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German Education in Mechanical Engineering, from the Perspective of the RWTH Aachen

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The subject of this paper is higher education in mechanical engineering at German universities. Details are given from the perspective of the RWTH Aachen, University of Technology. The role and importance for engineering education of research at universities, is explained. Important problems of engineering education are emphasized, such as the evolution of the number of students, and the increase of students' age. Ideas for reform are discussed from the author's personal view.

INTRODUCTION

THE MATERIAL for this paper was prepared for presentation at the Engineering Foundation Conference 'Making an Engineer: Learning from International Comparisons' held on 16–20 August 1992 in Santa Barbara, California. This conference was organized as a workshop, in order to understand the essential differences of engineering education in different countries, and to discuss problems faced by those education systems. The author's contribution concentrated on education in mechanical engineering at Technische Hochschulen or Technische Universitaeten (below called 'universities'), and mainly used the RWTH Aachen (University of Technology) within the state of Nordrhein-Westfalen (NRW) to illustrate the discussion of problems. The special problems of higher education in the new states, constituted after the unification, are beyond the scope of this paper. The discussion of problems in the German system of higher education represents the personal opinion of the author.

HIGHER EDUCATION IN ENGINEERING

The Federal Republic of Germany is a Bundesstaat with 17 Bundeslaender (federal states). The federal states are responsible for educational policy and planning; they provide the funds necessary for the daily operation of the higher education institutions. The Federal Government regulates this by statutes (Hochschulrahmengesetze) the general principles governing higher education and plans and finances investments.

Figure 1 shows the division of formal education into three levels: primary, secondary, and tertiary, the latter being 'higher education' [1]. German pupils enter higher education after at least 12 consecutive years of primary and secondary education (the entrance requirement for Fachhochschulen or colleges) or 13 years (the entrance requirement for universities). Degree studies at universities cover a range which integrates what is internationally called undergraduate and postgraduate education. In the state of Nordrhein-Westfalen (NRW), Gesamthochschulen ('Comprehensive Institutes of Higher Education' or 'Amalgamated Universities') have been established which combine the programs of universities and Fachhochschulen. The different institutions of higher education in NRW can be characterized as below.

Promotion and development of science through research and education are the main tasks of the universities. They also award the doctorates. Fachhochschulen are developed from the former Colleges of Engineering and have a strong practical orientation in the content and form of their courses. Gesamthochschulen provide a special form of education in NRW which offers a two-way course system.

By federal law, a standard period of study was declared for engineering higher education of 10 semesters (5 years) for universities and 8 semesters (4 years) for Fachhochschulen. Thus, the minimum age of students when completing the course of studies is 24 and 22 respectively.

EDUCATION IN MECHANICAL ENGINEERING AT RWTH AACHEN

RWTH Aachen—an overview

RWTH Aachen, the University of Technology, presently has 37 000 students, 4000 of whom are non-German, from about 100 nations. The RWTH

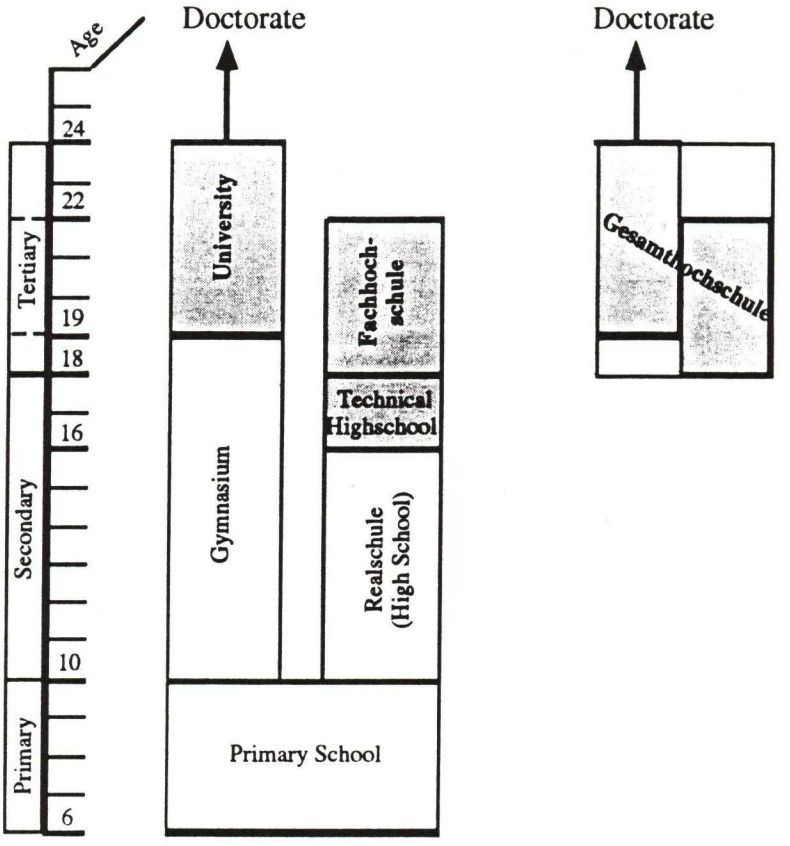

Fig. 1. Higher education system in NRW.

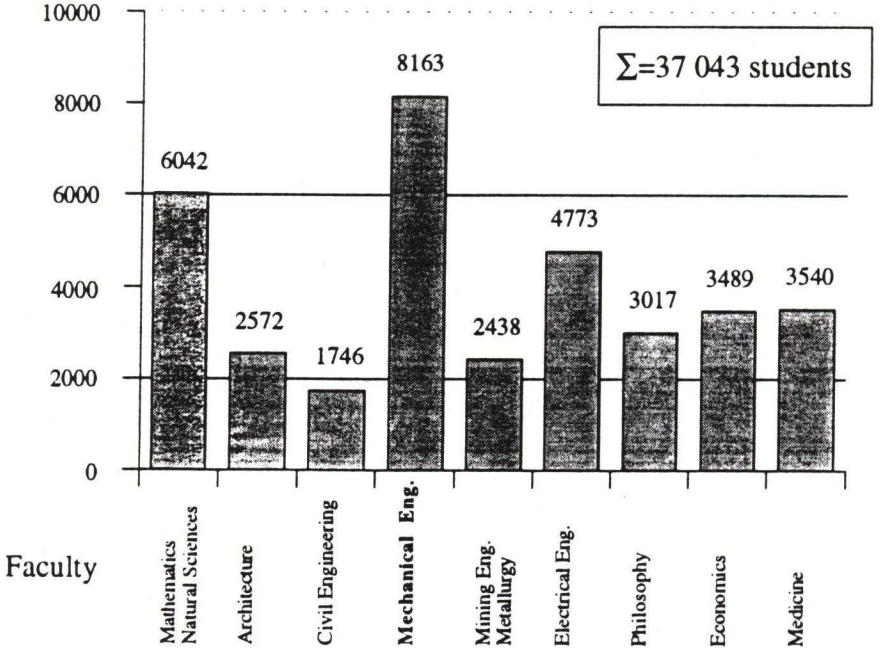

Fig. 2. Student distribution at RWTH Aachen.

consists of nine Fakultaeten (faculties), of which the Faculty of Mechanical Engineering is, with about 8000 students, the largest (Fig. 2).

As shown in Fig. 3, the RWTH is directed by the Rektor (the principal, elected for four years) and head of the Rektorat (the board of governors). He is assisted by three Prorektoren (vice-principals) who chair the three commissions of teaching research and finances. The Kanzler (the chancellor), the head of administration, is also a member of the Rek-

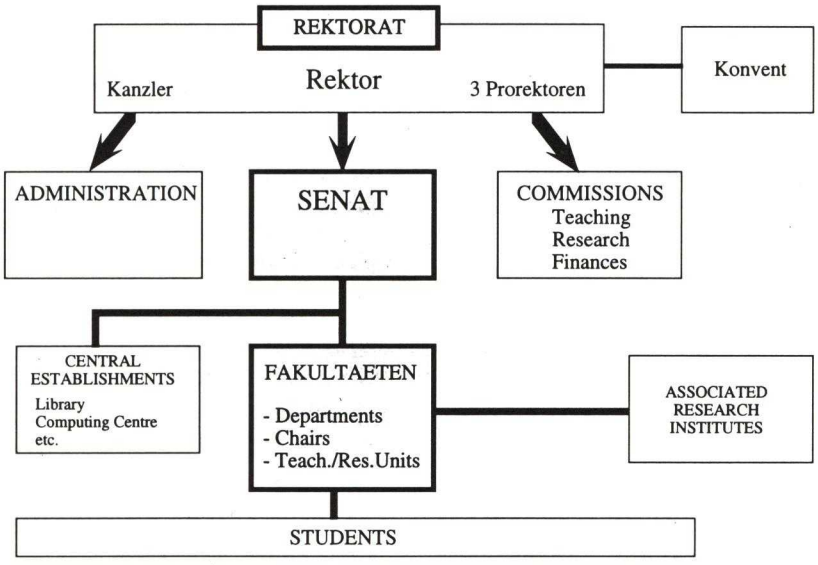

Fig. 3. Structure of RWTH Aachen.

torat. The Rektor presides over the Senat, which is the decision-making assembly on important general academic affairs. All groups of the RWTH are represented in the Senat, the professors, the scientific and the non-scientific personnel as well as the students. The backbone of the RWTH are the nine Fakultaeten (faculties). The Fakultaeten are fully responsible for teaching, examination, and research programs. They decide on the distribution of their ordinary budget and propose who are to be appointed as professors. The individual disciplines are located in institutes, chairs and research units headed by single or groups of professors. Apart from the institutes, the university has central scientific facilities, such as a university library and a computer centre. The Konvent, the assembly, consists of all the various groups, professors, scientific and non-scientific personnel and students and elects the Rektor and the Prorektoren.

The RWTH has 9000 staff members (Fig. 4) thereby being the largest employer in the region. There are 2000 scientific personnel, more than 400 of whom are professors. There are 1500 persons who have undergone practical training or are employed as trainees.

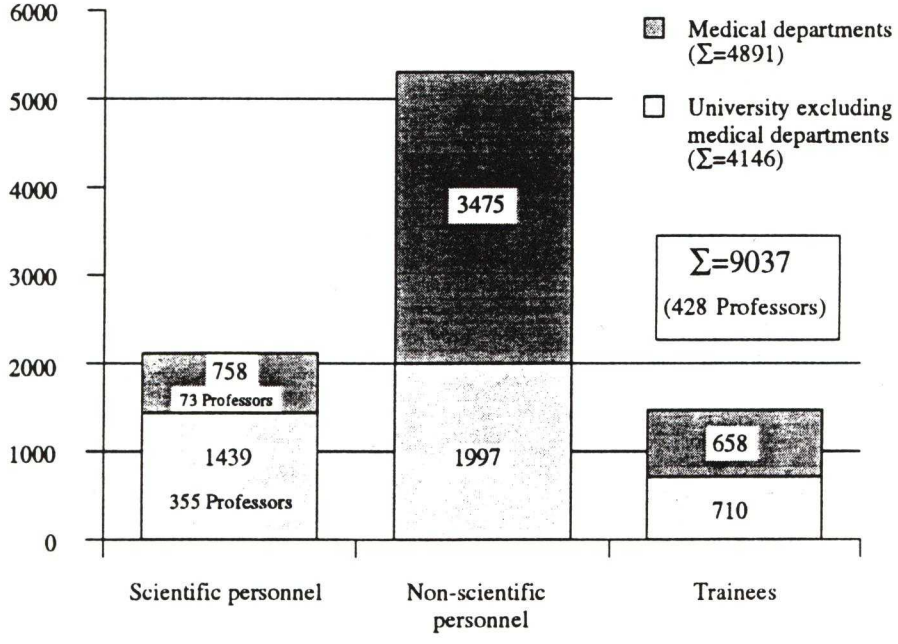

Fig. 4. Personnel of RWTH Aachen.

Mechanical engineering education at RWTH

A degree course in mechanical engineering is divided into basic studies, which last at least four semesters and are completed by an intermediate or Vordiplom Pre-diplom examination, and advanced studies which end with the final examinations, Diplom. The intermediate examinations do not constitute any professional qualification. The basic knowledge required for all engineering subjects without any specialization in an engineering subject, is presented in lectures and its application is practised. In contrast to the compulsory subjects found in the basic study stage, the main studies provide greater choice. Students choose among a number of disciplines in accordance with their personal interest and specialization. The faculty offers education in thirteen disciplines, such as manufacturing and process engineering, plastics and textile technology, various branches of energy technology, automotive and railway engineering, and aerospace engineering. Lectures are complemented by exercise and laboratory work, and the curricula of various disciplines combine theoretical and practical education.

An essential element of the education in the main study stage is the participation in research projects. Within the frame of research programs, students resolve limited problems in smaller experimental or theoretical studies (mini-projects) or in their diploma thesis. At least one of the mini-projects is design-oriented.

The academic year is divided into two periods, a winter and a summer term which comprises a total teaching time of about 25 weeks. The vacations leave time for the students to prepare for the exams, and to take part in industrial training which must be done before the admission to the final exams. In total, a period of 26 weeks in a factory is required for students in mechanical engineering.

Mechanical engineering can be studied at one of twenty universities. The twelve institutions, shown in Fig. 5, have similar basic study programs, so that there are no problems for students who want to change universities during or after the basic study stage. The universities of the new states are not included in this chart because their educational programs are being reorganized. The present distribution of the students in mechanical engineering is shown in Fig. 5. The Aachen faculty has the highest percentage of 18.4% of entering students, and has the related problems of a high load factor.

UNIVERSITY ENGINEERING RESEARCH

Research and education

University law of the state Nordrhein-Westfalen, has legislated that promotion and development of science through research and education are the main tasks of universities. This combination of research and teaching, equal in rank, as a precept for education at universities has a long history and can be traced back to Wilhelm von Humboldt (1767–1835). To the present day, research activities at universities form the hard core of research potential in Germany in many areas. These activities are supplemented by research institutions outside higher education in basic and applied research (Fig. 6). Staff members of external institutions often teach at universities and are thus able to present current problems and results of investigations in their courses. In addition, joint research

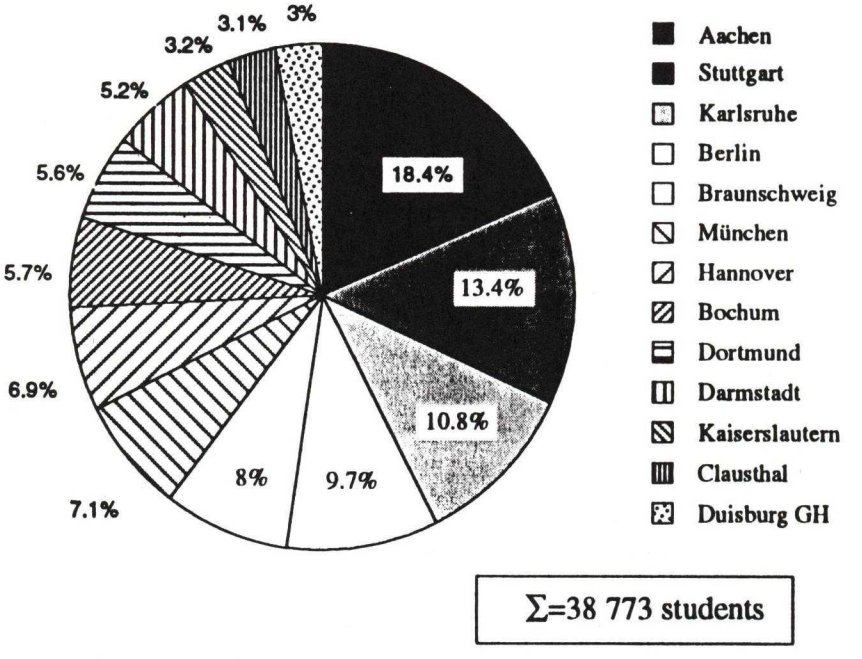

Fig. 5. Distribution of mechanical engineering students in German universities.

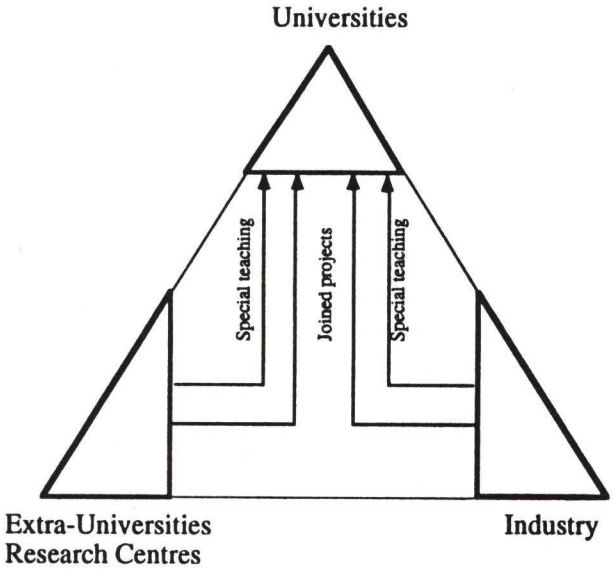

Fig. 6. Interaction in research and higher education.

programs are carried out. Research offers numerous advantages for the quality of teaching, such as:

- Teaching in the main study phase is updated from research activities of the lecturers.
- Students participate in research by conducting their own study work (mini-projects).
- Student assistants are engaged in research programs, learning at first hand, and earn money for their living expenses.
- Results of research projects can become the basis for a Doctoral thesis.
- Students come into early contact with industry and large research establishments.
- Young scientists gain experience and practice in teaching.

Funding of research

Today, the budgets of universities, which are funded by the various states, are mainly allocated for covering the teaching effort. Only limited funds are available for investments, maintenance and repair of research facilities. No direct funding for research projects is provided by the state NRW, so that third-party funding is required. The main sources of research funds are shown in Fig. 7. About 50% of these funds are provided by the Federal Ministry of Research and Technology and the Deutsche Forschungsgemeinschaft (DFG), the German Science foundation. Although the DFG is mainly funded by the Federal (60%) and the State Governments (40%), it is an autonomous, non-governmental institution, its members being the

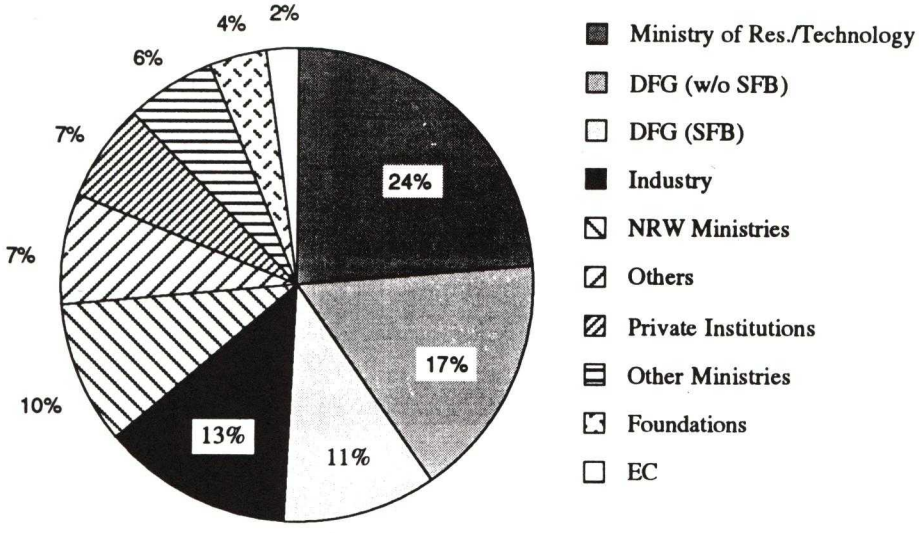

Fig. 7. Sources of funds for research.

universities and other research organizations. It supports basic research, mainly at universities. The budget of the DFG was 1.46 billion DM in 1991. New research programs are proposed by the scientific community and controlled by advisory boards. The following types of programs are supported:

- Single projects (Einzelvorhaben) proposed by individual scientists and funded over 2–4 years;
- Priority programs (Schwerpunktprogramme) co-ordinating the projects of 10–20 scientists at various research institutions, funded over 5 years;
- Special collaborative programs (Sonderforschungsprogramme, SFB), proposed by an interdisciplinary group of 10–20 scientists of one university, and funded over 12 years.

A third of the DFG funds are allocated in special collaborative programs which are long-term programs, defined by the scientists of one university, evaluated and approved by an independent specialist committee. They offer the opportunity to perform high quality research by concentrating and co-ordinating the scientific capability within the university under contract. Interdisciplinary cooperation occurs beyond the boundaries of labs, departments and faculties. The programs maintain relationships with other universities, research establishments and scientists, at home and abroad, as well as enabling education of students and postgraduates by participation in research projects.

The importance of third-party funding for the RWTH Aachen is shown in Fig. 8. More than 50% of the scientific personnel in engineering are third-party funded and participate in the education of students. Third-party funds for research at Fachhochschulen are negligible. Over a half of third-party funding for engineering research in NRW is concentrated at the RWTH Aachen, which amounts to about 130 million DM.

SOME PROBLEMS OF ENGINEERING EDUCATION AT GERMAN UNIVERSITIES

Within the last year the efficiency of the German higher education system has been given growing attention by politicians, industry and the general public. The request for more funds for universities and Fachhochschulen, which is connected with the growing number of students entering the higher education system, worries politicians who are already faced with the high financial burden related to the unification of East and West Germany. In addition to financial pressure for university reform, other problems exist which are differently weighted by politicians, industry and universities. A thorough analysis of the problems which could lead to an effective reform has not occurred. In this section of the paper some of the more important problems which are relevant to engineering education, will be briefly discussed.

Growth of student numbers, overload situation

Within the last 15 years the number of students at universities and Fachhochschulen has almost doubled, while the number of the first semester students has increased by 60%. In the same period, the number of scientific personnel has been kept constant, as shown in Fig. 9. Thus, the student/staff ratio has risen from 13:1 to 25:1. It is important to note that in engineering education at universities,

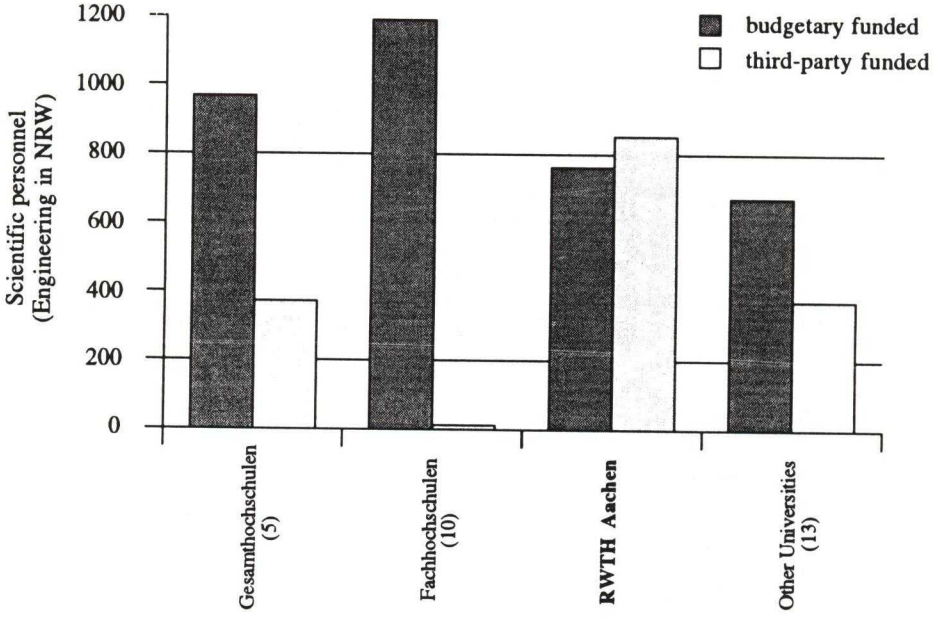

Fig. 8. Scientific personnel working for engineering education in NRW.

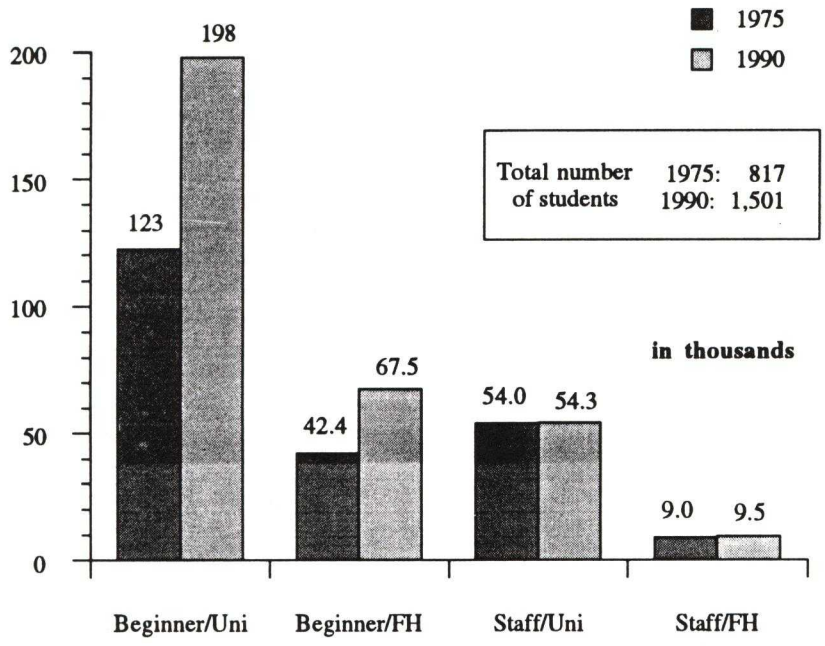

Fig. 9. Development of student numbers in higher education, 1975/1990.

most of the staff members are junior engineers, who are on the way to Doctorates and are not very experienced in teaching.

Figure 10 illustrates another aspect of the growing student numbers which worries industry and politicians. Within 10 years, the relationship between the number of apprentices and students of an age-class has changed dramatically. While the number of students has been considerably enlarged, the interest in an apprentice education reduced, so that the total number of students, at universities and Fachhochschulen, outnumbers the apprentices. This trend will continue and brings up several problems, such as the unlikelihood of the growing number of students matching an equivalent job growth, so a higher unemployment rate for higher educated people is to be expected. Also, the average student is finding it harder to study effectively and complete his or her studies within a reasonable period of time. Smaller companies needing manual workers are complaining about the difficulty in finding apprentices, which will lead to a lack of skilled workers in the future.

A consequence of this growing number of students is a considerable overload in many faculties and a restricted entry. Considering the prediction of a steadily increasing interest in higher education, the situation will be worse in the coming

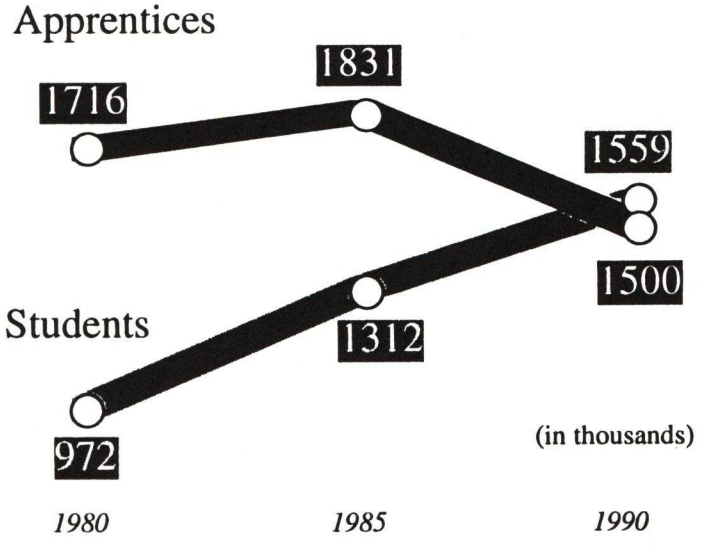

Fig. 10. Evolution of student and apprentice number, 1980/1990.

decade. A look at the Aachen situation (Fig. 11) reveals that almost all science and engineering faculties are overloaded, with the exception of the faculties of mining engineering and humanities. The faculty of mechanical engineering operates under a load factor of about 130%.

Increased age of students and duration of course of studies

A cause of concern for politicians and managers in industry is the growing age of students at the completion of the course of studies (Fig. 12). The median value (50%) of this age is about 27 with small differences for the graduates from universities and Fachhochschulen. Mainly two reasons are of influence on this age: first, instead of commencing higher education at an age of 19 and 18, students enter at an age between 21 and 22 (median value). Secondly, the average duration of study is statistically longer than the so-called 'standard period of study'.

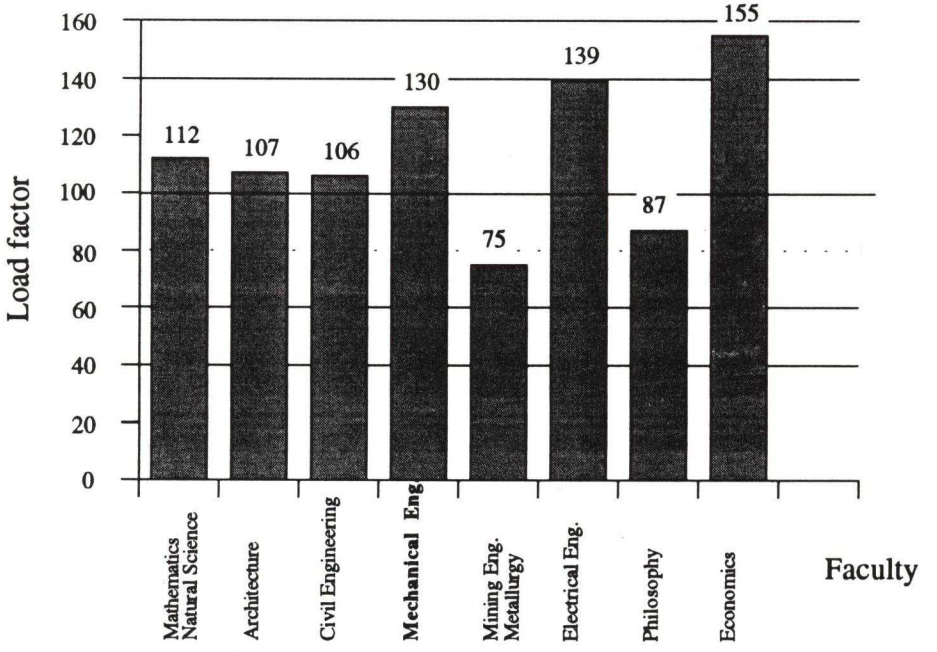

Fig. 11. Overload situation in the faculties of RWTH.

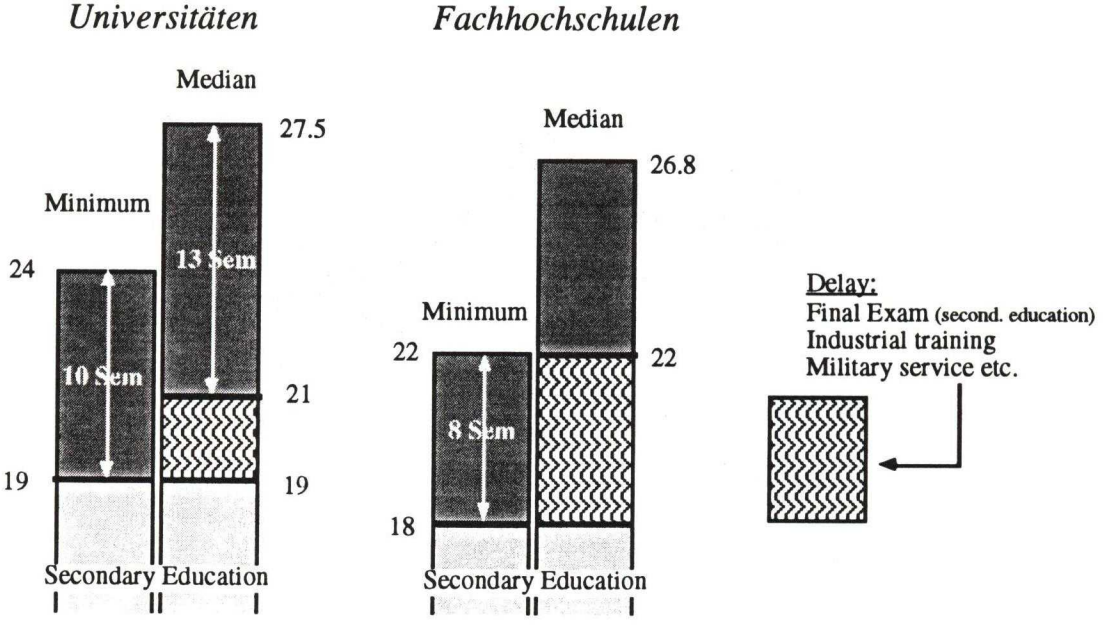

Fig. 12. Median value of students' age at first degree in mechanical engineering.

The delay in entrance age can be put down to several reasons

- pupils have to repeat a year in secondary education;
- several months of industrial training and practicals in a factory are required before admission;
- male students have military service;
- before entering higher education, pupils squeeze in a period for earning money.

At the RWTH Aachen, the age of entering male students is 21.1 year, while females enter at 20.4 year (both median values).

In Fig. 13 the median value of the duration of study is shown for several faculties of mechanical engineering at German universities. A 'standard period of study' of 10 semesters has been fixed for universities. The exam regulations have been adapted to a sequence of lecture courses, exercises and practicals that fit into that 'standard period'. Thus, the standard period is also the minimum period of study. In mechanical engineering, the actual study period (as a median value in which 50% of the students pass the exams) ranges from 11.5 to 14.5 semesters with a mean value of 12.8 semesters (6.5 years) instead of the standard value of 10 semesters. Figure 13 reveals a good correlation between the period of study and the student/professor ratio, which ranges from 55:1 to 140:1 where the latter ratio is the value of the RWTH Aachen.

Quite an interesting phenomenon is shown in Fig. 14. Here, in addition to the median, the quartile value is shown: 25% of the students manage to pass the exams in 11.5 semester, 1.5 semester earlier than the next 25%, but still 1.5 semester above the standard value. The 25% quickest students (the best ones?) seem to be less dependent on guidance from their professors, as is illustrated by the lower gradient of the quartile regression line.

To reach the goal of a standard period of study, students must pass the intermediate examinations after the fourth semester. In Fig. 15 the percentage of students is given who have passed a certain number of exams after the fourth semester (statistics for Faculty of Mechanical Engineering at the RWTH Aachen). Just 12.4% passed all 11 exams necessary for the intermediate exams, while 50% have passed less than 7 exams, and almost 20% have become lost. A similar statistic shows that after the fifth semester not more than a third of the students have passed the intermediate exams. Whatever the reasons for this low success rate may be, the delay in passing the intermediate exams cannot be compensated during the main study phase.

Figure 16 illustrates the fact that students who need more time for the intermediate exams also require much more time for the main study phase. This fact could have two explanations: first, students who cannot pass the intermediate exams are less capable, and therefore also need more time for the main study phase. Secondly, some students do not wish to finish their studies quickly, thus they take more time for the basic study and main study phases. It is possible that both factors are increasingly influenced by the 'prosperity' factor.

Personal reasons of students for prolongation of study

A strategy for reducing the students time for completing their higher education must consider a variety of influences. One important influence is

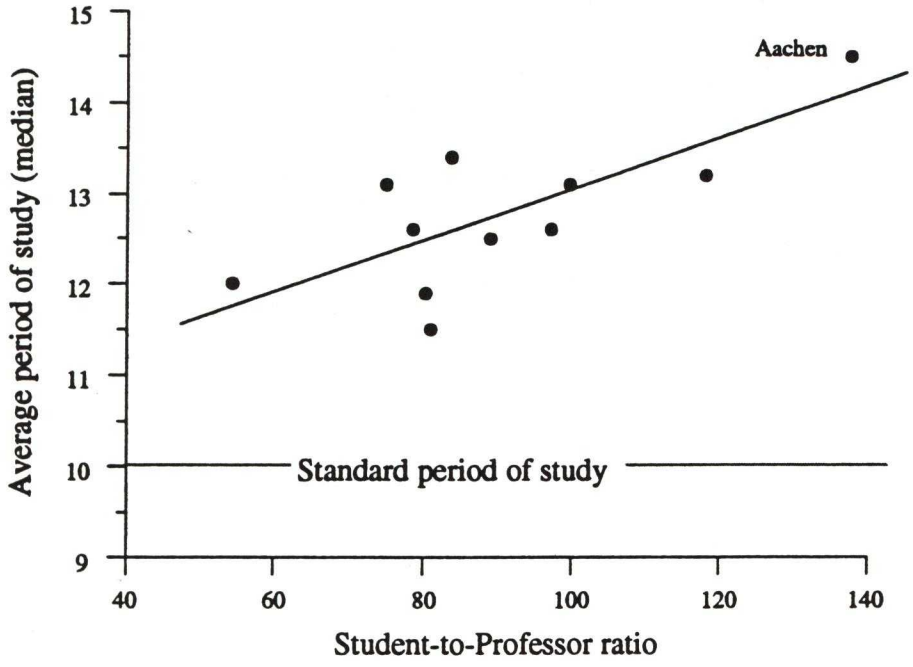

Fig. 13. Average period of study in mechanical engineering.

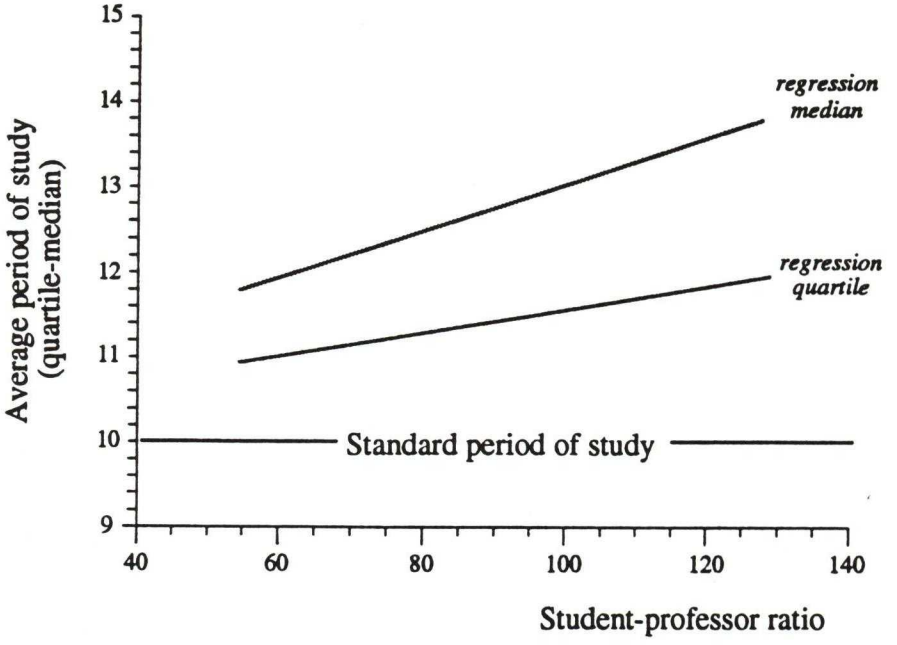

Fig. 14. Average period of study in mechanical engineering, median and quartile values.

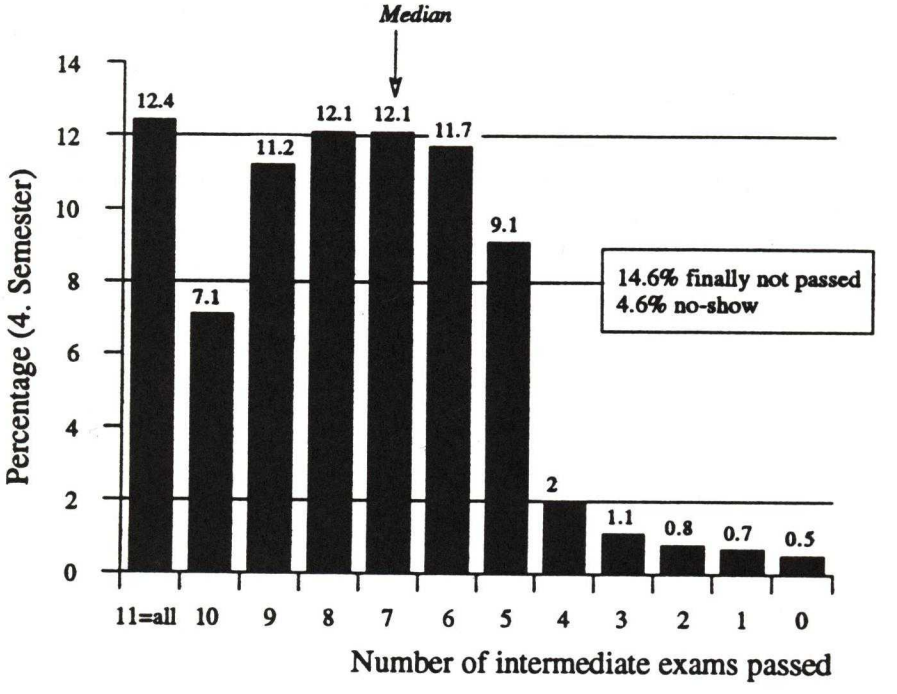

Fig. 15. Exams passed in mechanical engineering at RWTH after fourth semester.

the motivation of the students to complete the study in the shortest time. This motivation is quite weak for three reasons. First, German students are under little financial pressure to finish their study quickly. There is no official pressure to pass the exams in a given time. They do not pay tuition fees. Special grants are available if parents are in the lower income bracket, according to the provisions of a federal law, BAföG. Students have many opportunities for earning money, as well as being student assistants. Secondly, high priority is given to earning good grades and collecting experiences. Many students are members of groups which promote professional, social and cultural activities. They also participate in student's administration. Moreover, many students (poll results: 50%–60%)

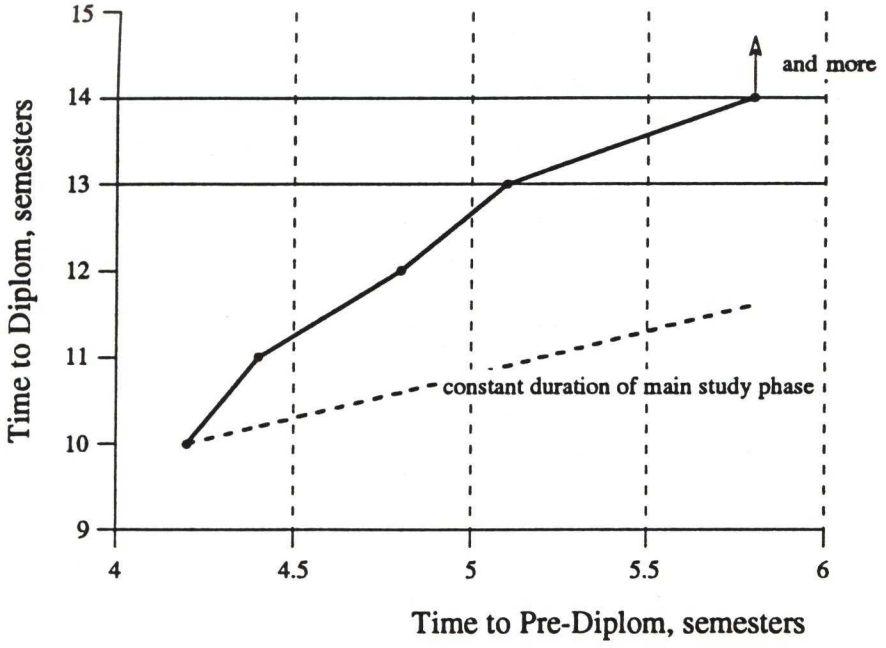

Fig. 16. Time of diplom versus time to intermediate for students in mechanical engineering.

place emphasis on participating in research, as research assistants. Thirdly, there is some tendency to postpone entrance to professional life. Often students look for gainful part-time employment to achieve a higher level of comfort (car, travelling, etc.)

Figure 17 shows that about 70% of all students in mechanical engineering are gainfully employed during their study period, with a very high percentage working just at the end of their study period. This can be explained at least partly, because many students work and are paid for by university research projects, in most cases only at the end of their education. The side effects of this employment on the quality of education must be taken into consideration and weighed against the inevitable prolongation of the study period.

Students and graduates of mechanical engineering were asked to suggest ideas for reducing the study period. The poll result [1] is shown in Fig. 18. Most of the suggestions require a much better student/staff ratio. Few proposals would reduce the quality of education.

The status of research

The overload situation and the reduction of funds available for research at universities must adversely affect the balance of research and teaching. Figure 19 shows the allocation of research at German universities compared to extra universities research centres and research at industry. The share of university research is going down steadily; in the period from 1978 to 1990 the university share has dwindled from 17.4% to 13.6%. Public

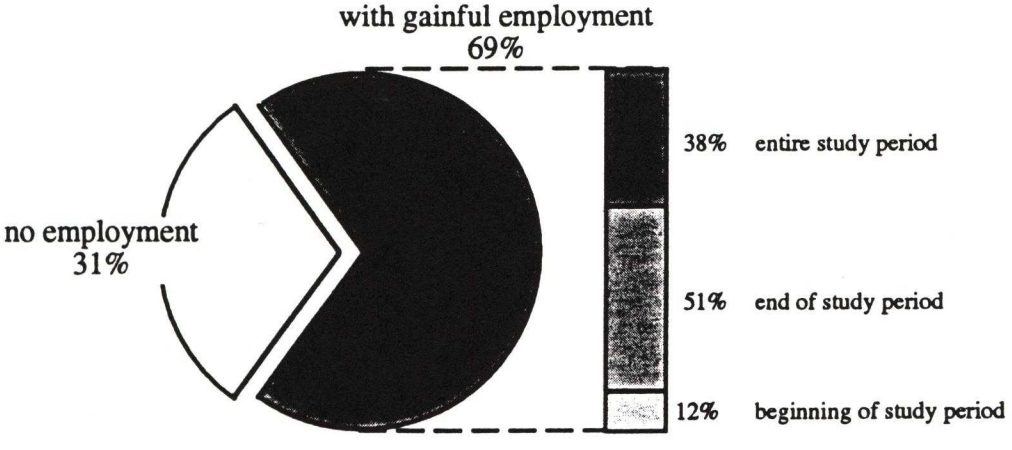

Fig. 17. Employment of students during the courses of study.

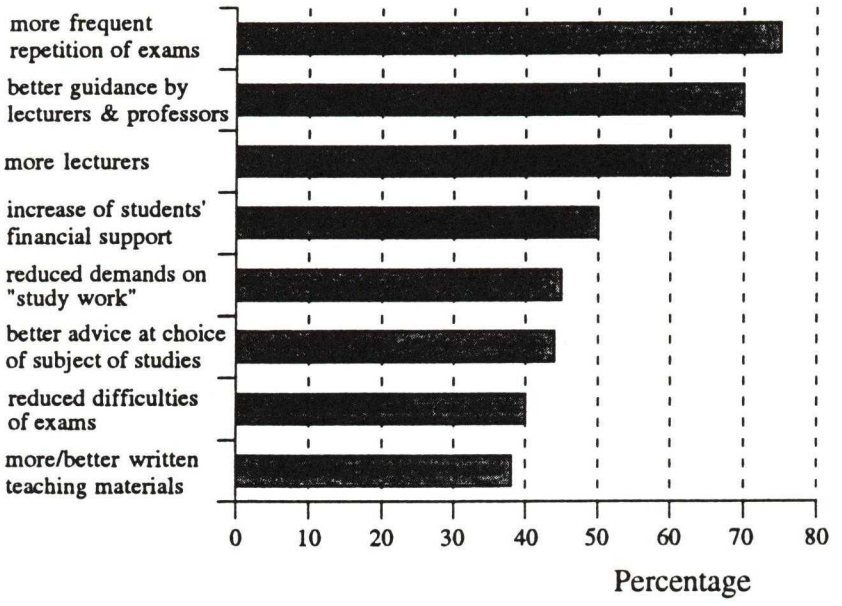

Fig. 18. Student suggestions for reducing the study period.

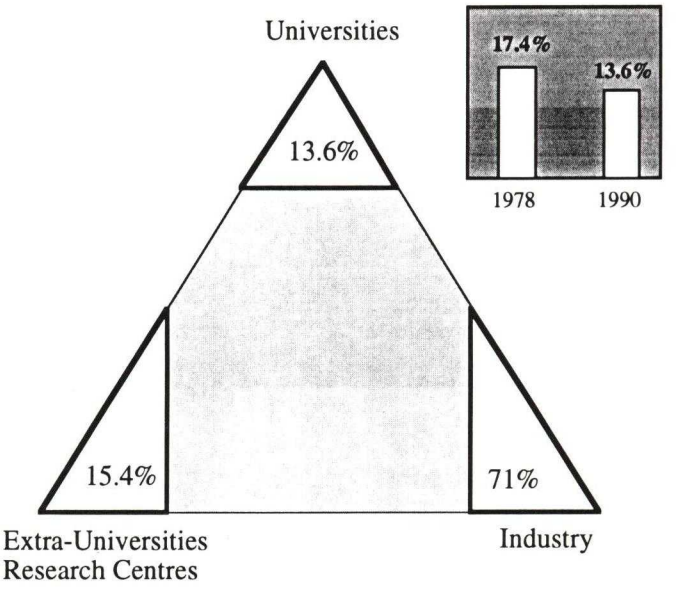

Fig. 19. Allocation of research at German universities.

funds are inadequate to maintain and modernize facilities, tools, equipment, and test instrumentation. Teaching and research are no longer equal in rank and balanced. It is increasingly difficult to fill vacant professorial chairs due to

- attractive wages for people in industry;
- high burden of teaching, steadily increasing student numbers,
- reduced public research funds;
- insufficient investment for new research areas.

Funds for research will not increase as long as the number of students grows, and the enormous need for funds for higher education in the states of the newly united Germany is considered. Moreover, national research funds are being transferred to EC organizations and networks, at an increasing rate. The application for these funds is very formal and too tedious for most universities.

Ideas on a reform of the higher education system

It is not surprising that the growing demand for secondary and higher education worries finance ministers and politicians. Because all political parties agree that higher education institutions should have open doors, the stream of students

entering higher education will steadily increase [3]. Until now, no pressure on students to stay within the standard period of study has been seriously discussed in the political arena. So, the problems of the system are mostly excluded from political and public discussion. Ideas on study reform concentrate on the academic sector and make suggestions which aim predominantly to reduce the study period. An example, which excels when compared to other suggestions, is found in a concept favoured by the NRW Ministerium für Wissenschaft und Forschung (MWF)—Ministry of Higher Education and Research—under the title 'Qualität der Lehre' (Quality of teaching) [4]. The main ideas of this concept are the following:

- Students will not be forced to pass their exams within the standard curriculum.
- Curricula should be simplified; less ambitious, and more concentrated; difficulties of exams have to be reduced.
- Students of 'average ability' and 'ordinary diligence' should be in the position to pass the exams within the standard period.
- Lectures and lecturers should be formally assessed by their students.
- The reform of higher education should be executed under the control of the Ministry of Higher Education.

Almost all suggestions on a reform of higher education are focused on the overcrowding of the higher education institutions while the aspects of quality and selection are mostly ignored. Therefore, they are of little use for creating a better education for engineers, who will be faced with an increasing international competition and are expected to maintain their global position.

FINAL, PERSONAL REMARKS

For an effective reform, the following personal viewpoints are presented as vital and indispensable:

1. At present, a wide range of ideas on academic reform is observed in political and public discussions. Some concepts aim at solutions which should be common for all faculties and disciplines. A standard concept may be 'aesthetically' satisfactory, but is considered not to meet the requirements for an effective education of engineers.
2. The quality of education at universities depends largely on the equal emphasis on research and teaching and their strong interactions. Today, the interaction of teaching and research is disturbed by the student overload situation and by cutting funds available for research. Reform must not cause further upset to the sensitive balance of the two educational elements.
3. The higher education of engineers in Germany is organized in a dual system of universities and Fachhochschulen which, in principle, is well accepted by the German industry. This dual system should be preserved, but the contours and the complementary character of both education routes should be brought out more clearly.
4. The prolongation of study period is of concern. But this situation might have less academic structural causes; it depends also on the quality of the pre-academic phase and is influenced by economical, sociological, political and cultural factors. Thus, this problem cannot be resolved by putting the burden primarily or even exclusively on the academic side.
5. It must be recognized that the overload burden of the higher education is mainly influenced by the number of entering students and only to a lesser degree by the total number of students. A consequence of this fact is that the overload situation can only be solved by academic and structural measures.
6. The limited look at the complicated aspects of study reform, present in much of today's public and political discussion cannot be helpful. A reform of the higher education of engineers should be prepared to take on the formation of future engineers, who should be prepared to work in a global environment faced with strong international competition.

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