On Providing Flexibility, Adaptability, Efficiency and Quality in Engineering Education*

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Typical universities of science and technology maybe considered as very large organizations with high budget, employment and expensive equipment; therefore they require efficient and effective management.

Moreover, one can observe the growing competition among universities, the rapid change of technologies and markets, the new requirements for better adaptability of the curricula, greater flexibility to students, the increased requirements for smooth management of all academic and administrative activities, the need for providing higher quality standards of teaching, and also the need for more efficient utilization of the limited academic resources.

These requirements are difficult to satisfy in traditional organizations and thus imply the need for better organization, improved methodologies for development of flexible and adaptable curricula and more efficient resource management. As higher education institutions, following the trend in the manufacturing and service sectors of the economy, start to move from "mass production" to "mass customization" [21], new ideas are required which make it possible to customize the studies, i.e. "to deliver education as it is needed by the individual".

In recent years, a number of new ideas have been presented on how to modernize engineering studies to meet the new challenges facing higher education [11, 20, 16,6,9, 10,7,24,3, 14]. A significant effort has been taken by many academic institutions all around the world to implement these ideas and adjust engineering curricula to the needs of the rapidly changing society [7, 8, 18,4, 5]. As most discussions on restructuring engineering studies indicate, flexibility and adaptability of the system of study are among the most essential features that could make engineering more attractive for the prospective students, and thereby allow engineering-oriented academic institutions to compete successfully on the market of higher education services. It should be also noted that flexibility and adaptability both affect the quality of education.

In this paper, we discuss our experience in introducing a flexible and adaptable system of study at the Faculty of Electronics and Information Technology at Warsaw University of Technology. We present and analyse a number of ideas already implemented at WUT which, if followed elsewhere, would enhance flexibility and adaptability of an engineering curriculum on one hand, and on the other hand would assure efficiency and relatively low costs of studies and also help to achieve high quality standards.

The organizational and managerial issues associated with the process of restructuring the system of study are discussed and some remarks on the impact of the proposed solutions on the quality of engineering education are given.

*Partially supported by KBN grant S505 03804

Effectiveness measures

An important strategic goal of restructuring an academic institution is to improve *efficiency* and *effectiveness* of the university. Efficiency is related to internal factors and the aim is to improve all university activities so that the teaching and research activities use less resources, i.e., productivity may be higher. Effectiveness is related to external factors such as improved flexibility and adaptability of the system of study, better satisfaction of the needs of students and improved academic quality standards.

Flexibility Flexibility of a system of study means, in general, that each student has a lot of freedom in design of his/her education path. To be flexible, the system must be characterized by a sufficient level of *diversity*, i.e., it must offer the student a variety of opportunist ies. Diversity is a necessary condition for flexibility, but it is not a sufficient one. The crucial question regarding flexibility is whether or not each student is allowed to take advantage of the available options. Essential features of a flexible system of study include:

⊙ Possibility to decide on the level of education in the course of study: The institution should offer programs that allow the students to design education paths of different duration, leading to different diplomas or certificates. The students should be able to design their education paths taking into account their capabilities, financial status, and other factors affecting the course of study, without being required to make difficult and restrictive choices at the very beginning of the study (or at the time when they apply for admission).

⊙ Possibility to choose one of many available specializations: The students admitted to the institution should be offered a wide range of specializations to choose from. However, they should not be required to commit to any specific area at the very start of their program; instead, they should be provided with an opportunity to select the field of study and, subsequently, the area of concentration, as they become more acquainted with the discipline.

⊙ Freedom in design of an individual program of study (course selection): A good indication of flexibility the student has in design of his/her individual program of study is a large fraction of "empty slots" in the curriculum. Such empty slots, that are to be filled with restricted or free elective courses, allow the student to design an individual program of study that well matches his/her interests and professional career objectives. Clearly, to take advantage of the available freedom, the students must be provided with a large and diversified offer of elective courses.

⊙ Possibility to adjust the workload in each term to individual capabilities and preferences. A full-time student should be allowed, within certain limits, to decide on the number of courses taken each term. This allows better students to complete their programs ahead of schedule. On the other hand, weaker students and those who take part-time employment get a chance to complete their programs instead of being dismissed for inadequate progress or inferior performance in the courses taken.

Adaptability With respect to the system of study, adaptability means that changes in the curriculum and other components of the system can easily be performed, The changes should reflect the outcomes of various forms of assessment (student opinions, self-assessment, external evaluation), advances in science and technology, trends on the labor market, and evolution of international standards for higher education.

There are three basic types of activity involved in the process of adaptation: recognition of the need for improvement in specific areas, recommendation of specific changes or adjustments, and implementation of the recommended changes and adjustments.

The system is adaptable if time and effort associated with these activities is minimized and if there exist mechanisms which stimulate and support these activities.

Efficiency Typically, the universities have to operate at a relatively limited budget. Hence, the requirements for providing flexibility and adaptability must be associated with efficient utilization of all university resources. It implies that effective management, including finance and resource management is very import ant.

It must be stressed however, that at a university the patterns of administrative management need to be carefully considered, since many managerial methods that are feasible for other types of organization, such as industrial companies, may frustrate the essential operations of a university, which is a more 'democratic' and diverse organization.

Quality As we already noted, flexibility and adaptability both affect the quality of education. This can be explained by referring to the goals that should be sought by an institution, stated by the 1S0 9000 standard in the following way [13]: "The organization should achieve and sustain the quality of the product or service produced, so as to meet continually the purchaser's (customer's) stated or implied needs".

Usually, the systems of quality assessment pay relatively little attention to flexibility and adaptability of the system of study. However, there is a strong relationship between diversity, flexibility and adaptability of the system of study and the quality of education [26].

Although diversity, flexibility, and adaptability are essential characteristics of a modern system of higher education, their impact on the education quality becomes really substantial if these features are combined with appropriate regulations and policies. We dare to say that an implementation of effective quality assurance mechanisms within a system which is not sufficiently diverse, flexible and adaptable might be quite difficult, if not impossible. Thus, the measures taken to enhance flexibility and adaptability of the system can be viewed, at least to some extent, as the mechanisms of quality assurance. Moreover, it appears that an enhancement of flexibility and adaptability of the system of study should be the first step in any systematic program aimed at improving the quality of education at an academic institution.

Design of effective system of study

Various measures can be taken to make engineering education more effective in terms of flexibility, adaptability and productivity. In what follows, we present a number of actions already applied at WUT that would help achieve this goal (see also [23,15,17, 26]). Some of the recommended actions are associated directly with the development of the curriculum, other are more general and relate to the organization of the system of study at a higher education institution. Our recommendations are formulated under assumption that the institution (college, department) is large enough to offer a wide spectrum of educational activities covering many areas of engineering:

⊙ Offer a single program (not two or more programs) leading to a particular degree, but allow for many options (areas of concentration). The idea is not to differentiate between related disciplines, such as electrical engineering and computer engineering, by introducing two separate undergraduate programs, but offer a single integrated program, such as the one leading to a bachelor's degree in electrical and computer engineering . Within this single program, a student should be offered a wide range of options (areas of concentration). Clearly, the student should not be required to commit to any specific area at the time he/she enters the institution; instead, he/she should be provided with an opportunity to select the area of concentration as he/she becomes more acquainted with general aspects of engineering.

⊙ Offer a large and diversified course offer. A sufficient number of elective courses should be offered, so that the student who has chosen an area of concentration could make further choices. It should not be required that all engineering courses are assigned the same number of credit hours. In particular, it would be highly desirable that basic courses, or more generally, courses intended for a large number of the students, be offered in two or more versions that differ with regard to the number of credit hours assigned and the range of topics covered. For example, two courses on a specific subject can be taught each semester:

a minimum course that covers only fundamentals and an extended course which covers some extra topics. The idea is to recommend the extended course, instead of the minimal course that satisfies the curriculum requirements, to those students who plan to specialize in some related area. Clearly, the student can earn full credit only for one of two or more courses having significant content overlap.

⊙ Structuralize the course offer. All courses offered by a higher education institution should be grouped into topical areas, such as mathematics, control systems, computer networks, etc.., hereafter referred to as *subject classes*. The motivation behind introducing subject classes is: (i) to facilitate the examination of a large course offer by the student and his/her advisor when looking for courses most suitable for inclusion in the individual program of study, (ii) to facilitate the coordination of syllabi of the courses included in the same subject class, but offered by different instructors, possibly representatives of different groups existing within a large higher education institution (such a coordination involves in particular: establishing common terminology and not at ion, eliminating unintentional content overlap, identifying not adequately represented topics, determining appropriate sequences of courses, ie. formulating prerequisite requirements).

⊙ Formulate curriculum requirements using subject classes rather than specific courses. Curriculum requirements are traditionally based on a rigid core of compulsory courses, with a certain number of slots (usually a small one compared with the number of compulsory courses) to be filled with restricted or free elective courses.

To enhance flexibility, curriculum requirements should be formulated using, whenever possible, the names of topical areas (subject classes) rather than the names of specific courses. A minimum number of credit hours that must be earned by the student in courses taken from each relevant subject class should be specified.

Within a given subject class, compulsory courses could be specified, but in principle, the mechanism of prerequisite and corequisite requirements should be employed to ensure an appropriate sequence of courses taken by the students.

⊙ Require "in-depth" education in some area and provide an opportunist y for minor specialization. Curriculum requirements should be formulated for each area of concentration. To obtain the degree, the student should be required to satisfy the requirements for at least one area of concentration - this would ensure "in-depth" education in some subarea of engineering. The coverage of engineering fundamentals and necessary breadth of the education can be guaranteed by including in the curriculum requirements a sufficiently large set of subject classes.

As the student can include in his/her individual program of study a certain number of free elective courses, he/she can either extend the knowledge in the selected area of concentration or study other topics. In particular, the student can take a certain number of courses associated with some area of concentration different from the one selected for major specialization. In such a case he/she should be awarded a certificate of minor specialization. This is of particular importance if there are students who, because of limited capacity of some advanced-level laboratories or short age of final project or t hesis supervisors, cannot pursue the program in their preferred area of concentration.

⊙ Decentralize the work on curriculum development and assign personal responsibility for the quality of individual components of the curriculum.

All the above discussed concepts have an essential impact on the flexibility of the curriculum. They also contribute to its adaptability because even modest changes are difficult to implement within an inflexible curriculum that has evolved in a traditional way, by adding new requirements and constraints on top of existing ones[8]. On the other hand even extreme flexibility of the curriculum may not guarantee that appropriate revisions are performed when needed. In many higher education institutions, all changes in the curriculum must be first discussed and approved by some committee and then, upon recommendation of that committee, again discussed and finally approved at the institution level by the faculty council or similar body. At large institutions that offer hundreds of courses, such a procedure obviously precludes

frequent adjustments of the curriculum.

Therefore, in practice, the adaptability of the curriculum depends primarily on how the work on its development and revisions is organized. To make the curriculum truly adaptable; a decentralized approach to the curriculum development must be taken. Only key decisions should be taken at the highest (institutional) level. Less critical decisions should be made by the curriculum committee upon recommendation of individuals who are assigned personal responsibility for keeping specific parts of the curriculum, such as individual subject classes, up-to-date. Minor adjustments of the curriculum might be even left to the decisions of these individuals.

⊙ Assure cost-efficient resource utilization and management. Making the curriculum more flexible, i.e. providing the students with extra opportunities, potentially increases the costs of running the institution. In particular, an extension of the course offer naturally results in an increased number of the courses actually taught, This, in turn, causes extra teaching loads and may also lead to extra expenses if there are not enough classrooms at the institution. To optimize resource utilization, an efficient procedure for scheduling of academic activities (lectures, recitations, meetings, examinations) is obviously needed. Besides, appropriate fund allocation policy should be adopted to discourage inefficient utilization of human and physical resources that occurs, for example, when undergraduate courses are taught for a very low number of students. Such a policy does not necessarily compromise flexibility or quality, it should rather stimulate work on better coordination of the course offer (at a large institution that offers hundreds of courses, two similar low-enrollment courses having a significant content overlap can often be replaced by one course that would attract a sufficient number of students to make it cost-efficient).

⊙ Adjust computer facilities supporting administration procedures. An enhancement of flexibility and adaptability of the curriculum may pose some problems in the area of administration. For example, as a result of relaxation of restrictions on the design of individual programs of study, significant changes in the set of courses taught and the number of students enrolled in each of these courses occur from one semester to another. This makes the process of updating the course schedule and classroom assignment much more difficult than in the case of the traditional curriculum. Also, the registration procedure is more complicated and might require a provision for simultaneous access of a large number of users to the database. Therefore, adequate computer facilities should be installed and appropriate software tools developed to support organizational and administrative procedures.

Size of the faculty A typical university consists of relatively independent units, such as faculties or schools. One important question which cannot be easily answered is: what is the most appropriate size of an independent unit? A larger unit has potential benefit, because there is a possibility of more flexible and efficient use of the available personnel and physical resources. On the other hand, managing larger unit is a more difficult task, and the potential benefits from managing larger integrated set of resources may be suppressed by difficulties of the management.

In large 'democratic' organizations, such as universities, with many employees, complex management structure, where top managerial positions (such as deans and vice-deans) are elective, the responsibility is dispersed and fuzzy. Many administrators and academics are involved only in a small part of activities of the organization — their needs, decisions and requirements, however, may poorly influence other aspects of the organization.

Due to potential difficulties in managing large faculties, there is a tendency, arising from the ranks, to organize university into a larger set of smaller units rather then into a smaller set of large units, so that the units can be more clearly controlled, although at expense of splitting up the resources and lower utilization of physical resources. The management of a smaller unit is easier and usually it does not require sophisticated management techniques in order to achieve acceptable performance.

A significant enhancement of flexibility and adaptability of a system of study is not a simple operation that can be effectively performed by any higher education institution. In particular, a small institution usually cannot afford a large and diversified course offer which is necessary to provide the student with a

real opportunity to design of an individual program of study that matches his/her interests and professional career objectives. In a very large institution, the coordination of a large number of different programs and hundreds of courses may be organizationally unbearable. It appears, however, that regardless of possible difficulties, both the institution and their students will benefit from an effort taken to make the system of studies more flexible and adaptable.

Efficient integration of smaller academic units (such as departments) into a larger unit (school, faculty) is a difficult managerial task. The useful tools, which help to organize and to manage efficiently a larger unit, are: a proper management methodology and techniques, appropriate computerized administrative and management information system.

The search for methodology for high efficiency and quality of teaching and research, important as it is, has many subtle perils. A university is a place where a deep knowledge of organizational and human aspects of appropriate behaviour of the individuals and organizations needs to be considered to select what can be workable in a particular case. In comparison to manufacturing companies, at a university there is no single performance measure, such as profit, which can be a principal measure of the efficiency of managerial decisions. Moreover, there may be many inconsistent personal and local interests which are in conflicts. Therefore, organization of academic activities needs to be investigated carefully from theoretical point of view in order to work out the best patterns of organization and management.

The Faculty of Electronics and Information Technology at Warsaw University of Technology has 6 distinct and relatively independent departments, about 3000 students, 400 lecturers, 2000 lecture hours per week. Many departments have been grown up over last years, so that the Faculty might be restructured easily into a few smaller independent faculties. Our experience shows however, that introduction of a more intensive and more profitable organization and better management provides significant benefits which proves that in order to achieve high flexibility and adaptability of the system of studies it is much more efficient to manage a large faculty instead of running separate smaller units.

Computer-assisted administration and management

A significant enhancement of flexibility and adaptability of the curriculum poses new challenges in the area of administration and management. Since 1990, a significant effort has therefore been taken to expand the computer network and to develop a new integrated information system ERES supporting a large variety of administrative and managerial tasks[22]. Its database contains information on the system of study (course offer, curriculum requirements, academic regulations), resources available, personal data of the students and academic staff, student records, etc.

The system currently supports the following tasks related to the management of education process: student registration, monitoring of student progress, course scheduling and classroom assignment, examination scheduling, publishing (printing course catalogue, course schedule, course rosters, student progress records, certificates, etc.), assessing fees for failed courses (studies are free of charge, but students must pay for courses in which they received a failing grade).

Now many new functions are added in the new version of the ERES system[1]. In particular, students will be able to enter their registration forms in an interactive manner (with concurrent verification of correctness) using computer terminals. The development of an integrated information system has been accompanied by many other changes in the administration and management of the Faculty, necessary to make the revised system of study feasible and cost-efficient [23, 25]

Finance and resource management One important issue are appropriate rules for financing teaching activities which would promote obtaining higher effectiveness together with maintaining high quality of teaching. At our Faculty the financing of the teaching activities of the departments is approximately proportional to the quantity of the *students workload* measured as the accumulation of cost units

(proportional to the number of hours of lectures) multiplied by the number of students attending lectures chosen at the departments.

Another important issue of the resource management is proper reallocation of space between departments. Usually, there are significant changes over years in numbers of students studying at particular departments, so there are also substantial differences in requirements for laboratory space. A periodical (say, every 3 years) assessment of the departmental requirements for space and redistribution of the rooms between the departments should be carried on so that the space reallocation between departments would level the space usage in the same proportion to all departments.

Timetabling A particularly important part of any general university management activity is timetabling. Timetabling is required for scheduling all academic activities (courses, meetings and examinations) with the aim of providing feasible schedules, the most efficient utilization of the human and physical resources, and providing a considerable freedom of choice among offered modules for students that plan their individual timetables.

Past experience at the Faculty showed that timetabling was the most crucial module which have created very serious organizational problems and caused bottlenecks and inefficiency. The new requirements of the modular systems for providing flexibility of choice of modules made the timetabling problem even much more difficult.

A considerable improvement of the timetabling was possible only after implementation of the new organizational rules and computer system for timetabling[3]. The results of the improved timetabling were significant. The number of the required lecture rooms was reduced by 2590, the timetables became much more convenient both for students and lecturers (on average). The most import ant result, however, was that the resulted timetable gave more flexibility to students who have the opportunity of designing their individual timetables.

Quality

Below we discuss how enhancing diversity, flexibility and adaptability of the system of study can affect the quality of education.

An opportunity to design an individual program of study that best suits student's capabilities and professional career objectives enhances student's interest in the higher education institution, its academic staff, courses it offers, and studying in general. Furthermore, the responsibility students take for their own education usually motivates them for more efficient learning which, in turn, results in better qualifications of graduates who enter the labor market.

An opportunity to take fewer courses in a term than normally recommended allows less capable students to perform well in all the courses taken, and thus successfully pursue the program. If, in addition, several "exit points" are available, the student, after recognizing his/her problems, can appropriately adjust the level of education sought. This way, almost all admitted students have a chance to complete the studies.

The freedom students have in designing their individual programs of study inevitably leads to potential conflicts in accessing critical resources. A conflict occurs, for example, when too many students attempt to register for an attractive course with a rigid enrollment limit. Regulations that resolve such conflicts by taking into account the performance of the competing students create an incentive for good learning.

A large and diversified course offer and the freedom students have in designing their programs results in a situation where only some fraction of courses offered by the academic staff are actually taught. This naturally eliminates outdated and poorly taught courses. Another possible flexibility-dependent measure that would create competition and motivate the members of the academic staff to continuously improve the quality of courses and their teaching methods is to assume that the distribution of funds among organizational units within the institution is somehow dependent on the share of teaching duties.

Within an adaptable system of study, necessary changes and adjustments in curricula and other components of the system of study are implemented fast. This is of critical importance for some disciplines, such as electronics and information technology, where in 3-4 years ca. 50% of knowledge becomes outdated and virtually useless. Thus, for such disciplines, adaptability is absolutely essential to guarantee the quality of education services.

A more detailed discussion on the impact of flexibility and adaptability of the system of study on the quality of education is presented in [26].

It must be noted that extended flexibility and adaptability can also pose some problems if appropriate measures are not taken. For example, with a large number of options available, the students might get lost if an effective counseling system is not provided. Also, the high degree of freedom the students have in design of their individual programs of study makes the design of an optimal schedule of courses and classroom assignment quite a difficult task (as the course offer is updated each semester and not all the offered courses are actually taught, to efficiently utilize available classrooms, the course schedule must change, at least in part, from one semester to another).

Measures of flexibility and adaptability

Clearly, it is quite difficult to represent the flexibility and adaptability of a system of study using quantitative indicators. Nevertheless, we can formulate a number of criteria that could be used to decide whether the system is sufficiently flexible and adaptable. These are:

(i) Existence of multiple education paths: This criterion refers to the options available to each student admitted to an institution or a program. These options concern the duration of study, the diplomas or certificates awarded, the fields of study and the spectrum of specializations. It is desirable that student choices could be made as late as possible in the course of study (and not at the beginning of the study).

(ii) Size, diversity, and structure of the course offer: A good course offer is characterized not only by a large number of elective courses that cover a wide spectrum of topics, but also by an existence of two or more versions of many basic courses. A large course offer should have a well-defined structure (i.e. should be subdivided into subject classes) which would facilitate a review of courses by the students and their advisors.

(iii) Formulation of curriculum requirements (degree requirements): The formulation of curriculum requirements (degree requirements) using credit points and subject classes, rather than the names of specific courses, not only adds to the flexibility of the curiculum, but also significantly enhances its adaptability.

(iv) Fraction of elective courses in the curriculum: The number (or fraction) of both restricted and free elective courses in the curriculum is a good measure of the level of flexibility the student has in design of his/her individual program of study.

(v) Support for interdisciplinary programs: A good indicator of an interdisciplinary character of the studies is the average number of credit points earned by a student for courses taken at other institutions.

(vi) Possibility of adjustments in student's workload: This criterion refers to the regulations that allow the student to decide, within certain limits, on the number of courses taken each term. In particular, it is important to recognize whether temporary difficulties (e.g. a failing grade in one course) do not imply larger- than-nominal workload in the following term.

(vii) Procedure for curriculum development: An effective procedure for curriculum development allows for fast recognition of the need for improvement and relatively effortless implementation of necessary changes and adjustments, so that it can quickly eliminate weak points in the curriculum and keep it up-to-date and well suited to the needs of the customers.

Besides the above listed criteria, there are some other ones that do not directly affect flexibility or adaptability of the system, but should be mentioned here because they constitute necessary conditions for

effective functioning of a flexible and adaptable system of study. These include:

(i) Comprehensive information and advising system: Such a system should provide the staff and students with 24-hours-a-day access to all necessary information in an electronic form (course offer, course syllabi, course and examination schedule, detailed description of regulations and procedures, etc.). Clearly, to be accessible, it must run on a computer network of appropriate size. Besides, it is highly desirable that the students have their individual advisors throughout the entire period of study.

(ii) Integrated computer-aided administration system: Such a system should support a number of administrative tasks related to education, such as student registration, monitoring of the student progress, course and examination scheduling, classroom assignment, publishing (print ing of course cat alogue, course schedule, course rosters, student progress records, certificates), etc.

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