# PART V: CONCLUSIONS AND RECOMMENDATIONS

# FUTURE DIRECTIONS FOR ENGINEERING EDUCATION: AN NSF PERSPECTIVE

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## INTRODUCTION

The education of an engineer should be continuous: an uninterrupted flow of knowledge and experiences, from primary through graduate school, and continuing through professional employment. Moreover, the preparation for engineering education is as important as engineering education itself. Pre-college education and pre-engineering education in college are crucial to the preparation of people for tasks they serve, whether in industry, government, or education.

Engineering education in the United States is as studied and self-critical as any of the professions. The reports of these studies tend to emphasize what can be improved and what is needed. The suggestions come from nearly every sector, and often the problems or shortcomings are overstated. In reading these reports one could easily get the false impression that engineering education in the United States has not contributed significantly to the many tasks facing engineers. But, it is important to keep in proper perspective the accomplishments as well as the criticisms.

Advances in communications, transportation, construction, and engineered materials have contributed much to our way of life. However, new directions are needed to meet future needs [2]. One area that is emerging in this new perspective is to place added emphasis and resources into undergraduate and pre-college education. This new dimension would complement the traditional education which has been for some time principally at the graduate level.

## ENGINEERING AND SCIENCE

Engineering and science are often considered as parallel in their approaches. However, it should be recognized that although science provides a strong and needed base for engineering, an equally important aspect for engineering is the role of technology-driven forces. Whereas analysis is the principal approach for science, synthesis is the principal approach for engineering. In engineering, analysis follows synthesis, with iterations provided to improve the resulting solution, therefore, the practice of engineering is based on problem identification and problem solution. The common thread of all engineering fields is design, and to improve a design is a major objective of the engineer; done through synthesis and analysis.

These distinctions carry over into the educational focus possessed by both engineering and science. During the past fifty years, schools of engineering have been established at universities alongside or following science departments, especially in the case of graduate programs. In most cases, these science departments have predominated in setting policies and procedures. Science units or fields of science which emphasize analysis need peer approval to build their reputation. Likewise, engineering units seek peer approval, but also must satisfy the needs of their clients -- the students, graduates, and employers -- if the national interest for competitive production is to be served. As competitiveness on a global basis has become more significant, engineering and engineering education have become more important. Thus, a complementary role between science and engineering is developing in the United States, and the educational programs need to reflect this relationship.

## CHARACTERISTICS OF ENGINEERING EDUCATION

Most engineering students enter the profession after the four-year B.S. degree. On the average, students take about four-and-a-half years to complete this four-year program. Thus, engineers enter their practice fields following the B.S., in contrast to many other professions in which a Ph.D. is required in preparation for entrance into the field. Engineering is not monolithic in that there are many different fields involved, as different as the fields in science. There are many parallel engineering and science fields, such as: chemistry and chemical engineering; physics and electrical engineering; physics and mathematics and mechanical engineering. In fact, there are over 30 engineering fields with accredited undergraduate curricula. Educational institutions and the accrediting agencies strive to assure that all fields have a basic core of knowledge in engineering. At least half of the course requirements are common for all fields of engineering, which provide a uniformly strong base but also permit considerable movement of students and graduates from one field to another. Some employers do not recognize the common background of engineering education; there is too great a focus on the degree rather than course work, which may limit the appropriate utilization of an important human resource.

Legally, graduates become registered engineers after having four years of practice and passing two examinations. These examinations assure a minimum level of competence in the fundamentals in all fields of engineering and provide for professional practice. This, of course, does not guarantee excellent performance, but minimizes the number of unqualified people practicing in the field, particularly where safety is involved.

Accreditation is used as a means of maintaining a minimum quality of engineering education at the first professional degree, usually at the B.S. level. Criteria for accreditation are developed in response to input by sponsoring organizations, industry and academia. Although accreditation is often blamed for limiting curriculum flexibility, it is often not recognized that one-fourth of the total curriculum can be specified by the institution, and not the accreditation agency. One-fourth of the curriculum is in sciences and mathematics, one-fourth in engineering sciences, one-eighth in engineering design, and one-eighth in humanities and social sciences. There is flexibility of courses and course content within these criteria. These criteria for accreditation are re-assessed and adjusted annually. There is also flexibility in accreditation policies to provide for and encourage experimentation to develop curricula not presently identified in universities, and to try different courses and approaches to meet various educational needs.

Upon graduation, most engineers enter the private sector. Most of these students enter their fields at the bachelor of science level, and the preparation for work on a particular task is of necessity minimal in undergraduate engineering education. There are no teaching "hospitals" or similar arrangements to help prepare graduates for activities in these other arenas. While laboratories and work experience help provide "experiential" skills, the major effort must be done by industry. A research experience for undergraduates would be exciting, challenging, and valuable, but more than one-half of the B.S. engineering students graduate from non-Ph.D. engineering institutions, where research opportunities are limited to faculty.

Large companies have training programs to help new engineers to become productive in an industrial environment. Thus, large companies that attract the highest ranking students have been quite complimentary about the high quality of graduates. However, managers of small companies generally do not feel that they have the resources to provide extensive training programs for recent graduates. Consequently, managers of small companies are often critical of a number of graduates because of their lack of ability to apply knowledge in an innovative and creative way. This criticism cannot be ignored, since the U.S. is highly dependent on small companies for innovation and creative products and processes which provide new job opportunities. It is imperative that more attention be given to the preparation of graduates to meet these needs.

## RESEARCH AND EDUCATION - NSF ROLE

From its beginning, the National Science Foundation has been responsible for providing support for research and human resources in science and engineering to meet future needs. NSF does not generally focus on research and educational problems to meet local and immediate needs, but on those that are seen as important issues nationally or which require in-depth planning. Other departments and agencies of government known as mission agencies are expected to focus on the more immediate problems. The role of the National Science Foundation is to support research and education of generic long-term importance not being carried out by or assigned to mission agencies.

The emphasis is on supporting quality programs, which means that proposals are judged on the basis of excellence or quality. The Foundation does not identify detailed problems to be solved or projects to be supported. It makes known its areas of emphasis in broad fields of endeavor, and often identifies some specially targeted fields for support.

But it is the external community, primarily in universities but also in other organizations, which sets the focus by submitting unsolicited proposals to help pose certain questions or solve problems. In that respect, the majority of our funding is used as "grants" in contrast to having "requests for proposals" to answer a certain problem or to meet a certain need. Proposals are evaluated using peer reviews and the judgment of program directors.

### Infrastructure

Another role for NSF is to develop and maintain the appropriate infrastructure for long-term education and research. Some of the emerging fields, such as lightwave technology, bioengineering, and biotechnology have been identified in engineering as those which are important to the future of the country. These require additional support if the infrastructure is to be developed which will provide the needed capital and human resources for research. In order to build the infrastructure, research is supported which is expected to involve and produce more engineers to meet future needs.

### Catalysts

The money needed to provide the required human resources would require funding far beyond that available to NSF. On the national scene, NSF is one of the smaller actors in research support, at about 1.3 billion dollars per annum. Thus, we cannot expect to provide the direct impact that might be desired. NSF must allocate its own money wisely, but also can be a catalyst to efforts by other government agencies, academia and industry. Thus, through our programs and experiences we expect that other agencies and institutions will be stimulated to continue or enlarge activities demonstrated by NSF to be important.

### Leadership

The leadership role of NSF is extremely important in assuring that those activities taken on by the Foundation which might be catalysts for others will elicit a significant response. Likewise, it may be determined that a particular response may not be the way to go. NSF provides this leadership by tapping and utilizing the best people in the field, in both industry and academia, to provide guidance, review, and suggestions through individual meetings, workshops, review of proposals, and special agency activities.

## GRADUATE ENGINEERING EDUCATION - NSF ROLE

One major area of emphasis for NSF is supporting graduate students in science and engineering. Last year approximately 13,500 graduate students were supported as a part of research projects. Another 1,650 students were supported by fellowships (SEE). Of these, 2,450 were supported on engineering projects, and 325 on fellowships. Thus, NSF support covers about 15 percent of the full-time graduate students enrolled in doctoral programs.

The student-professor bond is quite strong in these graduate programs and has led many students into academic careers in both science and engineering. Unfortunately that trend has not continued during the past ten years. As a result, critical shortages of faculty have resulted in several engineering-related areas. This is a major concern of NSF, and of educational institutions and industry as well.

To help attract and keep outstanding people in educational institutions, special programs have been developed by NSF, such as PYI's and minority assistance. There are also special activities in the Directorates, such as increased stipends (SEE), and the Engineering Initiation Award (ENG).

The graduate research programs help develop the capability for teaching undergraduates as well. Supporting research and graduate programs in academic institutions helps to develop infrastructure and undergraduate education in new areas such as biotechnology, microelectronics, bioengineering, and lightwave technologies.

## UNDERGRADUATE ENGINEERING EDUCATION - NSF ROLE

The National Science Board (the policymaking body of NSF) Task Committee on Undergraduate Science and Engineering Education has just completed a year-long study [4]. One important conclusion of the study is that serious problems of quality have developed during the past ten years in college-level education in mathematics, engineering, and the sciences. The Committee, following extensive hearings and studies, has recommended an increase of 100 million dollars in the Foundation's budget in the form of "leveraged" program support, working with States, universities, industries, and other government agencies. Included in this support would be money for laboratory development, instructional equipment, faculty professional enhancement, course and curriculum development, undergraduate research participation, and other activities. Since 1981, the Foundation has not been involved in course and curriculum development except in pre-college education. But the National Science Board is challenging NSF to put greater emphasis on undergraduate science and engineering education.

The Board realizes that undergraduate engineering education is a link in a system of education which prepares the practitioners and provides leadership to meet the future needs of the country. The quality is as important for undergraduate education as for the education that precedes and follows the bachelor's degree.

At the present time, many of the top engineering undergraduates go directly into the private sector, mainly because of the attraction of high salaries there as compared to faculty salaries they would earn if they continued on to finish their Ph.D. Graduates of top quality must be attracted to continue their studies at the Ph.D. level to maintain the quality of the undergraduate link. Both the government and academia alike must take steps to increase the attraction of graduate work in the engineering field, through generous stipends to graduate students, higher faculty salaries in engineering and other measures.

As the total pool of 18 to 22 year olds decreases in the coming years, it appears unlikely that engineering will continue to corner the market on the top high school graduates. When the quality level drops, the effects of the weakened state of undergraduate education will become all too clear. In contrast to quality, the quantity of engineering graduates at the B.S. degree level responds to the demands of the marketplace.

Following the report of the National Science Board, a workshop on undergraduate engineering education was organized to focus on analyzing that report plus other published materials. The workshop identified a number of problems confronting engineering education and linked them to the changing environment in which engineering will likely be practiced by the turn of the century. Highlights of this changing environment include [5]:

- "Need for public/private sector versatility in the practice of engineering (recognizing differences in management objectives);
- Shortage of raw material as well as capital resources;
- An increasingly global economy;
- Rapid scientific and technological change;
- Need for increased economic awareness."

Additionally, the studies indicated the increasingly interdisciplinary and cross-disciplinary nature of engineering.

Based on the projects of the environment for the practice of engineering, a number of issues for engineering education were identified. These include:

- "A broadly based undergraduate curriculum which recognizes the wide spectrum of kinds of engineering positions and may postpone deep disciplinary specialization;
- Stronger non-technical education;
- Experience in computer technology;
- Orientation to the realities of the work world;
- Personal career management;
- Development of management and communication skills;
- Preparation of continuing professional education."

## NSF - ISSUES AND CHALLENGES AND RESPONSES

The National Science Foundation has supported many activities, studies, workshops, and reports to help identify the major needs of engineering education in the U.S. The needs of undergraduate and graduate education are closely intertwined. If one views engineering education from the standpoint of improved products and processes to meet customer and client needs while being competitive, the following three major issues emerge [3]:

1) Provide stimulating experience for students via a high quality working environment, with up-to-date equipment

and instruments in order to enhance learning and to obtain knowledge of the state-of-the-art of engineering.

2) Provide modern, up-to-date instructional curricula and support materials to more adequately prepare graduate engineers to enter their professions and to be responsible and responsive members of their communities.
3) Maintain faculty quality by maintaining competent, effective, innovative and creative attitudes while being a good role model for future engineers in industry, government, and university.

The major response of the Foundation to meet several of the needs of engineering education and research has been to establish Engineering Research Centers with major funding levels. Eleven such Centers have been established, with 25 Centers as a goal over a five-year period. The study panel which provided advice to the Foundation recommended that: (1) "The goal of the Centers is to improve engineering research, so that U.S. engineers will be better prepared to contribute to engineering practice and to assist U.S. industry in becoming more competitive in world markets. Thus, engineering research and education must be firmly linked in these Centers and they must be judged by their success in achieving this linkage. More specificially, the study panel concluded that:

1) "The specific working ties with industry must provide a continual interaction of academic researchers, students, and faculties with their peers (namely the engineers and scientists in industry) to assure that these programs remain relevant to the needs of engineering practice and that they facilitate and promote the flow of knowledge between the academic and industrial sectors.
2) The programs of each Center must emphasize the synthesis of engineering knowledge, that is, the program should seek to integrate different disciplines in order to bring together the requisite knowledge, methodologies, and tools to solve problems important to engineering practitioners.
3) The programs must contribute to the increased effectiveness at all levels of engineering education."

In addition to the above, several other innovative programs help improve engineering education. For example, NSF recently initiated an experimental University/Industry/Government (U/I/G) Partnership for Quality Engineering Personnel program. One million dollars was provided to strengthen the ties between industry and university and to move knowledge and experience from the industry to the classroom.

Special support is also available for equipment for both instructional and research purposes, and it is used interchangeably for teaching and research. The equipment becomes part of the infrastructure for improving academic institutions.

In addition, the special programs to encourage the participation of undergraduates in research and the participation of underrepresented groups in research are being strengthened. The programs enhance the research-educational link which we are striving to strengthen.

There are other changes, too, particularly educational ones, which reinforce the emphasis NSF wants to project. For example, a new Division, titled Design, Manufacturing, and Computer-Integrated Engineering (DMCE), provides research support to assist educational institutions in building a knowledge base in such subjects. By developing this base, the country will benefit from a student who is better educated in these areas to meet tomorrow's needs. Likewise, a new Section in Emerging Engineering Systems helps establish engineering infrastructure for Lightwave Technologies, Bioengineering, Biotechnology, and Computational Engineering. A College Science Instrumentation Program (SEE) which also assists in laboratory development helps a limited number of institutions to improve undergraduate education.

## SUMMARY

The National Science Foundation is challenged to provide for this nation the best engineering talent in the world. A quality engineering manpower base is essential to maintain technological leadership. Faculty and students of high quality must be encouraged to venture into new areas of importance to the country. The combination of outstanding students in an appropriate study and work environment with a challenging up-to-date study program and an inspiring faculty are needed so that the quality of undergraduate engineering education equals or excels the other links in the educational system. This system must be interactive with industry and government people. The involvement of engineers in research at the undergraduate level, along with faculty, provides a mechanism to challenge creativity and innovation, and to better prepare human resources to meet future needs. The Engineering Research Centers (ERC) program adds a new cross-disciplinary dimension to engineering education. A quality engineering manpower base can provide the technological leadership that is an essential ingredient in economic competitiveness. NSF is positioning itself through its programs and actions to support new directions in engineering education.

## REFERENCES

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# DYNAMIC INTERACTIONS BETWEEN TECHNOLOGY TRANSFER AND ENGINEERING EDUCATION

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## INTRODUCTION

Science and technology policy should be analyzed within the general framework of policy science. However, there are some aspects which differentiate it from policy analysis in other areas, such as welfare, public works and financial policy.

I will describe here three of these aspects, which are relevant to technology transfer. These are: 1) the concept of demand articulation, 2) the sequence in technology assimilation, and 3) the manpower planning for engineers.

These three subjects are interrelated with each other in a dynamic way and are supposed to form the core policy agenda in government science and technology policy bodies and planning administrations, as far as technology transfer is concerned.

## DEMAND ARTICULATION

Science and technology policy planning is often defined as the process of transforming national needs into S&T requirements. Much effort is spent to identify national needs and to translate them into an S&T plan. However, very little effort is spent building the social process of identification and translation of demands.

It is very often assumed that the demand for S&T can be articulated without effort and cost. Several recent analyses indicate that this assumption may not be true. The conditions for accurate demand articulation instead consist of appropriate social mechanisms and people who are capable of identifying needs and of formulating strategies to satisfy needs.

It is said that the Japanese I.C (Integrated Circuit) industry has caught up with and passed that of the United States because of the Ministry of International Trade and Industry (MITI) policy of establishing the Engineering Research Association for Very Large Scale Integration (better known as VLSI) development, in which the major competing IC manufacturers are engaged in joint research. According to one analysis of the association, joint research resulted in members of the association jointly articulating their demands for IC manufacturing equipment, although none of the members was an equipment manufacturer. This articulation of demand by the association led to the creation of several equipment manufacturers and the entrance of existing firms into the equipment market. Thus, joint research of IC manufacturers had built an infrastructure of IC manufacturing, through articulation of demand for the IC manufacturing equipment.

In the field of comprehensive national planning of science and technology, more attention should be paid to identifying the policy means and the social mechanism for articulating demands for science and technology and to building such mechanisms into society.

## SEQUENCE OF TECHNOLOGY ASSIMILATION

It takes time to assimilate technology. It follows that the sequencing of technology assimilation deserves more attention. The following is a tentative conclusion drawn from some Japanese experiences. Although details need to be verified, I will attempt to clarify what I mean by the term sequence of technology assimilation.

We can assimilate technology only after the domestic demand for it has been articulated. It is often said that we should first assimilate the basic technology for upstream industries, as these form the industrial infrastructure. However, the technology for upstream industry cannot be assimilated unless it is known how downstream industries will use the outputs of the upstream industries.

We can articulate the demand for the upstream industry only after we assimilate the technology of the downstream industry. If we follow the logic of demand articulation the assimilation of downstream industry should precede that of upstream industry. In fact, without prior assimilation of downstream technology of oil products, Japan could never have assimilated oil refinery technology to produce fuel for automobiles with lower gasoline content.

An analysis of the growth of Japanese leading industries after World War II suggests the following observation. We could assimilate the technology for machine tools and computers, only after we finished assimilation of industrial technology for steel, shipbuilding, petrochemicals and automobile, which are the main user industry of computers and machine tools.

## MANPOWER PLANNING FOR TECHNOLOGY TRANSFER

Since technology transfer is a very dynamic process, the planning of technical manpower should be dynamic. The technology transferred changes over time in its fields as well as in its level of sophistication. Therefore, dynamic planning of technical manpower should include phased planning as to how much technical manpower supplied is to be increased over time. The point of analysis is whether there is a mismatch between the technology being transferred and the manpower being supplied; in terms of both quantity and quality.

The Japanese school system is described in Figure 1. The changes in the percentage of the enrolled students in the appropriate age groups at various levels of schools are shown in Figure 2. As early as 1920, we could attain almost 100 percent of attendance at elementary school, while the percentages of higher education started to increase as late as 1960.

A long-term history of Japanese engineering school enrollment is shown in Figure 3. The number of engineering graduates from lower secondary school levelled off around 1920. A rapid increase of the graduates from upper secondary school began before 1940 and that from technical colleges began after 1940. It was only after 1960 that the rapid increase of engineering university graduates began. It was after 1970 when the percentages of engineering graduate education became viable.

Since technology transfer is a social process, participation in this process is not limited to the engineers. The role of non-engineer is very important. In many cases, technology transfer begins with the import of machinery, and the repair and maintenance of imported machines follows before the technology is successfully assimilated. We need graduates from business schools who are engaged in the trade of imported machines and many technicians who are skillful enough to repair the imported machines without help from the original manufacturer. In fact, as far as the enrollment in vocational schools of upper secondary level is concerned, its increase in business schools preceded that in engineering schools, as shown in Figure 4.

These non-engineers contribute to the articulation of the domestic demand for the technology which should be developed. These factors should be accommodated in the manpower planning for technology transfer.

## CONCLUDING REMARKS

Japan has caught up with the western industrialized countries in some technological areas. Therefore, the technology transfer described above is less needed than before. The necessary technology transfer in present day Japan lies among different industrial sectors.

Japan is expected to play a more active role in the accumulation of the world stock of science and technology knowledge. Therefore, the requirements for engineering education becomes quite different from those in the past. Hence, in particular, the enlargement and enhancement of graduate education for engineers should be promoted.

Fig. 1. Japanese School System

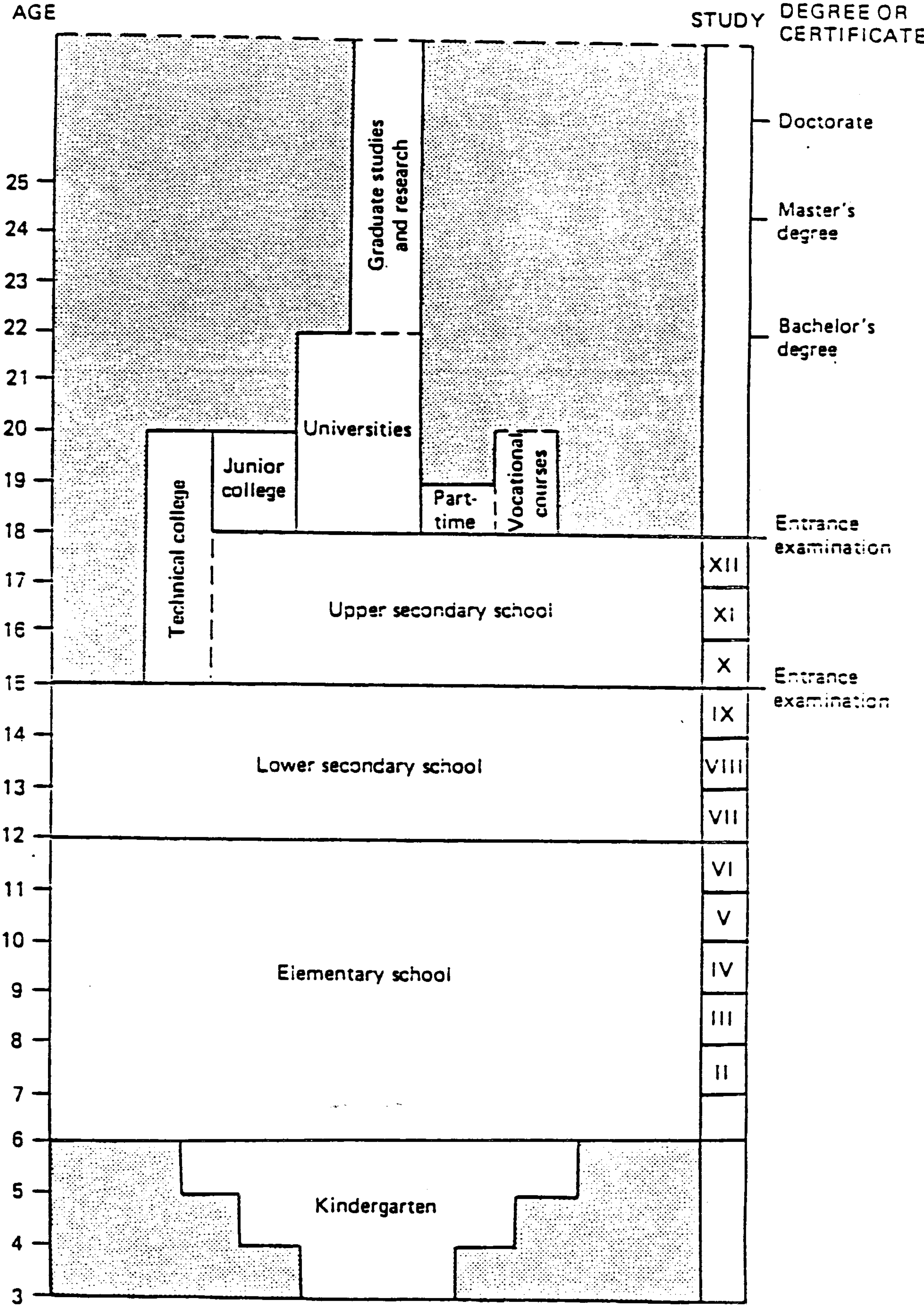

Fig. 2. The Changes in the Ratio of Enrollment to Age Group
(in percentage)

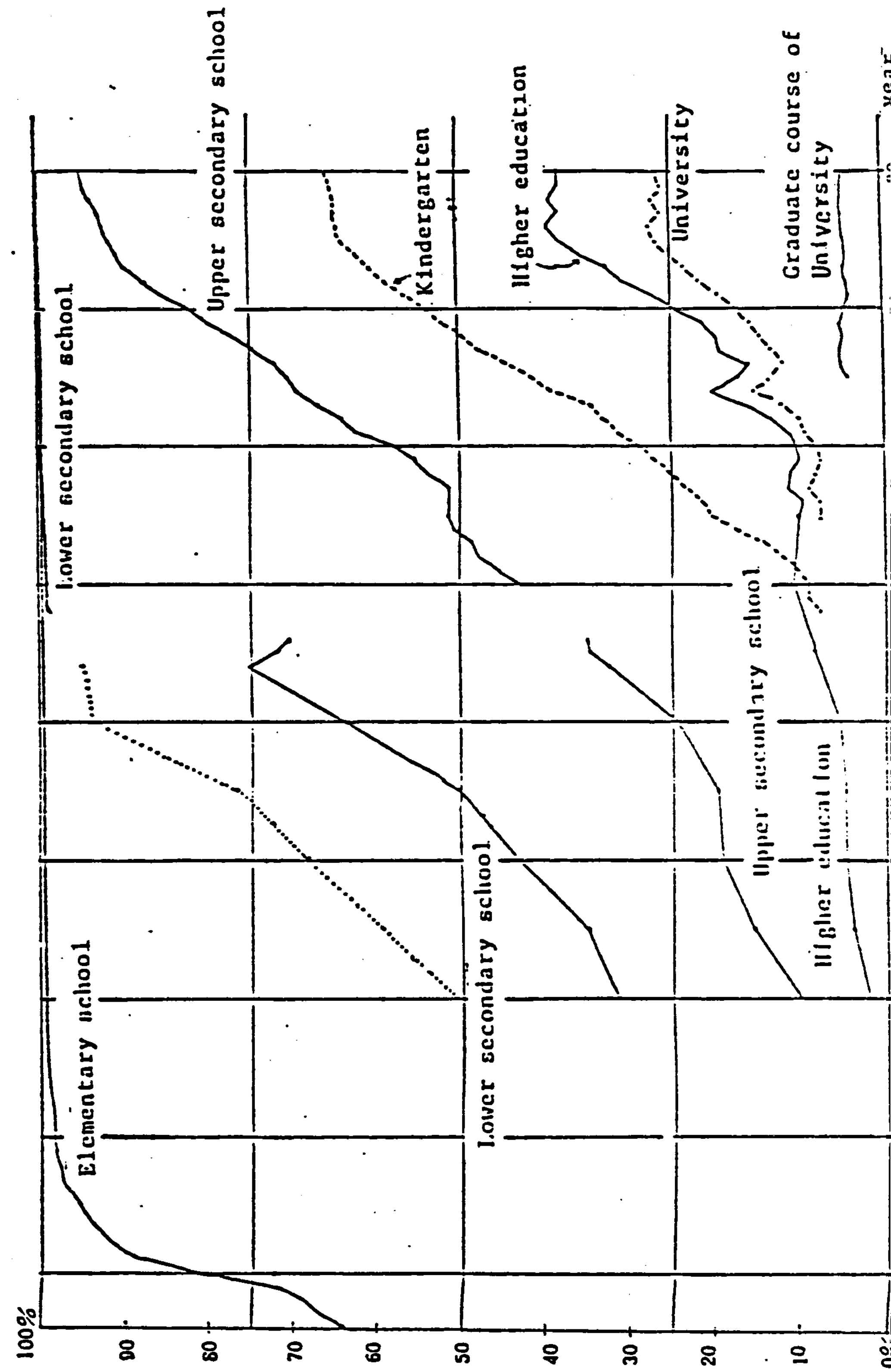

Fig. 3. Long-Term Trend in Engineering School Enrollment

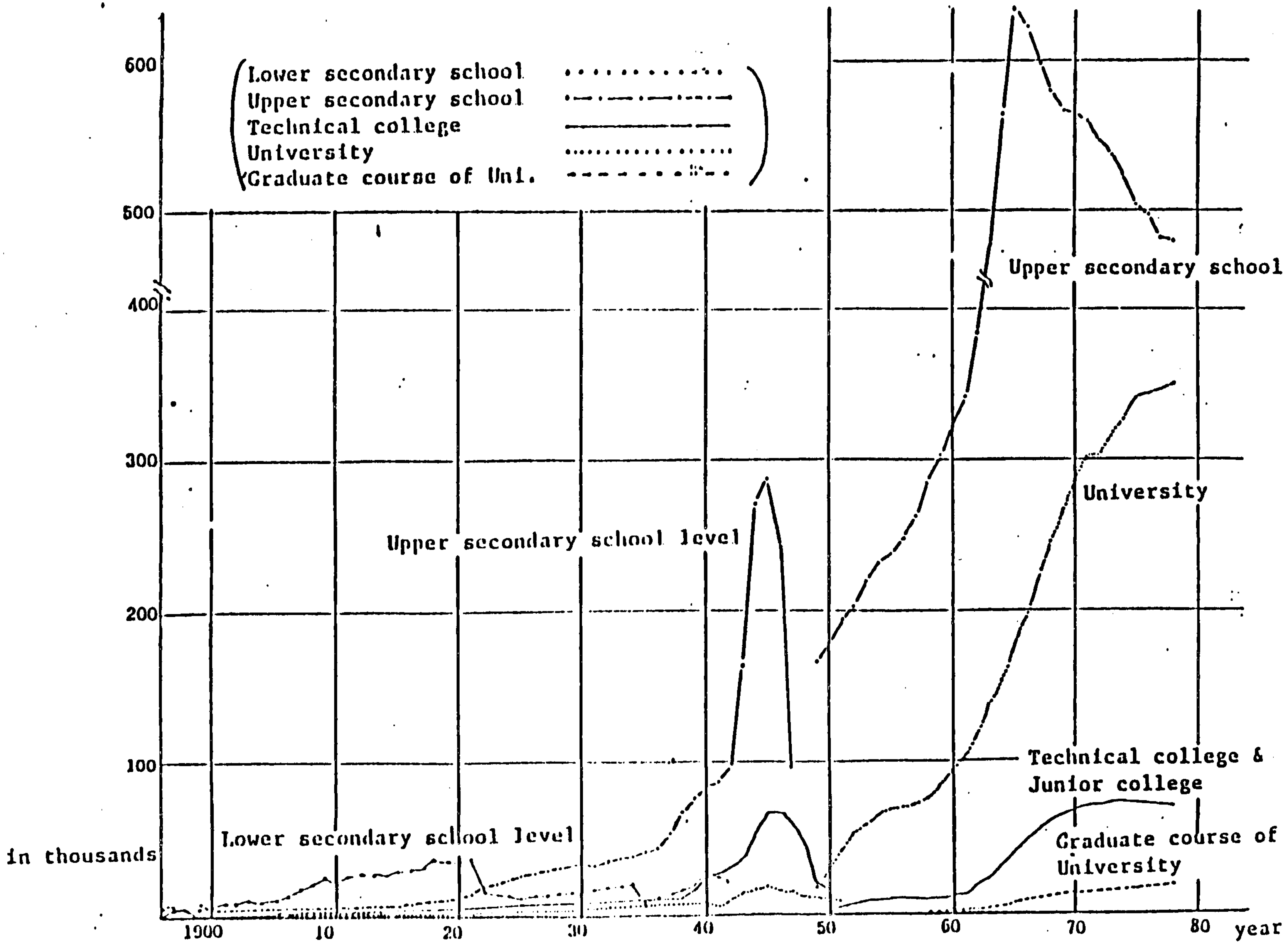

Fig. 4. Enrollment in Vocational Schools of Upper Secondary Level