and a technological community has become even more difficult.

To alleviate these difficulties, it is necessary for organizations or supporting governments to acknowledge the cost of international communication and travel as an indispensable part of research expenditures. It is also necessary to strengthen language education and to enhance the development of computer translation for alleviating language barriers. Construction and enhancement of databases for various scientific and technological disciplines should be promoted so as to provide scientists and technologists with opportunities for selective access to information, not only in their specific areas of interest but also in fringe areas to which they do not pay major attention. Higher education should be reorganized to educate scientists and engineers with the capability of understanding scientific and technological trends which are not a part of their immediate concerns. Fora

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for discussions among scientists and technologists should be promoted nationally as well as internationally to enhance opportunities for the exchange of ideas.

After all, the unfettered mobility and free exchange of ideas among scientists and technologists on an international level has been the prime mover for scientific discoveries and technological innovations that have brought sustained economic growth and improved the quality of life in the free world, while avoiding duplication of investment and diversification of industrial standards. Impediments, including protectionism, that may hamper the exchange of ideas should therefore be carefully avoided from a long term perspective.

2. Impediments that Hamper Communication

Despite the fact that a great variety of communities of interests has been expanding and extending throughout the world more broadly and more densely, there are several factors that hamper communication within a community of interest and among diverse communities of interest. The following are some of the most significant factors.

(1) International Travel and Telecommunications

Despite the fact taht international networks for air transport and telecommunications are expanding throughout the world and providing efficient and economical means of travel and communication, international travel is still considered by some governments and organizations as a part of tourism and international telephone as a luxury. However, the cost of international travel is sometimes less than that of domestic travel and international telephone charges are often comparable to domestic charges. Governmental regulations in this respect tend to lag behind what is happening in the real world. Without sensible changes in these regulations, the international mobility of scientists and the exchange of their views may fall below a reasonable level.

(2) Language Barriers

Today, more than 3000 languages and a much larger number of dialects, representing a large variety of cultural backgrounds, are spoken by people throughout the world. However, major languages (those spoken by more than 100 million people) number less than 15, and only English, French, Russian, and Spanish, and in some instances Chinese and Arabic, are generally acknowledged by international organizations as official languages. Documents are issued and simultaneous interpretation is provided in these official languages. Speakers such as the Japanese whose native tongues are not one of the official languages must either be bilingual or must make use of a simultaneous interpreter, who translates their native tongue into one of the official languages. As communities of interest in the world become more closely knit, the inconveniences of language barriers increase and misunderstandings mount.

Information technology provides a means for reducing language barriers. Electronic language laboratories and computer-aided instruction systems can help minorities to learn one or more major languages while retaining their own native language. If its cost is low enough, machine translation of simple, straightforward

text may help to lower language barriers, especially when the process can be adapted to the vocabulary and sentence structure of a particular body of material (for example, the technical manuals of one firm) or when the material to be translated can be written in a form that is easy for the machine to translate.

(3) Information Explosion

We are living in an age of an information explosion. In the developed part of the world in particular, information is generated in a volume which is far greater than can possibly be consumed. People are being frustrated because they cannot obtain the information they need from the flood of information that is being generated. For those scientific communities which have been increasingly information oriented, the means of collecting a vast amount of information and selectively providing the appropriate information for each scientist are especially indispensable. The construction of databases for various scientific disciplines is a crucial factor in promoting scientific activities and fostering communication among scientists.

The construction of databases, however, requires the sustained effort of a large number of specialists who collect, input and update a very large amount of data. Considering the fact that scientific communities of the world are now so closely knit, databases must cover information in a number of languages that originate from various regions of the world. Language barriers are clearly one of the factors that hamper the construction of such databases. Another factor is differences in governmental support for database activites. In some countries, substantial support and encouragement have been provided by the government, but less so in other countries.

(4) Fragmentation of Communities of Interest

While communities of interest continue to grow and span the world, larger communities of interest tend to split into a number of smaller communities, each of which addresses a narrower and deeper scientific area. Scientists and technologists are increasingly devoting themselves to one of these smaller communities of interest and tend to be indifferent to what is happening outside of their own communities. As a result, the exchange of scientific ideas between different communities has become increasingly difficult. Nevertheless, revolutionary scientific discoveries and dramatic technological innovations mav emerge from interdisciplinary areas that involve a number of diverse communities of interest.

Databases for various scientific and technological disciplines mav help scientists and technologists in a specific community of interest to acquire knowledge in other areas which are external to their major concern. In this regard, databases need to be constructed for dual purposes, providing not only detailed data but also informative summaries. An adjustment in higher educational systems appears to be necessary so as to provide scientists and technologists with the capability of a broader understanding that transcends community boundaries. Professional societies which tend to split into a number of smaller interest groups should develop coordinating mechanisms through which the exchange of knowledge between different interest groups can be fostered. Fora for discussions that cover

interdisciplinary areas should be promoted nationally and internationally.

(5) Rising Protectionism

Increasing competition in high technology areas has been casting a shadow on the free exchange of ideas among scientists and technologists who belong to different organizations, enterprises, or sometimes countries. In some high technology areas, it has become increasingly difficult to distinguish non-defense technology from defense related technology, or to draw a line between basic science and applied technology. This adds additional complications to the prevailing climate. As a result, various forms of protectionism are appearing on the horizon that would restrict the unfettered mobility of scientists and technologists and hamper the free exchange of scientific and technological knowledge.

If scientific and technological activities are split into a number of closed and isolated small universes, resources in terms of research funds and personnel will be fragmented, resulting in less efficient and greater duplication of effort. Industrial specifications may become more diversified and international standardization more difficult. Ultimately, the economic strength of the free world that has stemmed from sustained technological innovation may be weakend to a considerable extent.

3. Options to Enhance International Communication

To alleviate the various impediments to scientific communication mentioned above, the following action alternatives seem to be necessary.

(1) Bearing the Cost of International Travel and Telecommunications

Scientific organizations or supporting governments must understand the crucial role that is played by international travel and by international telephone and telex in maintaining communication among scientific communities on a global scale. No distinction should be made between domestic and international travel or telecommunications, in view of the fact that scientific communities are now as closely knit internationally as they are domestically. Organizations and governments should consider the cost for international travel and telecommunications as an indispensable part of research activities, rather than a part of tourism or luxury.

(2) Strengthening Language Education

To facilitate better communication between scientific communities in the U.S. and Japan, language education, including the use of computer-aided instruction systems, should be enhanced in both countries. In Japan, extensive support should be given to writing or translating scientific articles and books into English. Additional Japanese scientists should be encouraged to talk in Japanese-English, i.e. English spoken in the Japanese way. An international language of science is neither American-English nor the Queen's English; rather it is broken English. Japanese-English, if spoken and written by 120 million Japanese, would be one of the most powerful dialects of English, which no one could neglect or deny. On the other hand, American scientists should learn more about the Japanese language, because if they only read English translations of Japanese articles or

listen to simultaneous interpretation, they may not be able to understand the Japanese way of thinking or the Japanese culture as a whole, upon which Japanese articles and presentations are based. Despite the fact that during the war, Japanese language education for U.S. military personnel scored an enormous success, the postwar efforts in this respect in the United States seem to be far less than adequate. The fact that some U.S. businessmen regard the Japanese language as one of the significant non-tariff barriers clearly demonstrates the situation. It may not be a total waste for Americans to devote some time to understanding a language spoken by a community that supports 10% of the world economy.

Due attention should be paid to the usefulness of computer-aided instruction systems for language education. Although the cost for computer-aided instruction systems is generally known to be excessively high for general education, a well thought-out combination with electronic language laboratories has proven computer-aided language instruction to be extremely useful and cost-effective. It may be worthwhile to set up a joint project involving American and Japanese language instructors and computer specialists to develop computer programs for learning English and Japanese.

(3) Developing Language Translation Systems

Although it is impossible to translate mechanically an unrestricted English text into a complete Japanese text, it is possible to turn out an intelligible Japanese text provided the original English text was written with some restriction in terms of vocabulary as well as syntactical and semantic structure. The same is true in translating restricted Japanese texts into English. Such restrictions may be quite realistic when applied to specific scientific disciplines. Collaborative research and development programs should therefore be established for English-Japanese and Japanese-English translation of scientific articles or abstracts of specific disciplines with the participation of American and Japanese scientists, linguists and computer scientists. If operational language translation systems for several scientific disciplines could evolve from this collaborative program, a great deal of benefit could be brought about not only for the American and Japanese scientific communities but also for those who understand either of these two languages.

(4) Constructing and Enhancing Databases

To cope with the information explosion, especially in the sciences, it is highly desirable to construct and enhance databases for various scientific disciplines. In this regard, Japanese efforts have been far less satisfactory than those of the United States. Considering the fact that Japanese scientific output in terms of the number of published articles constitutes roughly 10% of the world output, it should be emphasized that the Japanese are responsible for constructing and enhancing databases of Japanese articles and for making such services available domestically as well as internationally. Without such Japanese efforts, world-wide scientific information can never be made complete. For international services, the information should be made available in one of the international languages, especially in English. Here again, language education and computer translation need to be promoted.

(5) Broadening Views of Scientists

In view of the fact that scientific disciplines are becoming narrower and deeper on the one hand while interdisciplinary approaches are increasingly required on the other, higher educational systems should be reorganized to educate scientists and technologists with the capability of understanding scientific and technological trends which are external to their major concern. It is also necessary to broaden the scope of scientists so that they can understand the socio-economic implications of science and technology in both the domestic and the international setting. Japanese scientists, in comparison with their U.S. counterparts, seem to confine themselves more narrowly within their own scientific disciplines and are less interested in socio-economic and international implications. Mobility of Japanese scientists across national boundaries should be promoted along with necessary changes in the Japanese higher education system, so that Japanese scientists can better understand and communicate with the rest of the world.

(6) Promoting Fora for Discussions

It is extremely important to promote fora for discussion among scientists and technologists nationally as well as internationally to enhance opportunities for exchange of views. Considering the fact that the U.S. efforts in the past for exchange of scholars, typically represented by the Fulbright Program, have provided many opportunities for Japanese scientists to exchange their views and work together with U.S. scientists, matched efforts on the part of the Japanese are urgently required. More U.S. scientists should be invited to participate in scientific programs in Japanese universities, research institutions and industrial laboratories. More opportunities should be provided for the U.S. and Japanese scientific communities to work together and to discuss problems of mutual interest.

(7) Avoiding Protectionism

Sustained economic growth and prosperity in the free world has been brought about to a large extent by scientific discoveries and technological innovations which have relied on the open exchange of scientific and technological knowledge among industrialized countries. Duplication of research and development investment has been kept minimal. Diversification of world industrial standards has been avoided to the maximum extent possible. The United States, in particular, has been extremely successful in this regard since the 1930's when an enormous flow of extremely talented scientists and engineers emigrated from Euuope to the United States, due mainly to totalitarianism and racism of the ruling Nazis. It is possible that, without the significant contributions made by immigrants and their sons, the leadership of the United States in science and technology would never have been established. The superiority of the free world in science and technology, centered around the U.S. leadership, has strengthened the economy and national security of the free world and thus contributed a great deal to the maintenance of world peace.

It is therefore crucial, not only for the United States but also for Japan, to maintain and enhance the unfettered mobility of scientists and the free flow of

knowledge at the highest level possible. For Japan especially, whose society has a distinct monoracial structure, it is highly important to encourage talented immigrants and visitors to come to Japan and participate in scientific programs sponsored by the public and private sectors. Some may insist that Japan is already over-populated and has no space for immigrants. But it may be said that adding a few hundred thousand immigrants to a population of 120 million may not seriously worsen the already existing problem of over-population. Rather, the impact of the immigrants on Japan's value systems, ways of thinking and so forth will be much greater. He who worries about the boomerang effect is the one who becomes less confident of his own innovative capability. The more he protects his knowledge, the more he becomes isolated from other scientific communities and ultimately becomes less competitive. Protectionism in any form should be very carefully and forcefully avoided not only to maintain the sustained growth of the free world economy but also to enhance the national strength in science and technology.

MOBILITY OF SCIENTISTS AND ENGINEERS TO EMERGING SCIENTIFIC SPECIALTIES: WHAT IS KNOWN?

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With the rapid advance in science and technology has come a proliferation of new subject areas or specialities at a rate never before experienced. Often these emerging areas are accelerating rapidly and are associated with increased demands on the available pool of scientific and technical personnel. The disciplinary composition of new graduates from higher educational institutions, the primary source of new scientists and engineers in the labor force, has historically lagged in response to rapidly changing human resource requirements, in part because of the long lead-time to develop and implement curricula specifically geared to new, rapidly expanding areas as well as the time it takes for individuals to move through the educational process. Thus, as new and rapidly developing scientific and technical specialties displace older ones, they often initially must draw upon available human resources trained in other existing fields. The inter-field and inter-specialty mobility of scientists and engineers therefore becomes a critical component in the ability to respond to changing manpower requirements in new and rapidly evolving scientific and technical areas.

It is widely recognized that the movement of scientists and engineers between jobs, employers, geographic locations and occupations is an important component of short-term adjustments to changes in labor market demand and research needs. However, mobility across disciplinary boundaries and, in particular, to newly emerging specialties has received less attention and is not as well understood as, for example, geographic migration and other types of mobility.

A search of the available literature revealed no systematic studies of mobility of scientists and engineers to emerging and rapidly expanding specialities. The few data that have been collected are fragmented and limited in scope, and allow for only very generalized impressions. This paper will examine some of the available data on inter-field and inter-specialty mobility in a selected number of emerging scientific and technical specialties, and raise some possible issues for further research and analysis.

Two broad categories have been selected for the focus of this preliminary

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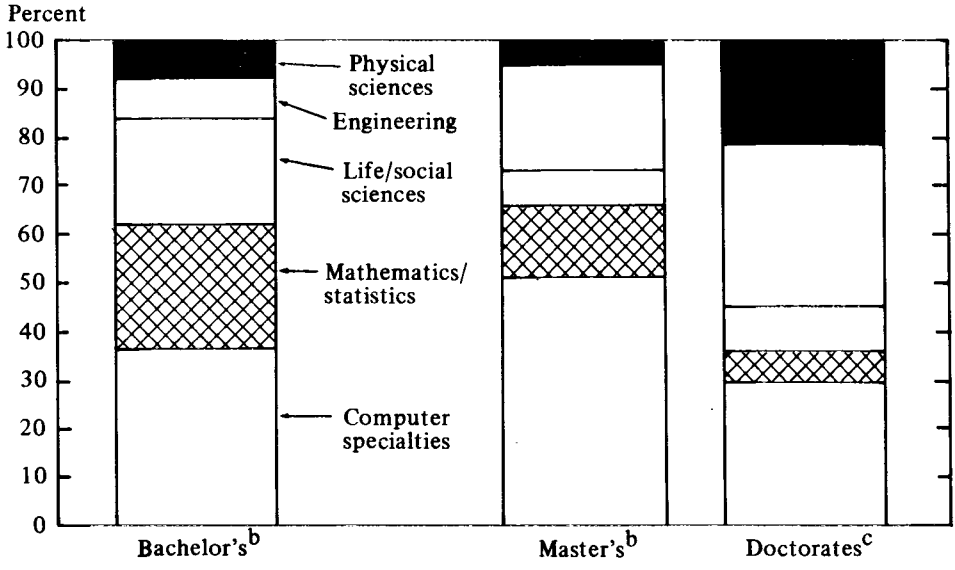
The views and opinions expressed herein are those of the author and do not necessarily represent those of SRI International.

analysis: computer-related specialties and biology-related specialties. In both cases, specialties that are examined include some that were formerly considered as emerging or in which rapid expansion earlier occurred, as well as some that represent more recent emergences. For example, in computer-related areas, we look at solid state physics, in which a rapid expansion occurred in the early 1960s, as well as artificial intelligence which is thought to be the key to the development of the next generation of computers. In biology-related areas, we look at molecular biology, which was considered to be a 'new' scientific specialty in the mid-sixties, as well as 'new' biotechnology, which represents a more recent emergence of a scientific and technical specialty largely based on earlier developments in molecular biology. In order to obtain some very rough sense of the scientific and technical personnel who are entering some of these emerging fields, available data have been pieced together where possible, and expanded by some additional very limited samples of professionals involved in these emerging areas.

A few of the more systematic studies that have been conducted of professional mobility between broad fields of science and engineering are then reviewed in order to gain some indication of those fields of training or prior employment experience which appear to provide the greatest capacity for movement into other fields. Ambiguities that are frequently associated with statistics at these aggregate levels are also discussed, both as a caution when using the data and because they would appear to have some bearing on any future data collection efforts that might be undertaken to analyze mobility to emerging areas. The paper concludes by identifying some of the important issues that are raised by the analysis and suggesting areas where systematic study is needed. Throughout, it must be borne in mind that this is a very preliminary discussion of a topic that clearly requires much further exploration.

A. Computer-Related Specialties

Computer science is a field not widely treated as a separate discipline until the mid-1960s (the formal beginning of the computer science "department" at Stanford University was in 1965). Many established scientists as well as new graduates in a multiplicity of fields such as solid state physics, mathematical logic, and electrical and electronic engineering, in a sense shifted their occupations to enter this rapidly developing field.[1] Colleges and universities are now turning out more than 11,000 new graduates annually at the baccalaureate level and close to 4,000 at the master's and doctoral levels, under curricula specifically designed to train individuals with the knowledge and skills that characterize computer sciences.[2] Even so, of the approximately 16,000 new science and engineering graduates at the baccalaureate level employed in computer science occupations in 1980, only about 37 percent had earned their bachelor's degrees in computer science. An additional 25 percent had earned degrees in mathematics, 21 percent in the social and life sciences, and 8 percent each in the physical sciences and engineering (see Figure 1). Of employed computer



[a]Excludes full-time graduate students and those holding postdoctoral appointments.
[b]1978 graduates in 1980.
[c]1977 graduates in 1979.

Source: National Science Foundation, "Science and Engineering Personnel: A National Overview," NSF 82-318.

Fig. 1. Distribution of Recent Science/Engineering Degree Recipients[a] Employed as Computer Specialists, by Field and Level of Degree

specialists at the doctoral level, those trained in computer science represented only about 30 percent, while those whose formal training was in the engineering fields represented about 35 percent and those from the physical and life sciences and mathematics represented the remainder.[3] The inter-field mobility of scientists and engineers to a few computer-related specialties (including solid state physics which, although a subfield of physics, is included because of its importance as the primary basis of modern computer systems) is discussed below.

Solid State Physics

After the commercial introduction of the transistor in 1954, research and development in solid state physics accelerated rapidly. In *The Uses of Talent,* Dael Wolfle reports that in 1964, there were only 86 persons who held Ph.D.s in solid state physics, only 46 of whom were working as solid state physicists; however, there were 1,894 Ph.D.s overall working as solid state physicists. In addition to the 46 with formal training in this new field, 1,388 held Ph.D.s in other branches of physics, 318 held Ph.D.s in chemistry, 109 in engineering, and 33 in a variety of other disciplines, including one who had earned the doctorate in horticulture.[4] This provides a vivid example of how new technological

areas can expand rapidly by drawing on individuals who have some of the skills and methods of thought required for the new discipline although their training and previous experience may seem to be in quite unrelated areas.

Robotics

Robotics represents a relatively new field that has emerged largely from a confluence of computer sciences and mechanical engineering. Developments in basic science and engineering research conducted primarily in the universities are now being commercialized by private industry (sometimes in conjunction with universities). A study by the National Science Foundation has characterized the development of this technology in three somewhat overlapping phases. The first was relatively simple mechanical arms programmed by a computer. In the second phase, robots with rudimentary sensing and feedback capabilities were developed; they are essentially preprogrammed robots whose programs can be modified by feedback from the sensors. The third phase, described as "intelligent robot systems," is at present viewed as a highly promising area for future development. The report notes that intelligent robots would be able to respond to their environment, to make rudimentary judgments, and to change work commands as needed; however, both the sensory capabilities of robots and their ability to deal with unforeseen contingencies are as yet quite limited.[5)]

In order to gain some idea of the background and career patterns of individuals who are currently involved in robotics research, a computerized search of *American Men and Women of Science* (15th Edition) was conducted to find those individuals who listed robotics among their subject specialties. Only 10 individuals so identified themselves. All but one of the 10 were employed in the academic sector, with the other in government/defense. Nine of the 10 had doctoral degrees, all of which were in the engineering fields. The breakdown was as follows:

Electrical Engineering	4
Mechanical Engineering	2
Industrial Engineering	1
Operations Research	1
Bioengineering	1

Bioengineering appeared to be a subcategory of electrical engineering. Only 2 of the 9 had prior experience in industry, although one additional individual had served in a consulting capacity. Five of these individuals had received their Ph.D.s prior to 1970 and 4 since 1970, but there was no particular pattern in the breakdown of engineering disciplines between the two categories.

In order to gain a sense of whether the sample of individuals who self-identified their subject specialties as robotics was representative of the backgrounds of people who are involved in this area of research, we tried a different approach, again with a very limited sample, based on professionals employed in a non-profit institution research center where the designated research activity is robotics. The resulting sample of 14 professionals ranging from experienced senior scientists to entry-level researchers gave a much different picture than

that which was obtained from the sample based on professional self-identification of subject specialties, where all had been formally trained in the engineering fields. Instead, a variety of disciplinary backgrounds was found. In terms of highest degree, 8 of the individuals in the robotics research center sample had doctorates, 3 had master's degrees and 3 were at the bachelor's level. Overall, the breakdown by field in which these individuals' highest degrees were obtained was as follows:

Computer Sciences	6
Physics	4
Electrical Engineering	2
Systems Engineering	1
Artificial Intelligence	1

The last received his highest degree in 1979.

Only 3 of these individuals completed their formal education prior to 1970, the rest having received their highest degree in 1970 or later. Among the 3 more experienced scientists who had completed their highest degrees prior to 1970, 2 had a Ph.D. in physics and 1 in electrical engineering. All of those whose formal training was in computer sciences had received their degrees since 1970. In terms of other professional experience, 5 of these individuals had prior experience in research with private industry, and only 1 in academic research. The large differences in career backgrounds between the sample based on employment in a research department with a designated research focus and that which was based on self-identification of field of specialization is a problem that will be seen to affect many of the inter-field mobility data and is addressed in Section C below.

It would appear that future advances in robotics will require even greater interdisciplinary expertise than has thus far been the case. In describing the training that is likely to be required for future advances in robotics, the National Science Foundation's *Five-Year Outlook on Science and Technology 1982* notes the following:

> ... robotics research will need to make use of a much wider range of classical mathematics and physics than it has been involved with until now. This includes computational algebra, computational geometry, servomechanism theory, mechanics, theories of elasticity and friction, materials science, and manufacturing technology. Mathematics, physics and engineering departments will be in closer contact with computer science than ever before.[6)]

Artificial Intelligence

Robotics is often considered a subarea of 'artificial intelligence,' which in some ways might be considered the principal area of basic scientific research underlying much of the advanced robotics technology, particularly that involving sensing and feedback capabilities. Artificial intelligence is the branch of computer science that attempts to make a computer behave in ways that mimic

intelligent human behavior. The aim is to increase the ability of computer-based systems to solve problems, communicate with people, and perceive and interact with the physical world. Research in artificial intelligence, which has existed as a scientific specialty for about 25 years, is moving ahead on many fronts, including robotics, natural language understanding, image and speech understanding, cognitive modeling, and theorem proving. The next generation of computers, the fifth generation, is being thought of in terms of "artificial intelligence machines." In recognition of this, the Japanese have renamed the fifth generation "knowledge information processors" or KIPs.[1] It appears in this case that even at the level of the theoretical and applied research underlying much of the technology that is now being commercialized, a number of traditional scientific disciplines are involved.

A sample of 12 professionals involved in a research center with the designated focus of artificial intelligence in a non-profit research institute found a variety of educational backgrounds. All but one of these individuals had a Ph.D., with the other having a master's of science degree. Five had received their highest degree prior to 1970. The breakdown of highest degrees by field was as follows:

Computer Science	4
Electrical Engineering	3
Theoretical Physics	2
Linguistics	1
Mathematics	1
Artificial Intelligence	1

The degree in artificial intelligence was earned in 1979. Among the more experienced scientists who had completed their formal education prior to 1970, 2 had received their highest degrees in the field of electrical engineering, 1 in mathematics, 1 in linguistics and 1 in computer science (1969).

In terms of other professional experience, 4 of these individuals had prior research experience in private industry, with 2 of these 4 also having worked in research laboratories of the Federal government. Five of the 12 included in the sample had university-teaching experience, but it is unclear to what extent 4 of these may also have been involved in academic research.

A recent study of artifical intelligence machines, or the next generation of computers, found that these machines will "allow, almost insist upon, the function of many different technologies and human services."[1] Here again, the increasing importance of the transfer of knowledge from one discipline to another is clear.

B. Biology-Related Specialties

Twentieth-century advances in biology have culminated in the understanding of the chemical nature of genes, the basic unit of heredity, and in the unraveling of the genetic code. These advances have generated a great deal of excitement about the progressive application of novel microbiological techniques to

a wide range of industrial areas. Much of the current advance in biology-related technologies has stemmed from efforts to explain biological functions in terms of molecular structures and mechanisms.[7] We will examine two related and in many respects overlapping 'specialties' associated with advances in modern biology – molecular biology, and 'new' biotechnology.

Molecular Biology

Many of the current applications of fundamental studies in biological research stem from a major breakthrough in modern genetics: the discovery of the chemical structure of genes and enyzmes, the molecular mechanisms of protein synthesis, and the mechanisms of gene replication and mutation. In a recent analysis of the dynamics of twentieth-century science, Fritjof Capra states that "a crucial element in the breaking of the genetic code was the fact that physicists moved into biology ... These scientists brought with them a new vigor, a new perspective, and new methods that thoroughly transformed genetic research. Physicists, biochemists and geneticists [subsequently became convinced] that a new frontier of science had opened where great discoveries were imminent. From now on these scientists began to refer to themselves as 'molecular biologists,."[7]

A 1967 study of mobility of scientists and engineers between scientific and technical specialties included a case study on "molecular biology," which at the time of the study was considered a "new" discipline representing a convergence of several lines of inquiry.[8] The study pointed out that work on problems at the cellular level had been going on in a variety of traditional disciplines, including microbiology, cell physiology, biochemistry, and biophysics, before the developments that allowed work at the intracellular level to be pursued. As it became known that the fundamental molecular biological processes are essentially subject to the same "laws" regardless of broader differences in the cellular material between, for example, plants and animals, many of the people working in the older disciplines came to be concerned with the same scientific problems. It is in this sense, in part, that molecular biology was considered to represent an area of convergence of a number of traditional lines of inquiry.

The study examined the career descriptions in *American Men of Science* (11th Edition) of 13 individuals who had received research grants from the National Institutes of Health in 1966 in categories having to do with molecular biology. Only 2 of the 13 described their career specializations as molecular biology. None described the field of their doctorate as molecular biology, and none described their dissertation research as molecular biology.

The researchers also examined the background of a sample of principal investigators who had received grants in molecular biology research topics from the National Science Foundation in 1964. The breakdown of the claimed disciplinary "specialties" as found in *American Men of Science* was as follows:

Biochemistry	11
Molecular Biology	3
Biology	3
Physical Chemistry	2
Biophysics	1
Other	6

The authors pointed out that there were at that time no real "courses" in molecular biology; rather, molecular biological research findings were taught as part of the overall study of biology. The study found evidence to suggest that after a more general education in biology at the doctoral level, post-doctoral programs in molecular biological research often completed the training process.

At the time this study was conducted in 1967, molecular biology was considered a "new" scientific specialty, which represented the convergence of a number of more established disciplines. As noted above, however, few scientists who were engaged in what would have been considered molecular biology research so described their disciplinary specialty. Today, fifteen years later, 1,604 scientists listed in *American Men and Women of Science* (15 Edition) claim molecular biology among their disciplinary areas.

Biotechnology

The development in 1973 of hybridoma and recombinant DNA technologies, or genetic engineering, brought molecular biology into the marketplace.[9] As early as 1975, two years after recombinant DNA techniques were developed in university laboratories, several companies had begun to explore the commercial implications of the new techniques. Today, more than 200 firms in the United States alone are engaged in "new" "biotechnology" activities.

Biotechnology is considered to be more than a subdiscipline of biology; it is not a single technology but a number of related techniques that have their roots in classical biology, chemistry and engineering. Commenting on the multidisciplinary nature of biotechnology, a recent study by the Office of Technology Assessment (OTA) noted the following:

> Individuals seeking to be well versed in applications of biotechnology must have interdisciplinary training. Bioprocess engineers, for example, need some knowledge of biochemistry and microbiology as well as knowledge of engineering design so that the most efficient combination of microorganism and bioreactor can be determined. Similarly, plant molecular biologists need to know both plant physiology and molecular genetics. People working in microbial enhanced oil recovery need training in microbiology as applied to a specific geological environment.[9]

The OTA study includes the results of a survey of firms involved in the commercialization of biotechnology to determine the number of individuals currently involved in industrial biotechnology R&D and the major areas of their technical expertise. Of 219 U.S. firms now estimated to be engaged in biotechnology activity, 95 responded to the survey. The large variety of subject area specialties represented by current employees in these firms is shown in Table 1.

Among the major categories of technical personnel involved in the industrial development of biotechnology, several were thought to be especially important. These include specialists in genetic manipulation, such as molecular biologists and immunologists (categories a, b and c), which represent about one-third of the personnel in the survey; specialists in scale-up and downstream processing, such as bioprocess engineers, biochemists and microbiologists (categories g, h, j, k and s), which represented another third; and enzymologists and cell culture specialists (categories f and l), which are important to many aspects of biotechnology and represented another fifteen percent.[9)]

Table 1. Scientists Currently Employed by Firms Involved in Biotechnology R&D in the United States, by Level of Degree

	Ph.D.	M.S.	B.S.	Total	Percent of Total
a. Recombinant DNA/Molecular Genetics	293	126	167	586	23%
b. Hybridomas/monoclonal antibodies	89	50	108	247	10
c. Animal reproduction/embryo transplantation	1	1	1	3	★
d. Classical genetics	30	8	12	50	2
e. Gene synthesis	26	5	14	45	2
f. Enzymology/immobilized systems	97	36	86	219	8
g. Industrial microbiology	58	34	43	135	5
h. Bioprocess engineering	71	47	68	186	7
j. Analytical biochemistry	37	20	28	85	3
k. Biochemistry, general	117	41	83	241	9
l. Cell culture	42	47	98	187	7
m. Cell fusion	11	4	11	26	1
n. Cell biology/physiology	18	7	18	43	2
o. Plant molecular biology	40	18	18	76	3
p. Plant biology/physiology	30	7	20	57	2
q. Pharmacology	9	7	14	30	1
r. Toxicology	13	2	16	31	1
s. Microbiology, general	82	33	84	199	8
t. Physiology	8	3	15	26	1
u. Other biotechnology specialties	51	23	44	118	5
Total	1,123	519	948	2,590	100%

★Less than 0.5 percent

Source: Commercial Biotechnology: An International Analysis (Washington, D.C.: U.S. Congress, Office of Technology Assessment), OTA-BA-218, January 1984.

The OTA study noted that there are few U.S. undergraduate or graduate programs in biotechnology that are interdisciplinary in nature. The study found, for example, that bioprocess engineering education is offered almost exclusively at the graduate level where it is closely tied to chemical engineering education, and there is relatively little interaction with biologists. Training in

classical plant breeding has generally been offered at agricultural research stations and land-grant colleges, whereas research in plant molecular biology is generally conducted in the universities; thus, there are communications barriers between these groups that may slow the advances in agricultural research.

Among the general conclusions of the OTA study was that "The multidisciplinary nature of biotechnology has extensive implications for educational and industrial structures. To excel in biotechnology, universities will need to draw on the resources of several departments. Diversified companies may have an inherent advantage over other companies, because technologies perfected for the production of one product (e.g., a pharmaceutical product) can be modified and used for the production of another (e.g., a food additive)."[9] Once again we see the emphasis on the importance of the convergence of knowledge from diverse scientific disciplines as fundamental to the advance of knowledge in an emerging specialty.

C. Mobility Between Broad Fields of Science

The extremely limited data that we were able to price together on scientific and technical personnel in emerging fields show that in every case where backgrounds could be obtained on the people that were found in these fields, a large number of diverse disciplines were represented. The available evidence seems to point to the continued importance of a wide range of disciplinary specialties in future advances in many of these areas. Thus, inter-field and inter-specialty mobility appear to play an important role in the transfer of knowledge from one discipline to another and in the synthesis of knowledge from diverse disciplines in "newly defined" scientific specialties. While it is not easy to estimate in any quantitative way the amount of such mobility in general that takes place or the role of the interdisciplinary stimulation and cross-fertilization of ideas in leading to new advances in science, some of the more systematic studies that have been conducted of mobility between broad fields of science provide an indication of those fields of training or experience in which scientists or engineers exhibit the greatest tendency to move into other areas and the directions in which they tend to move.

One of the most detailed sources of insights at an aggregate level into career patterns and mobility of scientific and technical personnel, the extent to which professionals educated in scientific, engineering and technical fields are working in occupations apparently unrelated to their training, and the activities and duties that are actually performed by persons classified in scientific and technical occupations is provided by the National Science Foundation study entitled "The 1972 Scientist and Engineer Populations Redefined," also known as the 1972 Post Censal Survey.*

* Unfortunately, many of the questions included in the 1972 Post Censal Survey that yielded particularly good information on field mobility and career patterns have not been included in the soon-to-be-released survey based on the 1980 Census of Population. Thus, 1972 Post Censal data, although extremely dated given the rapid pace of scientific advances, are used herein to reflect the direction and extent of field and occupational mobility of scientists and engineers.

The Post Censal Survey relied on three criteria for redefining the scientist and engineer population that had been identified in the Census: professional self-identification, present and past employment, and education (in terms of level of highest degree or years of education obtained and major field of study). Because a number of criteria were used to define scientists and engineers, the percentages were thought to underestimate those whose occupations differed from the field of specialty pursued in their formal schooling. It should also be noted that the Post Censal data are not standardized for age or years in professional employment. In most cases, the difference would be fairly small, but for rapidly changing fields and new fields, it might be significant.

Table 2 shows the distribution of U.S. scientists and engineers by field of formal training and by occupation in 1972. Overall, about one out of five persons trained in science and engineering fields was employed in an occupation other than his field of training. However, much of the movement out of these fields represented changes into teaching or managerial and administrative positions or to other occupations not classified as science or engineering. In terms of mobility to other fields within science and engineering, the highest rate was in chemistry, in which a total of 15 percent changed their occupation to other science and engineering fields. This was followed by physics/astronomy at 13 percent, biology and mathematics at 10 percent each.

In chemistry, almost 85 percent of the movement within science and engineering fields was to other areas of the natural sciences, especially the medical sciences. In physics/astronomy, on the other hand, over half of the mobility to other science and engineering fields was into engineering occupations. In mathematics, close to half of the occupational change within science and engineering fields was represented by movement into computer science occupations (which in 1972 was still a field in which relatively few individuals had been formally trained).

The fields of science and engineering in which individuals showed the least propensity to change to science and engineering occupations other than the field in which they were trained were computer science and engineering at 1 percent each. Those computer scientists who moved into other science and engineering fields changed most frequently into engineering, while those engineers who moved into other science and engineering fields changed most frequently into computer sciences. Overall, the mobility within science and engineering fields is strongly dominated by movement from training in the more basic science areas to employment in the more applied scientific fields.

The National Science Foundation has also collected data on mobility patterns between occupational fields at different stages in the scientist's career.[11] These occupational mobility data are based on a resurvey in 1974, 1976 and 1978 of those scientists and engineers originally surveyed in the 1972 Post Censal Survey. As the resurvey did not include new entrants to the labor force after 1970 (the censal year on which the 1972 Post Censal Survey was based), the average age of the sample is higher and consequently the mobility rates

Table 2. Distribution of U.S. Engineer Population, by Occupation and Field: 1972 (In Percent)

Occupation	Total	Aero-nautical and Astro-nautical	Agri-cultural	Chemical	Civil, Environ-mental and Sanitary	Elec-trical and Elec-tronic	Indus-trial	Mechan-ical	Metal-lurgical & Materials	Mining and Petro-leum	Nuclear
Total employed	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Engineers, total	80.1	88.9	95.8	80.8	88.6	87.3	82.1	86.6	86.1	80.6	89.6
Aeronautical, astronautical	4.0	77.2	0	0.1	0.2	0.9	0.2	1.5	0.4	0	0
Agricultural	0.5	0.2	79.3	0.4	0.1	0.1	0	0.2	0	0	0
Chemical	4.1	0	0.6	70.4	0.1	0.1	0.1	0.4	1.0	0	0
Civil and architectural	11.4	0.1	0.7	0	74.0	0.1	0.4	0.5	0.1	0.9	0
Electrical and electronic	19.4	1.4	2.8	0.6	0.3	80.0	1.7	0.7	0.4	0.3	0
Industrial	4.7	0.1	0	0.5	0.5	0.5	73.5	0.8	0	0	0.6
Mechanical	15.9	4.7	3.9	0.8	0.8	0.2	1.9	73.6	1.6	1.4	3.3
Metallurgical and materials	2.2	0.4	0.6	0.7	0	[1]	0.1	0.5	78.5	0.7	0
Mining and petroleum	1.4	0	0	0.4	0.1	[1]	0.1	0.4	0.1	74.8	0
Nuclear	0.8	0	0	0.6	0.1	0.1	0	0.5	0.4	0	79.4
Environmental and sanitary	1.5	0.1	0	1.9	7.3	0.1	0	0.6	0	0.5	2.4
Other	14.1	4.8	7.9	4.4	5.1	5.1	4.1	7.0	3.5	2.0	4.0
Computer specialists	0.8	0.4	0.9	0.8	0.3	1.7	0.5	0.2	0	0.8	0
Mathematical specialists	0.2	0.4	0	0.3	0.1	0.2	0.6	0.3	0	0.5	0
Natural scientists	0.2	0	0	2.0	0	0.3	0.2	0.1	0.3	0.4	0
Social scientists	[1]	0	0	0.3	0	0	0.2	0.1	0	0	0
Technicians, total	1.5	0.8	0	0.6	1.7	2.0	1.4	1.8	0.4	0.6	3.7
Teachers	0.3	0.3	0	0.2	0.1	0.5	0.4	0.2	0	0	0
Administrators and managers	15.2	7.1	3.3	12.9	8.0	6.4	12.2	8.5	12.1	15.1	6.2
Administrators and managers, scientific research	3.7	2.9	0	3.1	0.5	1.5	1.8	1.0	4.0	1.1	0.4
Administrators and managers, production/operations	5.4	1.3	0	5.1	2.4	2.2	5.9	3.0	3.4	10.6	5.8
Other administrators and managers	4.5	2.1	0.7	2.6	3.6	1.8	3.4	2.8	3.7	2.9	0
Self-employed propriators	1.4	0.7	2.6	2.0	1.5	0.9	1.0	0.9	1.1	0.5	0
Other occupations	1.6	2.2	0	2.1	1.2	1.7	2.4	2.1	1.0	1.9	0.4

[1] Less than .05 percent.

Note: Detail may not add to 100.0 percent because of rounding.

Source: Calculated on the basis of data contained in "The 1972 Scientist and Engineer Population Redefined" (Engineers, by Field), National Science Foundation, NSF 76-306, p. 1 (1976).

lower than would be expected if new entrants were also included.

Table 3 shows the distribution of these "experienced" scientists and engineers by occupation in 1972 and occupation in 1978. Overall, over 25 percent of all scientists and engineers changed their major occupational field of employment during this period. However, as was also the case in the Post Censal Survey, the large majority of these changes – approximately four out of five – were into managerial and administrative positions or other non-science and engineering occupations. Only 5 percent of all scientists and engineers, one-fifth of those that were occupationally mobile, moved from one occupational field to another within science and engineering.

In terms of mobility to other science and engineering occupations, mathematics showed the highest outflow ratio, at 19 percent. This was followed by physical sciences at 12 percent, other scientific fields (primarily environmental) at 11 percent, and computer sciences at 10 percent. Mathematicians changed their occupations most frequently to engineering occupations and to computer specialties, which together accounted for more than three-fourths of the movement of mathematicians to other scientific and engineering occupations. Almost half of those physical scientists who changed to other science and engineering occupations moved into engineering; however, another fourth moved into occupations in biology. As with the Post Censal Survey, almost three-fourths of the movement of computer scientists to other science and engineering fields was into engineering occupations.

These data, like those of the 1972 Post Censal Survey on changes from field of formal training to field of occupation, show the majority of inter-field mobility to be in the direction from the basic science fields into the more applied and engineering-oriented areas. Of the 56 possible occupational transfers considered in the 1972–1978 period, only 4 displayed movement of 5 percent or more. These were mathematicians to computer science occupations (7 percent), and mathematicians, computer specialists, and physical scientists into engineering occupations (8, 7, and 7 percent, respectively).

Studies of mobility such as those described above indicate that while the majority of scientists and engineers remain within the areas of their formal training or prior experience, a significant portion of these professionals do shift across broad disciplinary boundaries. However, because the data are classified by broad fields of science only, they involve certain ambiguities that make it difficult to quantify precisely how much movement from one scientific specialty to another actually occurs. For example, it is impossible to distinguish those cases which by broad field of science would be classified as a change of field but for which if the subfield of science were known it would be clear that the field of education had actually provided training related to the field of occupation. This would be the case, for example, with an organic chemist employed in biochemistry, a nuclear physicist employed as a nuclear engineer, or an electrical engineer working in computer sciences. On the other hand, certain instances in which a real change in field has occurred can be overlooked when only

Table 3. Occupational Mobility of Experienced Scientists and Engineers: 1972–78

Occupation in 1972	Occupation in 1978										
	Total	Physical scientists	Biological scientists	Mathematicians	Computer specialists	Psychologists	Social scientists	Other scientists	Engineers	Managers and administrators	Other non-scientists/ engineers
	In thousands										
Total	830.5	64.5	53.0	18.5	51.9	20.4	22.3	19.8	406.3	117.0	56.9
Physical scientists	80.3	56.9	2.4	.3	.8	(1)	.1	1.4	4.2	9.0	5.1
Biological scientists	67.8	2.7	48.6	.2	.1	.2	.5	.6	.8	6.1	8.1
Mathematicians[2]	27.6	.3	.1	16.1	1.9	(1)	.5	.1	2.1	3.5	2.9
Computer specialists	66.5	.3	(1)	.7	43.1	.1	.2	.3	4.8	13.1	3.8
Psychologists	24.1	(1)	.1	.1	(1)	19.2	.4	(1)	(1)	1.7	2.6
Social scientists	32.5	(1)	.2	.4	.1	.6	20.4	.1	.2	5.0	5.5
Other scientists[3]	21.2	.8	.7	(1)	.1	(1)	.1	16.7	.7	1.5	.7
Engineers	510.5	3.5	.8	.6	5.6	.3	.2	.6	393.5	77.1	28.1
	Percent distribution										
Total	100.0	7.8	6.4	2.2	6.2	2.5	2.7	2.4	48.9	14.1	6.9
Physical scientists	100.0	70.8	3.0	(4)	1.1	(4)	(4)	1.7	5.2	11.3	6.4
Biological scientists	100.0	3.9	71.7	(4)	(4)	(4)	.7	.9	1.1	9.0	12.0
Mathematicians[2]	100.0	1.2	.5	58.4	6.8	(4)	1.8	(4)	7.7	12.5	10.5
Computer specialists	100.0	.5	(4)	1.1	64.9	(4)	(4)	.5	7.2	19.7	5.7
Psychologists	100.0	(4)	.6	(4)	(4)	79.6	1.5	(4)	(4)	7.1	10.6
Social scientists	100.0	(4)	.7	1.3	(4)	1.9	62.8	(4)	.5	15.3	17.0
Other scientists[2]	100.0	3.7	3.1	(4)	.5	(4)	(4)	78.6	3.3	6.8	3.3
Engineers	100.0	.7	(4)	(4)	1.1	(4)	(4)	(4)	77.1	15.1	5.5

[1] Less than 50.
[2] Includes statisticians.
[3] Primarily environmental scientists.
[4] Not calculated because of small sample size.

Note: Components may not add to totals because of rounding.

Source: National Science Foundation

broad fields of science are considered: the mobility that occurs when a scientist or engineer changes his occupation to another subfield within the same broad field of science but the two subfields are only remotely related. Thus, although an organic chemist employed as a nuclear chemist, or a nuclear physicist working in acoustics would not be included among individuals who had changed their field when data are aggregated by broad field of science, the disciplinary change is nevertheless real.[12)]

Some indication of the extent to which ambiguities such as those noted above can affect data on mobility across broad fields of science is provided by a 1975 study by the National Academy of Sciences (NAS).[12)] The study was based on detailed information on field mobility of Ph.D.s collected in a 1973 survey of a representative sample of doctoral scientists and engineers. By examining the subfields of science in which these professionals were trained and employed, the NAS study concluded that 15 to 20 percent of those scientists who met the criterion for changing broad fields were actually working in fields for which they had been trained. On the other hand, it was also found that approximately the same percentage of Ph.D.s who in reality had changed to relatively unrelated disciplines were not captured when looking only at mobility between broad fields of science. In mathematics, for example, approximately 10 percent of those who had received mathematics doctorates were employed in other broad fields of science. However, it was found that over 50 percent of these individuals had earned their doctorates in applied mathematics subfields such as probability/statistics, applied mathematics, and computing, and changed employment to related fields such as operations research and biometrics/biostatistics.

Another ambiguity possibly affecting the overall statistics is the fact that much of the apparent field switching between physics, chemistry, biology and engineering may be more definitional than real. For example, many trained physicists may have classified themselves in physical chemistry (a subfield of chemistry), engineering physics (a subfield of engineering) or biophysics (a subfield of biology).[12)]

Statistics on mobility between broad fields of science can also be affected by ambiguities over the actual function that the field switcher performs in his new field. What precisely characterizes the borderline, for example, at which a physicist who works as a member of a group of scientists whose research would primarily be characterized as chemistry should be classified as having changed his field to chemistry or should still be considered as primarily functioning in the role of physicist? What factors make us say that mobility from one field to another has actually occurred?

The studies of mobility described above essentially relied on the scientists' own identification of current field of occupation, and in general this would appear to be the method of preference. As Dael Wolfle points out, "Perhaps the most satisfactory method [for counting the number of people who move from one specialty to another] is to rely on what people call themselves. If a man

with a Ph.D. in zoology stops calling himself a zoologist and says he has become a psychologist, for purposes of classifying the members of the labor force we should agree that he is a psychologist, for we have no better basis than his own testimony for deciding when a man has switched from one field to another."[4)]

There are a large number of specialists, however, who would continue to classify themselves within their original field of training but who work in research departments or as members of research teams that would primarily be classified as engaged in research in other fields. Such scientists would not show up as field switchers among statistics based on self-identification of current occupational field, but nevertheless would appear to play an important role in the dissemination of ideas and techniques across disciplinary boundaries. This is a particularly important aspect to professional mobility in that new advances in science and technology frequently depend on the convergence of techniques and approaches from a variety of scientific disciplines.

Some insight into this aspect of mobility is provided by a recent survey of physicists employed in universities in the Netherlands.[13)] Instead of relying on self-identification of current field of science, this study focused on the academic department in which these professionals were found to be employed. The study found that fully one-fourth of the professionals in Dutch universities who were physicists by training were employed in other academic departments. The greatest percentage of these migrants were in medicine (30 percent), electrical engineering (10 percent) and mathematics and chemistry (6 percent each).

One of the most interesting findings of this study emerged from its attempt to determine the extent to which the migrant scientists considered themselves to be physicists. Overall, about one-third of the scientists still considered themselves to be primarily physicists, another third considered themselves to be both a physicist and a scientist in the new discipline, while the remaining third considered themselves to be primarily scientists in the new discipline. In a related question, when physicists working in other academic departments were asked to characterize their field of research, only about 26 percent considered their research to fall entirely within the field of the other discipline. Most (62 percent) considered their research to be along the disciplinary border between physics and the other discipline, and 11 percent considered their research to fall primarily within the field of physics itself.

The physicists employed in other academic departments were found to spend approximately 13 percent of their time "advising others on research." The authors report that other studies of the activities on which academic staff spend their time "suggest that this activity occupies much less time or is even non-existent among non-migrants in most fields."

The authors conclude that "the results indicate that migrated physicists render a useful and important service. We suspect that persons trained in other disciplines lack the specific knowledge and capabilities that physicists generally possess. The migrants fill the gap. They are required to help deepen the results

obtained in research. They are expected to back up research results by giving theoretical interpretations and by developing formal theories."[13]

A similar view is reflected by Dael Wolfle when he speculates on the characteristics of people who move out of their original fields of research:

> "They are not the traditionalists whose interests lie close to the center of a discipline. Nor are they usually the people who have strong commitments to the discipline itself, the persons who write its basic texts or serve as its professional officers. They are more likely to be in one of the less specialized fields or subfields, to have interests that lie close to its disciplinary border, or to its applications, or to be interested in problems that are also of interest to persons in other disciplines ... In general, those professionals who switch fields constitute a flexible and capable element of the labor force that makes it possible for new areas of work to develop rapidly."[14]

D. Conclusion

The rapid advance of science and technology has meant an acceleration in new definitions of problems and phenomena to be investigated that frequently make demands on new combinations of skills, expertise and talents. As a result, new subject areas or specialties have proliferated. Often such developments represent the convergence of a number of traditional lines of inquiry in diverse existing disciplines. At the same time, the traditional boundaries that were thought to differentiate science from technology are dissolving, with science, engineering and technology increasingly synergistically linked.

The inter-field and inter-specialty mobility of scientific and technical personnel appears to play an extremely important role in the way in which the demand for R&D personnel in emerging areas is met. However, the mobility of scientists and engineers between fields and specialties of science also appears to be an important factor in the ways in which the various disciplines influence one another and come together in newly emerging specialties. Thus, apart from the important function of inter-field mobility in meeting short-run changes in market demand, the mobility of human resources is a significant factor in the transfer of knowledge from one discipline to another and in the synthesis of knowledge from diverse disciplines in "newly defined" scientific specialties. There are costs to mobility, but they are generally short-run costs. Because most jobs require some familiarization with the process or organization of the firm, an employee will not function at his maximum level of efficiency immediately upon assuming a new position; and costs such as these are probably even higher when the employee is undergoing a change to a field relatively unrelated to his field of training. However, given the importance of mobility to the effective utilization of scientific and technical personnel and to the advancement of science in general, such costs would on balance appear to be minimal. There are therefore important policy issues surrounding the question of how to maximize the opportunities and minimize the barriers to inter-field and inter-specialty communication and mobility.

Data Collection

One of the most immediate concerns is that the available data base is inadequate for a satisfactory analysis of the various dimensions of inter-field and inter-specialty mobility on which many of the rapid advances of science and technology depend. Some ambiguities associated with the existing data bases have been identified, but a design for the most effective approach to the collection of mobility data at the level of less-aggregate and rapidly changing specialties is needed. Without a better statistical base on which analysis and forecasts can rely, many of the issues that need to be addressed in the areas noted below cannot be adequately dealt with.

Education

What should education policy be? The increasing importance of the convergence of knowledge from diverse scientific disciplines to the further advance in many emerging areas has major implications for university training and research. For example, to what extent does concentration in the educational sector upon single specialties or highly focused curricula, as opposed to the most broadly construed technical curricula, essentially work against the job and specialty mobility of the science and engineering professional and prevent him from being capable of entering the variety of new fields that appear? Within the various specialty fields, it would appear that physics, a very broadly construed and very broadly educated field, has the greatest transferability; is theoretical physics being adequately represented in the curricula for the more applied science areas? What mechanisms can be established to facilitate greater communication between academic departments that have traditionally been separate? How important is on-the-job-training as opposed to specialized training courses in enabling individuals to move to new specialties?

Industry

As the boundaries between basic research and technological innovation fade, and industry increasingly draws upon scientific and engineering research professionals from universities as well as upon graduates at the bachelor's degree level, thus "eating its own seed corn," how is the type of research unfettered by immediate commercial application or proprietary secrecy to be conducted? What types of industry-university cooperative arrangements, including the sharing of people and facilities/instrumentation, could help mitigate this drain?

National Policy

Finally, what policies could or should be adopted by the Federal government to facilitate or encourage the movement of R&D personnel into new and rapidly expanding areas? Mobility in the United States is primarily guided by economic considerations – differentiation of salary, more rapid advancement, fringe benefits, etc. – with the decision to move into new areas made by individuals acting primarily in terms of what they perceive to be their own interest. Government-funded programs, however, can work to increase the private gains to individuals in certain selected fields, and thus while allowing individuals to maintain freedom of choice, simultaneously encourage them to select fields

which the government wishes to emphasize.

Although not addressed in this paper, mobility of scientific and technical personnel in the United States is considered to be much greater than in other countries, where other methods of adapting the existing supply of workers to changing demands for scientific and technical personnel have often been adopted. What are these methods and what might be learned from them?

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SURVEY TEAMS

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I. Historical Background

Overseas survey teams reviewed in this paper are those consisting of more than several members which are organized by government agencies and other institutions and are sent abroad on a relatively short term basis with the aim of collecting information relating to the policy-making decisions of the organizing bodies.

Being a small island country located in the Far East, historically Japan has been relatively isolated from other nations. Under this natural isolation, coupled with a unified culture and language, the Japanese people have absorbed the most progressive thought, knowledge and practical techniques from the advanced nations of the day and applied the knowledge thus obtained to the creation of an independent Japanese culture.

In the 4th through 5th centuries A.D., when a central government was emerging in Japan with authority over the entire country, techniques relating to agriculture and daily life were brought in by naturalized Korean and Chinese people. After the 7th century, the central government regularly sent government missions consisting of officials, priests and students to China and Korea in order to learn about these advanced cultures. In those days transportation was restricted to small boats in which a given envoy would ride as a team. *Kentoshi* (Japanese envoys to China) that had been successively sent by the Japanese government in the 7th–9th centuries were typical examples of this kind of arrangement.

However, from the beginning of the 17th century, when the Tokugawa government reunified the nation after 200 years of civil war, trade and cultural exchange with advanced foreign countries, like Portugal and Spain. were wholly prohibited. The government was apprehensive that Christianity brought in by missionaries from these countries might threaten the public order that was being restored at that time with the spiritual support of Buddhism, Confucianism, etc., which had already been transferred to Japan from China.

In 1853, M.C. Perry, commander of the U.S. East Indian Fleet, made a port call in Uraga with a letter from the U.S. President calling for the conclusion of a trade and commerce treaty between Japan and the United States. After several years,

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The views expressed in this paper are those of the authors and do not represent an official position of the Japan Society for the Promotion of Science.

the Tokugawa government signed the treaty, which was followed by the conclusion of similar treaties with other Western countries.

In the 1850's, the Tokugawa government, recognizing the importance of the development of modern industry, began to dispatch missions and students abroad. As the government authority began to fade at that time, feudal clans (local governments) also started to send similar missions abroad. However, successive dispatching of envoys, students and others on a larger scale had to await the Meiji Restoration, which had successfully reorganized the social structure to provide for the development of modern industry.

II. Brief history of survey teams sent as well as received by Japan since the Meiji Restoration

II-1 Meiji Restoration (1867) through the end of World War II (1945)

(1) Iwakura Mission

In November 1871, several years after the Meiji Restoration, the newly established government sent a mission headed by Tomomi Iwakura, Minister of the Right, who was concurrently appointed Ambassador Extraordinary and Plenipotenciary. This mission visited the U.S. and 11 European countries (United Kingdom, France, Belgium, Netherlands, Germany, Russia, Denmark, Sweden, Italy, Austria and Switzerland) over a period of about 2 years. The mission's objectives were: (1) to visit signatory countries of trade and commerce treaties concluded by the Tokugawa government, and to present the sovereigns of these countries with its credentials; (2) to begin preliminary negotiations concerning amendment of these treaties; and (3) to investigate the social systems and civilizations in these advanced nations in order to help Japan modernize. This mission headed by Minister Iwakura consisted of about 50 members, including vice envoys and such top government executives as Takayoshi Kido, Cabinet Councilor, Toshimichi Okubo, Minister of Finance, as well as talented junior officials who studied abroad. In addition to other duties, the mission members made inquiries into educational and research institutions and modern factories.

After returning to Japan, Kunitake Kume, a member of the mission, edited the *Beio Kairan Jikki*[1] (a record of the mission's actual activities in the U.S. and Europe), consisting of 100 volumes written in a diary style. In reality, the mission itself compiled two kinds of official reports: *Taishi Jimu Shomoku* (Envoy's Business Report, in 27 volumes) and *Rijikan-Shisatsukan Shomoku* (Councilors and Inspectors Report, in 4 volumes), and therefore this *Jikki* was seemingly not an official report. Mr. G.H. Verbeck, who had come to Japan earlier from the United States as a missionary but at that time served the government as an advisor, and upon whose recommendation the mission-sending project was initiated, said in his recommendation that all mission members, particularly secretaries, should write down in detail all information and impressions they received during their stay in foreign countries and should obtain as much information as possible in the form of transcriptions and printed matters. He also recommended

that this survey report be published for the benefit and enlightenment of the Japanese people. Iwakura, following his advice, assigned such a task to Kume and another official and was accompanied by the two men everywhere he visited. Thus, *Jikki* was in a way an official report. It contains excellent descriptions of overall viewpoints, scientific observations and other useful knowledge which remain pertinent even today.

In the *Jikki* Kume mentioned something about the fundamental cultural differences between Japan and these countries. With regard to cultural propagation and interchange among countries, for instance, he pointed out the following:

> The United States has a mild climate and large tracts of arable land, and has marvelously developed the nation's wealth, without parallel in the world, by transferring manpower from Europe and other areas, manufacturing sophisticated machines, etc. I think that this success can be attributed to the independent spirit leaders have and the fact that common men are provided with practical knowledge. However, this independent spirit is not inherent in this nation, and not contained in the general atmosphere of the land, but was brought in with the Europeans who migrated to the United States. Presumably, immigrants from other countries were refugees or vagrants, but among them there were distinguished people possessing both wealth and intelligence, who came to the United States in order to realize their ideals. They apparently felt their native countries were narrow in nature and dominated by undesirable traditional customs, and also hoped that the new world could accommodate their desire for free human life. In this respect, it might be said that the United States is a cultivated garden of Europe. It is due to this reason, that in the United States politics for the people has been able to achieve great benefit.

This description is seemingly very common and does not raise any question. However, in its explanation we can distinguish the viewpoint that the culture of the United States and Europe are identical in origin, and that therefore there exists a fundamental difference in culture between Japan and these countries; Japan had accepted Buddhism, Confucianism, Shintoism and Western rational thought, which were influencing each other and slowly permeating the daily life of the nation, while the West had long been cultivated by Christianity and a modern rational spirit. This cultural difference itself, which was one of the reasons that the Japanese government dispatched the Iwakura mission, basically remains unchanged even today, more than 100 years after the Iwakura mission. In this connection we would like to emphasize that what urged the dispatching of the Iwakura mission also urged many institutions to take this same action in the following period.

Because the mission's visit was made during the cradle period of Japan's modernization, and because the government officials who participated in the mission were fully responsible for policy-making in Japan, results of the survey made by the Iwakura mission exerted immeasurable influence on subsequent government policies in such fields as politics, industry, research, education etc.

(2) After the Iwakura mission to the end of World War II

For the purpose of developing Japan, transforming it from a feudal country into a modern one, the Meiji government rapidly imported science and technology from the United States and European countries, employing many foreign professors and engineers as well as sendig Japanese students abroad. Figure 1 indicates the number of these activities.

During this period we find no data indicating such large-scale missions as Iwakura's. Two possible reasons for this are (1) training of researchers, engineers

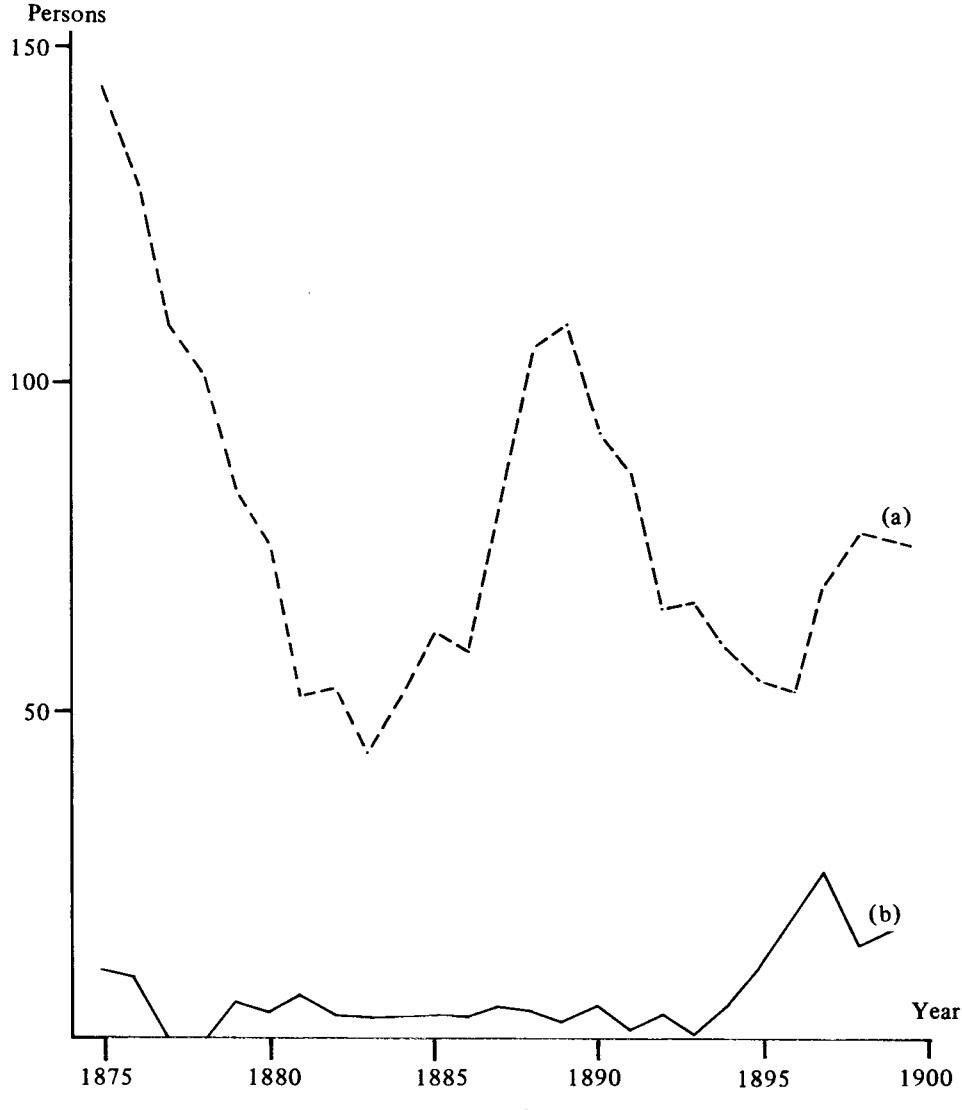

Fig. 1[2)]

(a) Number of foreign professors employed by the Ministry of Education, Science and Culture. (b) Number of Japanese students dispatched abroad by the Ministry of Education, Science and Culture

and specialists soon came to be carried out under the government's overseas student dispatching program, so that surveys in foreign countries were conducted by these elite individuals rather than survey groups, and (2) the modernization of the nation's research system was being realized through the establishment of national universities and research institutes as well as learned societies, so that interchange with foreign countries began to take place through affiliations with international academic societies and institutions.

Incidentally, many scientific and technological books and journals were coming in from abroad during this period as interchange with advanced foreign countries increased. Many of these books and articles were translated into Japanese. It was a hard task when one considers that the translators had to create tens of thousands of new Japanese words corresponding to foreign terms denoting concepts or objects that had not existed in Japan before.

II-2 Postwar period through the 1960's

(1) Visit of U.S. survey missions to Japan

During the years following the termination of World War II, several U.S. survey missions visited Japan, most of which were dispatched at the request of the Supreme Commander of the Allied Powers (SCAP), which was then encouraging the sweeping democratization of the Japanese social structure. After making thorough inquiries and exchanging views with Japanese nationals concerned with the issues, these missions submitted recommendations to the authorities. Main survey missions are shown in Table 1.

These missions exerted great influence on the reform of the nation's social system; in a sense, the changes which took place during this time were comparable in scope and depth to those instituted by the Meiji government 80 years earlier, reflecting SCAP's absolute authority.

(2) Exchange of students and researchers

Exchange of students and researchers, suspended during World War II, was reinstituted soon after the termination of the war. Exchanges made during the Allied Occupation were primarily conducted with the United States, and were for the most part based on U.S. invitations extended to the Japanese.

About 1,000 Japanese were awarded grants under the GARIOA program from 1949 to 1951, of whom 800 were researchers. In the earlier stages of the Fulbright Fellowship Program, which succeeded GARIOA, most of the Japanese grantees were education-related people who went to the United States with the intention of surveying the education system there, in order to develop a model for the reform of the Japanese system. It is interesting to note that during the period between 1951–1980, about 5,000 Japanese were awarded grants to pursue academic and cultural activities in the U.S. as lecturers, researchers, graduate students, and language instructors, while 1,200 Americans came to Japan.

Table 1. U.S. Survey Missions[3)]

Mission	Duration of visit	Recommendation
Education Mission headed by G.D. Stoddard, 27 members	Jan. – Feb. 1946	Reform of education system (to SCAP)
Scientific Advisory Group of the National Academy of Science	Jan. – Mar. 1947	Reorganization of research system in science and technology (to National Academy of Sciences)
Library Mission	Dec. 1946 – Feb. 1947	Establishment of the National Diet Library (to SCAP)
Cultural Science Mission, 5 members (E.O. Reischauer, etc.)	1949	Role, nature and financing of research in humanities and social sicences (to SCAP)
Educational Exchange Group, 5 members	Aug. – Oct. 1949	Initiation of educational exchange programs. (to SCAP)
Tax Mission, headed by C.S. Shoup	1949	New tax system (to SCAP)
2nd Education Mission, headed by Dr. W.E. Givens, 5 members	Sept. 1950	Follow-up of the first Education Mission (to SCAP)
Engineering Education Mission, headed by H.L. Hazen, 15 members	Jul. – Aug. 1951	University-industry cooperation, establishment of Engineering Education Society, etc. (to SCAP)

(3) Reopening and patternization of survey missions

In the 1950's, the Japanese economy made a rapid recovery, and exchange with other countries of the world began to develop in all sectors. One of the first government survey missions in science and technology after the war was the Atomic Energy Mission which was sent to the United States and European countries from December 1954 through February 1955.

In the 1960's, Japan had the highest economic growth rate in the world, with a GNP that quadrupled during the 10 years between 1960 and 1970. Reflecting this phenomenal growth, Japan's research expenditures also multiplied as shown in Figure 2.

Most of the survey teams currently active were first organized during this period, and have taken on stereotyped forms and functions over the years.

A. Government

The Council for Science and Technology. The first survey mission, headed by Sadaharu Suginome, President of Hokkaido University, was organized in 1960 with 12 members, including a few presidents of large companies. The delegation visited Great Britain, France, West Germany and Switzerland over one month period from September through October to study policies on promoting science and technology. In the report[5)] prepared after their return to Japan, Dr. Suginome

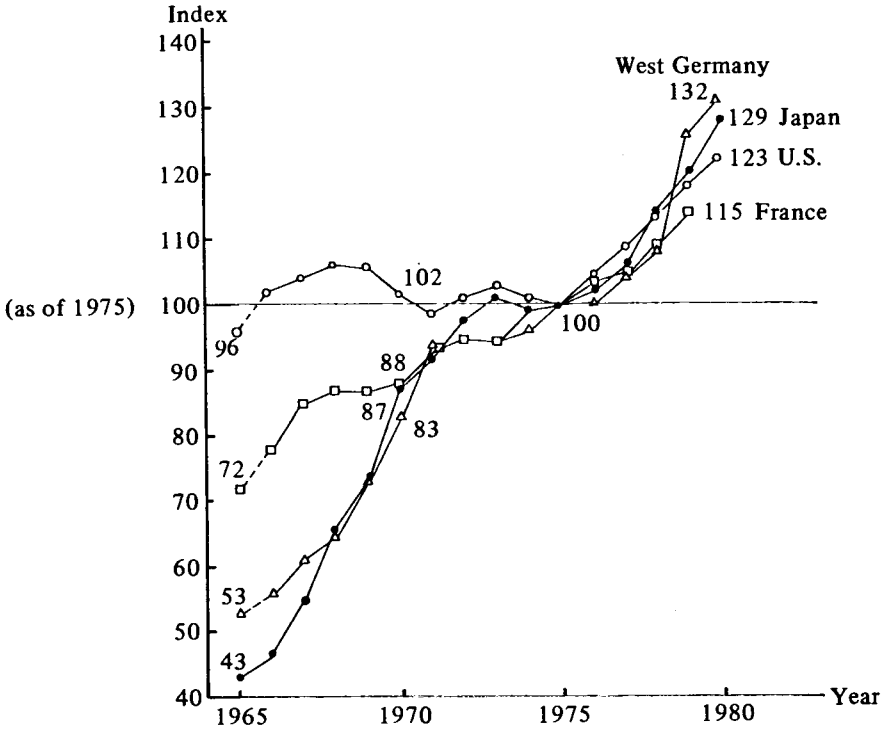

Fig. 2[4] Growth Rate of Substantial Research Expenditures in Main Countries

writes:

> We were deeply impressed, after making on-site inspections of scientific and technological facilities and talking with related personnel, with the fact that these countries have far exceeded Japan in their recognition of the importance of science and technology, as well as their emphasis on basic research. In particular, we were astonished by the restoration and modernization of student education programs and university facilities in the basic research fields of science and technology. Japan's present condition makes a striking and disturbing contrast, with old experimental equipment that has been in use since we ourselves were students decades ago, and with research allocations to university professors even half that of the prewar period.

This report, submitted to the Council for internal governmental use, was not intended for general distribution. However, private institutions, including the Japan Federation of Employers Associations and the Japan Federation of Economic Organizations, joined such government agencies as the Science and Technology Agency and the Ministry of Education, Science and Culture in discussing the issues that arose in certain specific fields covered by the report. As a result of these various discussions, appropriate measures were eventually formulated to improve the situation.

B. Private sector

The Japan Productivity Center, established in 1955 with the intention of attaining higher productivity through a nation-wide movement involving all social sectors, launched overseas survey programs the same year. The Center organizes survey teams consisting of business managers, company personnel and labor union leaders for the purpose of obtaining first-hand information on scientific administration methods and techniques in foreign countries.

The Japan Federation of Economic Organizations, since sending its first survey mission to Southeast Asia in 1956 to explore possibilities of economic cooperation, has organized survey teams on a regular basis to make inquiries into economic conditions and to exchange views with government, business and labor leaders in foreign countries.

The Japan Machinery Exporters' Association has sent survey teams on a regular basis to study different kinds of machinery since 1972.

II-3 1970's to the present

(1) Continuation of programs and their expansion

A. Government

The Council for Science and Technology has continued to send survey missions. However, after the second mission in 1962, mission members have usually consisted of middle-level government officials. Between 1960–1980, about 180 people participated in these missions. Countries frequently visited are West Germany (8 times), the United States, Great Britain and France (6 times each), Italy (5 times), and the Netherlands (4 times). During earlier stages of the program, advanced Western countries were generally selected, but since the latter part of the '70s, there has been a tendency to visit developing countries, including those in Central and South America, Southeast Asian countries, China, etc.[6]

Other government agencies began sending survey missions organized in two different ways; either the government agency itself organizes the teams, as is done for example with the Ministry of Education, Science and Culture's survey missions for fundamental planning on international educational cooperation,[7] or the government agency entrusts quasi-government or private organizations with implementation.[8] The latter method is more popular, particularly for survey missions to developing countries (see (2) below).

B. Private sector

The Japan Productivity Center dispatched about 13,300 survey team participants between 1960–1980, consisting of 3,900 participants to Europe, 9,300 to the United States and 100 to both the United States and Europe. During this period, the Center received about 1,900 participants of foreign survey teams. In FY 1981, for example, 39 teams with a total of 230 members from the U.S., 12 teams with 210 members from France, 4 teams with 40 members from the West Germany, etc. were received.[9] Besides survey teams that have been sent by the Japan Federation of Economic Organizations,[10] the Japan Federation of Em-

ployers' Associations began to send its survey team in 1970.[11]

(2) Survey missions to developing countries

The number of survey teams sent to developing countries with the aim of conducting preliminary surveys for economic and technological aid to those countries increased dramatically in the 1970's.

Development and Investigation Program of the Japan International Cooperation Agency (JICA).[12] JICA conducts an overseas survey program as part of its general activities. It organizes survey teams consisting of specialists who study social conditions relating to public development plans in developing countries and who compile reports or implementation plants to contribute to the development policies of these countries. In FY 1981, 14 teams were sent to Indonesia, 10 teams to Thailand, 8 teams to the Philippines, 5 teams to China, etc.

Overall Development Investigation Program of the International Development Center (incorporated foundation).[12] Prior to working out development plans in mining and manufacturing industries, agriculture, social development, etc., the Center organizes information collection teams at the request of the developing country in question and through Japanese government agencies. These teams draft overall development plans either for a whole country or for specific regions within that country, and prepare reports. In FY 1981, the following 10 survey projects were implemented at the request of government agencies: 3 projects for the Ministry of Construction, 2 projects each for the Ministry of Foreign Affaires and the Economic Planning Agency, and 1 project each for the Ministry of International Trade and Industry, the Ministry of Transportation, and the Ministry of Agriculture and Fishery.

III. Conclusion

As described above, survey missions sent abroad in the past in order to introduce new knowledge and social systems from advanced countries were very successful in helping to modernize Japanese society, as well as advancing the economy, science and culture of Japan. Due to our predecessors' efforts, and the kind cooperation extended to them by colleagues in foreign countries, Japan has recently achieved remarkable economic growth and rapid progress in science and technology.

Under these changing circumstances, the practice of sending survey teams on the same basis as in the past seems questionable. Results from recent survey teams are rarely as productive as those obtained by similar teams in both the Meiji period and the immediate post-war period. It seems to us that the most efficient means of collecting information now lies in free exchange between Japanese individuals or institutions and their counterparts in foreign countries, an exchange which can take place on a cooperative basis as they pursue their respective programs. It no longer seems possible for survey teams to obtain information

relating to the core of their subject simply by asking receiving parties to share their opinions and current status.

We also feel that the time has come for Japan to fulfill another role in international activities: not the role of collecting information from foreign countries, but that of disseminating abroad information concerning activities taking place in Japan. The need for this kind of activity has grown noticeably in recent years, as more and more people express interest in the scientific and cultural conditions in today's Japan.

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PROGRAMS IN APPLIED JAPANESE STUDIES: THE NORTH CAROLINA JAPAN CENTER AND ITS UNIVERSITY-INDUSTRY CONNECTIONS

Samuel K. COLEMAN*

I. Problems and Challenges

Trends in technical and scientific communication between Japan and the United States point to a growing need for knowledge of Japan's language and social organization among American specialists in science and technology. Contrary to prevailing assumptions, the American scientific community is not indifferent to Japanese research activity. Science and engineering faculty in universities in the United States are aware of Japanese contributions to scientific and technological knowledge and regard Japanese colleagues' research with interest. A 1982 survey that I conducted at North Carolina State University found faculty across a wide spectrum of scientific fields holding a very high regard for Japanese colleagues' research, and wanting more channels for collaborating with them. (Please see the appendix for a brief description of relevant results.) Granted, a sample of one university hardly provides a complete picture of university faculty attitudes nationwide, but North Carolina State is typical enough of large land-grant universities to merit serious consideration of the survey results. In addition, some United States university-based specialists have published evaluations of Japanese advances in their fields that call for a more serious regard for Japanese accomplishments and potentials. (See, for example, Kenney and Bowen 1983; National Research Council 1982.)

Accordingly, there is a growing interest in the United States in Japanese scientific and technical information (JSTI). A recent conference organized by MIT's Japan Science and Technology Program, sponsored by the U.S. Department of State, devoted itself to examining the importance and availability of JSTI. Among its conclusions were that, although American science and technology could benefit considerably from greater availability of printed information in the sciences from Japan, only a small fraction is currently available, and efforts to obtain it are piecemeal and uncoordinated (Gillmor and Samuels 1983).

The greatest obstacle to increased availability and use of JSTI is, of course, the Japanese language itself. There has been conjecture that Japanese technical specialists do not publish more in European languages because they are more

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intent upon contributing to their own organizations than seeking international recognition, and that only a concerted effort to "internationalize" research results will avert the danger of international frictions (Takayama 1981). Although Japan's volume of English language reporting of research results may indeed become an issue in U.S.-Japan tensions over technology transfer, it would be unreasonable – as the MIT conference participants agreed – to expect the Japanese to publish primarily in English: the Japanese experience as much difficulty in preparing manuscripts for publication in English as Americans do in translating Japanese articles; moreover, the primary audience for such communication is, understandably, other Japanese scientists, and an effort to convert all of these writings into English would slow the flow of scientific communication both within and without (Gillmor and Samuels 1983: 163). In addition, Japan is gaining a greater degree of independence in world political affairs, which could in turn prompt less of a sense of obligation to make some forms of information available in English.

A critical factor, then, in future scientific and technological communication between our two countries, will be the American scientific community's ability to assimilate information in Japanese – oral as well as written, for a considerable portion of information transfer takes place in face-to-face encounters, and such personal contacts will probably play an increasingly important role. The conclusion of the MIT conference on JSTI states the case well:

> . . . a major element in any long-term solution to the problems encountered in acquiring and utilizing JSTI is investment in programs to produce technically-trained people with a command of the Japanese language. For the vast majority of Americans . . . Japan remains a "black box." This situation will not improve much until reasonable numbers of scientific and technical personnel are available who can peer into the "box" and facilitate a more balanced exchange of STI (Gillmor and Samuels 1983: 164; see also Cooper and Jones 1983: 43).

Despite the importance of Japanese language knowledge to the American scientific community, we have yet to marshall our resources to promote Japanese language study among our younger scientists currently receiving their education. We need to facilitate Japanese language study among science students, articulate and advertise the new career opportunities for those who have Japanese expertise, and provide incentives for students who add Japanese language study to their already demanding curriculum. Currently, science students with an interest and ability in Japanese do not get sufficient encouragement. Take, for example, the case of the senior majoring in physics at the University of Michigan who, despite an A-average in Japanese and an overall grade point average of B, has decided to discontinue language study because "Japanese study requires a lot of time and the rewards just don't seem to justify the work." (This example comes from a three-university study in progress by Prof. Hiroko Kataoka, Language Coordinator for the North Carolina Japan Center. Her University of Michigan sample of 98 Japanese language students has only 7 majors in the sciences.)

The current orientation of university administrators and Japan specialists hinders their ability to help produce a new generation of scientists with Japan expertise or to play a facilitating role for American scientists who are eager to learn more about developments in Japan. University administrators tend to classify all "international" activities as acts of American good will (in which information only flows out from the U.S. source), or as efforts toward such abstract goals as mutual understanding or a well-rounded education for their students. One indication of this approach is in student exchange programs; American administrators overlook the benefits of information *in*-flow and network-building from foreign students who come from Japan and other OECD countries (see, for example, Goodwin and Nacht 1983). Contributors to a 1982 special edition of *Engineering Education* on international education programs failed – to the editor's dismay – to include any articles concerning projects involving other industrialized countries (Bugliarello 1982: 266).

Academic Japan specialists as well have not recognized the need for programs to aid the American scientific community. The only professional association for Japanologists in academia, the Association for Asian Studies, has not evidenced any interest in activities to assist the scientific community. (A panel proposal on the subject for the 1984 national meeting was rejected.) A dramatic increase in Japan-related courses in graduate-level professional programs has been taking place in colleges and universities; they represent mostly heightened interest in Japanese business management practices, however, and academic Japanologists view the trend skeptically as a "fad" (Japan Foundation/Social Science Research Council 1983: 4–5).

II. Solutions and Potentials

The organizational structures generated to support university-industry cooperation in the United States could be very useful for improving Japan-related knowledge in the American scientific community as well. U.S. universities are playing an ever greater part in supporting technological innovation through links with industry in research and education (National Science Board 1982; U.S. Government, General Accounting Office 1983).

The following factors appear important to successful university-industry collaboration (see the 1983 U.S. Government GAO report): commitment on the part of university administrators and faculty to allocate a portion of university research and expertise toward industrial needs; strong leadership enjoying the respect of both academic and industrial communities; sustained sources of funding; and – in the case of research parks – a measure of luck (circumstantial factors beyond administrative control).

These ingredients are evidenced in North Carolina's Research Triangle and in the industry-related programs of North Carolina State University, the most active university partner with Triangle research firms and agencies. The Research Triangle is a three-cornered area in central North Carolina bounded by Duke University in the city of Durham to the northwest, the University of North

Carolina at Chapel Hill to the west, and North Carolina State University in Raleigh, the state's capital, to the southeast. In its center is the Research Triangle Park, a 5,800-acre tract currently containing some 45 research-oriented firms and agencies with a workforce of about 20,000. One measure of the park's success is the economic development it represents; its buildings are worth over a billion dollars, and new investments totaling over $100 million are either completed or are in the working stages.

The park originated in the late 1950's, when a group of North Carolina citizens acquired the land that constitutes the park and endowed the Research Triangle Foundation with it. (The Foundation, a non-profit organization, manages the park.) The concept received the cooperation and encouragement of the state's government; like the citizen's group, the then Governor, Luther Hodges, was concerned about out-migration of the state's university graduates, and recognized knowledge-intensive industry as the most promising course for the state's economic development. Through the state government, the three major universities in the area participated in the planning of the park. Together, they formed the Research Triangle Institute, under joint ownership but separate management. The Institute, together with the Chemstrand Research Center, became the park's first residents in 1960. The dramatic growth of the park only began some five years later, however, when IBM designated the place for its development and manufacture of communications equipment and the U.S. Environmental Protection Agency announced its plans for placing its Environmental Research Center in the park.

The park's history reflects the ability and the perspicacity of the state government. Note also that the universities were oriented from the very beginning to responding to industry needs and interests. The sizeable land investment in a strategic area had created a solid base for subsequent growth. Luck played a part in the natural amenities of the region, which enjoys a mild climate and scenic variety – important "quality of life" factors. One might also assign to luck the contiguity of three prominent universities.

For North Carolina State University in particular, responsiveness to industry needs antedated the Research Triangle Park: it was a condition of the university's creation. The university was founded in 1887 under the terms of the Morrill Act of 1862, the federal government's first effort to foster university-industry cooperation. The law authorized creation of land-grant colleges to provide an academic base in agriculture and the "mechanic arts."

NCSU has taken the model of agricultural extension – the United States' oldest recognized system for transferring technology from university to industry – and has modified and elaborated on the theme in non-agricultural industries. These non-agricultural programs have stature and scale in the university that approach its agricultural extension. The Schools of Textiles, Engineering, and Forest Resources have particularly strong links with the research and educational activities of the university. The educational activities of these programs include short courses in company workshops, packaged courses for continuing education

in engineering, and videotaped and televised courses. The constituencies served by these programs are generally well-organized politically, which helps assure continued state support (U.S. General Accounting Office 1983).

NCSU's interaction with the Research Triangle Park has mostly taken the form of education and consulting. The number of cooperative research projects involving area industries, such as the Center for Communications and Signal Processing, has also grown in recent years, however. In addition to information transfer, one of the primary benefits to NCSU in its relationship with the Research Triangle Park has been the teaching talent available to the university from area industries' specialists; in 1983, some 220 specialists held adjunct positions in the university.

The North Carolina Japan Center at North Carolina State University has created and promoted its Japan-related activities in science and technology by linking up with the university's industry-related programs. The Japan Center was established in 1980 at NCSU by Governor James B. Hunt, with $140,000 from the State legislature and significant additional funding from the university. The state's creation of a Japan Center represents part of a series of investments designed to foster cooperation among industry, universities and the state's government in developing the state's economy. Contemporary developments with the same objective include the Microelectronics Center of North Carolina and the North Carolina Biotechnology Center. The Japan Center was established primarily to make the state more attractive to Japanese capital, but it was given a broad mandate to conduct Japan-related activities for the benefit of the state. Its location at North Carolina State University reflected the planners' desire to draw upon and complement the university's greatest strengths: science, technology and public service.

Under the Center's first formal program, the Faculty Fellows Program, some 30 faculty members and professional staff were trained in elementary Japanese and provided a four-month period in Japan for professional activities. Ten of the Fellows are scientists and engineers; and another four are specialists in library service or televised educational production.

The Japanese language program at NCSU, the largest in the southeastern United States, is noteworthy in its student composition; over half of the regularly enrolled graduate and undergraduate students taking Japanese are majoring in the natural and applied sciences, and they are our best language students. This representation of the sciences in a Japanese language program results partly from a language program that is more accessible to such students because the number of weekly class hours is less than that of the typical Japanese language program. It also represents active promotion beyond the traditional target population of students in the humanities.

Most of the Center's programs have grown along the lines of university extension and public service programs. The Center has been providing a ten-week on-site language and culture course to IBM's quality assurance staff, who travel to Japan frequently. The course enables the traveler to Japan to interact with

Japanese colleagues with more self-confidence and fewer misunderstandings, and to be more independent when negotiating basic traveling tasks in Japan. The Center is also preparing a packaged course with the same objectives for the continuing education of businesspeople. Another Center project adapts some unothodox but highly effective televised education methods from an extension program; through one of the Fellows, an innovator in videotaped educational productions for the School of Textiles (Teacher Oriented Televised Education), we have devised a well-structured course in Japanese with qualified supervision for small and geographically dispersed groups of students.

Clearinghouse activity relating to scientific and technical publications from Japan takes place through the university's Technical Information Center. Its director, another Center Fellow, has identified over 350 technical periodicals from Japan in the library's collection, 213 of them current. The Japan Center has also provided information on technical translating services to university faculty and to industry, as well as travel-related information for those who go to Japan in the course of their professional work.

One other Japan Center contribution to improving scientific and technical communication between Japan and the United States resides in another adaptation of an existing NCSU program, Cooperative Education. Under the program, students alternate periods of supervised employment with their classroom courses. There are approximately 500 engineering students currently involved in the program. In the Japan Center version, students who have career goals that could benefit from Japan expertise, particularly students in technical and scientific majors, become eligible if they have demonstrated superior performance in the study of the Japanese language as well as maturity and solid achievement in their fields of specialization. Successful candidates spend a three-to four-month period as interns at cooperating firms in Japan, including affiliates and subsidiaries of U.S.-based companies. The program has just begun with two students who were accepted by Japan IBM's Fujisawa Development Laboratory to work in their respective fields of electrical engineering and computer science. This program will probably remain small for a good while to come because we are adhering to a stringent set of selection criteria, but it should nevertheless help encourage Japanese language study among our students in the natural and applied sciences.

These confluences between Japan Center programs and existing university structures are extremely recent; the issue of activities involving Japan, as of 1980, had been entirely new to North Carolina State University. Up until then, there was no Japanese language offering, save for a self-instructional program involving one or two students. There had been (and still is) no East Asian studies program.

Japan did previously enter university history: the first foreign graduate was Japanese (an 1898 Bachelor of Science degree in Engineering); and the university's Provost from 1962 to 1974, Harry C. Kelly, had had a distinguished postwar career of cooperation with the Japanese scientific community. Unfortunately, however, neither of these individual connections had any programmatic

results. (NCSU's lack of institutional connections with Japan makes the results of the faculty survey summarized in the Appendix more noteworthy.)

Adding the Japanese dimension to university activities has necessitated knowledge and skills that overlap with those of academic Japanology but are intrinsically action-oriented. What does one teach an engineer in industry who has just been assigned to Japan? How does one apply knowledge of Japanese social organization to the structuring of collaborative research projects? How can Japanese language education best be structured for the demanding curriculum of a physics major? These are a sample of the questions that involve Japan expertise.

The Japan Center is not unique in addressing such challenges. The MIT-Japan Science and Technology Program is a kindred organization in goals and, in some cases, a leader in approaches. New York University has been planning a program that will encourage Japanese language study among computer science majors, and Ohio State University is investigating a number of possibilities for Japan-related programs in science and technology. All of us share the task of putting our Japan-related knowledge to the service of the scientific and engineering community.

Despite the increasing call for the practical use of Japan-related knowledge within the university, there has yet to emerge such a subdiscipline among Japanologists. It is easy to imagine such a specialization; just as, years ago, anthropologists created Applied Anthropology to promote the use of anthropological concepts in structuring, analyzing and evaluating social programs, the current needs of the American scientific and industrial sector call for Applied Japan Studies. If the reader will forgive a homely analogy, social scientists have long been aided in their statistical analyses of large data sets by packaged programs created specifically for their use by computer specialists. Similarly, scientists in academia and industry could benefit from a distillation of Japan expertise that is formulated with their needs in mind, given the limitations of time and energy that prevent these people from becoming full-blown Japan specialists in their own right.

Universities with extensive industrial cooperation provide the best context for applied Japanology, not only because demand is greatest there, but because – perhaps more importantly – such schools encourage practical applications and public service as legitimate intellectual endeavors. Moreover, America's best examples of university-industry cooperation may eventually provide a new locus for expanded joint U.S.-Japan high-technology projects in which the private sectors of both countries can participate extensively. Their success, in turn, will require a new generation of American scientists and engineers with a working knowledge of Japanese language and society. It is the university with an applied Japanese studies orientation that will produce these experts.

Appendix

NCSU Faculty Survey Summary

Date of Survey: November, 1982
Location: North Carolina State University, Raleigh, North Carolina, U.S.A.
Population: 1,384 Rank Faculty (lecturers, tenured faculty, and tenure-track appointments)
Responses: 819
Return Rate: 59 percent
Major Findings: 23 percent of the sample reported some form of current professional involvement with Japanese colleagues.

Over a third of the sample indicated that they were interested in developments in their field in Japan but lacked the channels for making use of them.

30 percent of the sample gave an "excellent" rating to Japanese research in their field. Of the nine schools within NCSU,[a] the six science and engineering schools registered the highest evaluation of Japanese colleagues' research. The mean evaluation, where 4.0 = "Excellent," was as follows:

School	Mean Ranking	No. of Question Respondents	No. of Survey Respondents
Engineering	3.68	59	73
Physical & Mathematical Sciences	3.59	91	123
Textiles	3.59	22	28
Veterinary Medicine	3.55	33	45
Forest Resources	3.48	21	39
Agriculture & Life Sciences	3.47	169	264

Variation among departments was considerable. Copies of the full survey report are available on request to the North Carolina Japan Center.

[a] The other three schools are Design, Education, and Humanities & Social Sciences.

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