Shortening a Path to PhD – Impact on Quality of Engineering Education

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1. INTRODUCTION

1.1. Engineering education in Poland

In Poland, a university is an art and science oriented institution and has no engineering college or engineering departments. Programs of study in engineering are offered by other academic institutions: technical universities (also referred to as universities of technology or polytechnic institutes), technical academies, and engineering colleges. A higher education institution that offers engineering programs is usually organized into a number of fairly autonomous faculties, such as the faculty of mechanical engineering, faculty of electrical engineering, etc.

A vast majority of students admitted to technical universities pursue a five-year (10-semester) program leading to the MS degree in the selected field of engineering. Shorter, 8- or 7-semester programs leading to the degree of BS or BEng are offered mainly by engineering colleges.

Engineering curricula have been traditionally based on a rigid core of compulsory courses, with a certain number of slots to be filled with restricted or free elective courses. Student's work load is quite heavy - frequently the student has to take 10 or more courses per semester, with over 30 hours of regularly scheduled lectures, recitations, and laboratory sessions per week. Each graduating MS student has to submit and defend a thesis.

A recipient of a Master's degree can follow one of two basic paths leading to a PhD degree. One way, typical for the 70's and 80's, but still frequently adopted, is to take a position of a teaching assistant or research assistant at a higher education institution or research institute and pursue - in parallel with routine teaching, research and administrative duties - research work in the selected area, under supervision of a senior member of academic or research staff. An alternative is to pursue a program of study leading to a PhD degree. Such programs are currently offered by most technical universities. The students are required to take some number of advanced courses and conduct research work under supervision of a senior member of academic staff, but their other duties (in particular, teaching duties) are quite limited. In either case, to obtain the PhD degree, the candidate must pass a qualification examination in the selected field of study, and additional examinations in foreign language and humanities, and then submit and defend his/her dissertation. As mentioned earlier, regardless of the path taken, the process leading to the PhD degree is quite long - most of the candidates receive it at the age of 29-31.
After political and economic transformations initiated in 1989, higher education institutions have functioned in quite a new environment. Its most relevant features that particularly affect engineering oriented institutions are:

- a lot of autonomy, in particular, a lot of freedom in organizing the studies and designing curricula, given to leading academic institutions by the new Higher Education Act of 1990;
- financial crisis - as a result of severe economic recession, in the period of 1990-1997, financial support (per candidate admitted to university studies), received by higher education institutions from the Ministry of National Education, decreased on average by more than 60%;
- new rules of financing academic institutions which make the state support for public universities dependent on the number of students rather than on the actual costs of running the programs of study (as before);
- unattractive career prospects for university employees: academic staff, especially talented young people, are attracted by significantly higher salaries offered by private or even state-owned industrial or business enterprises;
- bad shape of most Polish industrial companies resulting in a diminishing number of research and development projects supported by industry and little demand for staff training programs offered by the universities, but also affecting decisions of candidates to university studies.

More information on changes in engineering education in Poland after 1989 can be found in other publications 7,8,11,12,16.

1.2. Problems with education at the PhD level

To deal with tremendous challenges associated with recent advances in technology, especially in the areas referred to as high technology, a large number of highly qualified young people graduating from engineering schools are needed. Unfortunately, for the last several years, the number of recipients of a PhD degree in the field of engineering has not been large enough to satisfy current and future needs of a modern industrial society. There have been three major reasons for this:

- Economic transformations following the political changes of 1989 have resulted in a growing demand for specialists in areas related to the free market economy (business, management, marketing, law, public relations). Good job prospects and sharply rising salaries in these areas have lead to a significant decrease in the number of candidates applying for engineering studies. For example, in the early 80's, the number of applicants for studies at our institution, the Faculty of Electronics and Information Technology, Warsaw University of Technology, exceeded the enrollment limit by a factor of 5 (at that time each candidate for university studies could apply to only one institution), whereas in the period of 1992-1993 the number of candidates only slightly exceeded the enrollment limit. A decreasing number of candidates has had a significant impact on students' capabilities. Those admitted in the 80's were good and very good students, almost all capable of pursuing a quite demanding program of study leading to the MS degree, and a large fraction of them could – at least potentially - successfully pursue a PhD program. Those admitted in the early 90's had generally a lot of trouble in pursuing the MS program, and only a small fraction of them were good enough to enter the PhD program.
As a result of growing diversity in educational background and capabilities of candidates admitted to engineering studies, higher education institutions that follow the traditional pattern of university-level engineering education in Poland - a five-year program leading to an MS degree – have been faced with an unattractive alternative: either to dismiss a large percentage of students who are not able to meet rigid requirements for the MS degree or to relax these requirements. In practice, for economic reasons, the latter solution has been frequently adopted. This has had a disastrous impact on the quality of education at the Master's level and the preparation of candidates for PhD studies.

In Poland, the education process leading to a PhD degree is quite long. A secondary school graduate must first complete a five-year program leading to an MS degree. As the research work carried out to meet the PhD degree requirements is usually unrelated to the MS studies, it typically takes 5-7 years. This means that most of the candidates who decide to seek a PhD can expect to receive that degree at the age of 29-31. This is not a very attractive prospect for gifted young people and therefore only very few of the best MS graduates decide to stay at the university and pursue a PhD program.

To improve the effectiveness of PhD programs, i.e. to increase the number of engineering students receiving the PhD degree, it is necessary:

- to continuously improve the quality of the MS program, thereby increasing the number of candidates who can successfully pursue the PhD program,
- to make the doctorate studies more attractive to the best MS graduates by reducing the time it takes to receive the PhD degree.

In this paper, we present an effort aimed at attaining these goals at our institution - the Faculty of Electronics and Information Technology, Warsaw University of Technology.

2. TOWARDS IMPROVING THE EFFICIENCY OF PHD STUDIES

The Faculty of Electronics and Information Technology is the largest teaching and research center at the Warsaw University of Technology: it has more than 2700 full-time students and 320 members of academic staff. A network of more than 900 computers supports education, research, and administration of the Faculty.

To respond to challenges faced by engineering oriented academic institutions, we have departed from the traditional model of engineering education in Poland and restructured the system of study. The key solutions that allow us to improve the efficiency of PhD studies are:

- introduction of a new structure of studies in which
  - only a fraction of students entering the Faculty can obtain the MS degree,
  - a formal PhD program is part of the system of study at the Faculty,
- integration of MS and PhD curricula,
- making the system of study more suitable to the needs and expectations of the candidates, and thereby attracting more good candidates for studies at the Faculty.

In what follows, we discuss these issues in some detail.
2.1. Introduction of a new structure of studies

Until recently, following the traditional pattern of university-level engineering education in Poland, the Faculty of Electronics and Information Technology offered the secondary school graduates almost exclusively the five-year MS program. MS graduates could then proceed towards the PhD degree either by taking a position of a teaching assistant or research assistant at the Faculty and conducting the PhD research work in parallel with routine teaching, research and administrative duties, or by entering the PhD program. This PhD program was almost entirely separated – with regard to both curriculum and administration – from the MS program.

In 1992-1994, drawing from the international discussion on challenges facing the engineering education, a significant effort was made by the members of the academic staff to work out the general philosophy and some detailed concepts regarding the restructuring of the system of study at the Faculty. As a result, the fundamentals of the three-stage system of study, comprising a BS program, an MS program, and a PhD program, were formulated and approved by the Faculty Council.

With the beginning of the academic year 1994/95, with the formal approval of the University Senate, the two-stage system of study was introduced as the first step of the restructuring of the education scheme. In the new system, instead of the traditional 5-year MS program, the following programs of study are available:

- the first-stage studies available in two versions:
  - a 4-year program leading to the BS (BEng) degree,
  - a 3-year program leading to the certificate of basic education in engineering; such a certificate is sufficient to apply for admission to second-stage studies,
- the second-stage studies: a 2-year program leading to the MS degree; the candidates must hold the Bachelor's degree in engineering or related discipline or the certificate of basic education in engineering.

In 1996-1997, the details of the last stage of the system, i.e. a 4-year program leading to the PhD degree, were worked out and approved by the Faculty Council.

The general organization of the system of study at the Faculty is illustrated in Figure 1. The first-stage studies are divided into 3 phases: A (semesters 1-4), B (semesters 5-6), and C (semesters 7-8). At the end of phase A, after 2 years of basic studies in mathematics, science, electronics and computer engineering, the student selects his/her specialization (area of concentration). Twelve areas of concentration are available, including Biomedical Engineering, Computer Engineering, Optoelectronics, Software Engineering and Information Systems, Telecommunication Systems and Networks. Phase B is designed as an introduction to the selected area of concentration. At the end of the third year, the student decides whether to continue with the first-stage studies (BS program) or to apply for admission to the second-stage studies (MS program). During phase C, specialization-oriented courses are taken and a final design project is carried out.

The second-stage studies (MS studies), which normally take two years, are intended not only for the graduates of the Faculty, but also for other holders of BS-equivalent degrees in electrical engineering, computer engineering, or other related discipline. The students of the first-stage studies at the Faculty can enter the second-stage studies after completing phase B or after
receiving the BS degree. In the latter case, the student can transfer to the second-stage studies some credit received for the courses taken during phase C of the first-stage studies. In the extreme case, with this transfer only one year of studying may be necessary to complete the second-stage studies and receive the MS degree.

Figure 1. System of study at the Faculty of Electronics and Information Technology

As the curriculum requirements for the second-stage studies include a significant number of advanced courses, to enter the MS program, the candidates must demonstrate adequate achievements and capabilities confirmed by the grade records. Admission requirements and the annual enrollment limit for the second-stage studies are set so that only a certain fraction of students who enter the first-stage studies at the Faculty pursue the Master's program.

The third-stage studies (PhD studies), which normally take four years, are – like MS studies – intended not only for the graduates of the Faculty, but also for candidates who received their degrees at other institutions. As in Poland, holding a Master's degree is virtually a necessary condition for starting a formal procedure that eventually leads to the PhD degree, only candidates with Master's degree in electrical engineering, computer engineering, or other related discipline who demonstrate adequate achievements and capabilities, are admitted to the third-stage studies. An candidate admitted to PhD studies can, however, transfer some credit received for the courses taken during the Master's studies. In particular, a PhD candidate who received the MS degree at our Faculty can transfer as much as an equivalent of more than one full year of study, as is explained in detail in the following section.
2.2. Integration of MS and PhD curricula

Until recently, the PhD program offered at the Faculty of Electronics and Information Technology was - like in all other Polish technical universities – almost entirely separated, with regard to both curriculum and administration, from the MS program:

- The curriculum for fourth- and fifth-year MS students included mainly restricted or free elective courses which could be selected from more than 150 courses offered each year by the members of academic staff. As virtually no quality assessment and control mechanisms were employed to eliminate poorly designed and taught courses, the quality of education at the Master's level was questionable.

- The requirements for the PhD degree emphasized the individual research work; the number of advanced-level courses to be taken was very limited. Some number of advanced courses intended primarily for PhD students were therefore developed, but this offer was quite limited, and the PhD-level courses were rather infrequently attended by MS students.

With an introduction of the new system of study, the curricula for the second-stage (MS) studies and for the third-stage (PhD) studies have been made much more compatible.

By decision of the Faculty Council, the MS degree is now offered in one of the following four fields of study (areas of specialization):

- Computer Science and Engineering,
- Control Systems,
- Electronics,
- Telecommunications.

The names of these fields correspond exactly to the names of scientific disciplines in which a PhD degree can be awarded. Thus, a direct relationship between the second-stage studies (MS program) and the third-stage studies (PhD program) has been established.

A large number of new, advanced-level courses intended for both MS and PhD students have been introduced. These courses can be classified into 5 groups: one group includes advanced math and science courses, and the other 4 groups correspond to the 4 fields of study (areas of specialization). The number of courses offered in these groups is given below:

- advanced fundamental (math and science) courses – 16,
- advanced courses in of Computer Science and Engineering – 8,
- advanced courses in Control Systems – 6,
- advanced courses in Electronics – 16,
- advanced courses in Telecommunications – 14.

The differences in the number of courses in the four fields of study are related to the different numbers of areas of concentration (profiles) offered within each field. A profile is defined by a sequence of four advanced-level courses in one field. Currently, 13 profiles are defined: one profile in Control Systems, two profiles in Computer Science and Engineering, six profiles in Electronics, and four profiles in Telecommunications.

Each advanced-level course is assigned 2-4 (most commonly 3) credit points (credit hours). The curriculum requirements for both the MS and the PhD degree specify the number of credit points
that must be earned by taking advanced courses from the above listed groups. Other MS curriculum requirements are associated with courses in the area of humanities and social studies, introductory (BS-level) specialization-oriented and free elective courses, and individual research work leading to the degree. The curriculum requirements for the MS degree are given in Table 1. With the nominal course load of 24 credit points per semester, accepted as a standard student workload for all types of studies at the Faculty, it takes 2 years to complete the program.

The difference between the traditional Master's program and the new one lies not only in the length of studies (5 years vs. 2 years due to separation from the BS program) and in the level of courses offered. The MS studies are now much more research-oriented; like for the PhD program, it is required that the individual research and Master's thesis be associated with some research project carried out at the Faculty.

<table>
<thead>
<tr>
<th>Table 1: Curriculum requirements for the MS degree</th>
<th>number of credit points</th>
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<tbody>
<tr>
<td>humanities and social studies</td>
<td>8</td>
</tr>
<tr>
<td>BS-level specialization-oriented and free elective courses</td>
<td>20</td>
</tr>
<tr>
<td>advanced math and science courses</td>
<td>8</td>
</tr>
<tr>
<td>advanced specialization-oriented courses</td>
<td>12</td>
</tr>
<tr>
<td>advanced elective courses</td>
<td>6</td>
</tr>
<tr>
<td>MS seminar</td>
<td>4</td>
</tr>
<tr>
<td>individual reading and design project</td>
<td>12</td>
</tr>
<tr>
<td>individual research and MS thesis</td>
<td>26</td>
</tr>
<tr>
<td>total</td>
<td>96</td>
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<tr>
<th>Table 2: Curriculum requirements for the PhD degree</th>
<th>number of credit points</th>
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<tbody>
<tr>
<td>humanities and social studies</td>
<td>12</td>
</tr>
<tr>
<td>free elective courses</td>
<td>10</td>
</tr>
<tr>
<td>advanced math and science courses</td>
<td>16</td>
</tr>
<tr>
<td>advanced specialization-oriented courses</td>
<td>24</td>
</tr>
<tr>
<td>advanced elective courses</td>
<td>8</td>
</tr>
<tr>
<td>PhD seminar</td>
<td>12</td>
</tr>
<tr>
<td>individual research and PhD dissertation</td>
<td>110</td>
</tr>
<tr>
<td>total</td>
<td>192</td>
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The curriculum requirements for the PhD degree are given in Table 2. With the nominal work load of 24 credit points per semester, it takes 4 years to complete the PhD program. However, some credit points earned during the MS studies can be transferred to partially satisfy the PhD curriculum requirements. Appropriate credit transfer rules have been formulated which specify the maximum number of credit points that can be transferred in each group of courses and the conditions under which such a transfer can be made.
An example of credit transfer is illustrated in Fig. 2. An MS graduate from the Faculty admitted to the PhD studies in the same area, can automatically transfer from the MS record:

- 8 credit points earned in humanities and social studies courses,
- 4 credit points earned in Master's seminar,
- 26 credit points earned in advanced courses (math and science, and specialization-oriented courses),
- 20 credit points earned for Master's research.

If, during the MS studies, the student - in addition to the required 26 credit points in advanced courses - earns 4 extra credit points by selecting one or two advanced courses as free electives, the total number of credit points transferred to the PhD program is 72. This corresponds to 3 full semesters of nominal course load, which means that, at least in theory, the PhD requirements can be completed in 2.5 years after receiving the MS degree. Clearly, such a reduction of the period of PhD studies is only possible if the topic of the PhD dissertation is closely related to the individual research work done at the Master's level.

However, in any case, the MS program can, to some extent, be considered as part of the PhD program.

Noting that in the system of study at our Faculty, the shortest path to the MS degree (with the last phase of the BS program skipped) takes nominally 5 years, but – with appropriate design of an individual program of study – can be shortened, it is possible to receive the PhD degree in 7 years after graduating from the secondary school and entering the Faculty. This might be considered an extreme case, difficult to implement in practice; an 8-year period of studies at the Faculty leading to the PhD degree appears, however, quite realistic.

2.3. Making the system of study more attractive

The main feature of the new system of study which makes it attractive to our students is its flexibility\textsuperscript{10,11}. Besides giving the student a possibility to decide on the level of education (BS, MS or PhD), various other measures have been taken to make the system flexible, especially at the first (BS) and second (MS) stage of study. In particular:

- **A large, diversified and well-structured course offer is provided:** More than 400 courses are offered each academic year. Almost any engineering course involves some practical and hands-on experience in the form of a design project or laboratory that accompanies traditional lectures. All courses are grouped into 40 topical areas (subject classes), such as "mathematics", "control systems", "computer networks", etc. This facilitates the examination of the course offer by the student and his/her advisor when looking for courses most suitable for inclusion in the individual program of study.

- **Curriculum requirements are formulated using credit points and subject classes:** In the curriculum requirements, the names of subject classes are used rather than the names of specific courses; a minimum number of credit points that must be earned by the student in courses taken from each relevant subject class is specified. Sometimes, within a given subject class, compulsory courses are specified, but in principle, the mechanism of prerequisite and corequisite requirements is employed to ensure an appropriate sequence of courses taken by the student.
Fig. 2. Transfer of credit from MS studies to PhD studies
A large offer of specialization areas and an opportunity for minor specialization at the BS-level is provided: At the BS-level, 12 areas of concentration are available. Some of them, e.g. "Software Engineering and Information Systems" and "Management of Telecommunication Networks and Services", have been introduced in response to the trends on the labor market. Free elective courses enable the student to either extend his/her knowledge in the selected area of concentration or study other topics. In particular, the student can take a certain number of courses in some area of concentration different from the one selected for major specialization. In such a case, he/she is awarded a certificate of minor specialization.

A possibility to individualize the intensity of the study is ensured: The student is allowed to adjust his/her work load (number of courses taken) in each semester to his/her capabilities and preferences, as long as he/she satisfies the minimum performance requirements. This means, in particular, that a good student can earn the degree earlier than scheduled and immediately start his/her job career. A less capable student can take fewer courses per semester than his/her colleagues and thereby avoid being dismissed for inferior performance in the courses taken. The student is also allowed to register for fewer courses than recommended and take a part-time employment or submit an "empty" registration form and take a full-time job during a one-semester or even one-year "leave of absence".

A large number of available options allow each student to design an education path which best matches his/her interests, professional career objectives, capabilities, financial status, and other relevant conditions. This makes engineering education at our Faculty quite attractive compared to other institutions that offer traditional, less flexible systems of study.

3. IMPACT ON EDUCATION QUALITY

The restructuring of the system of study at our Faculty has had a significant impact on the quality of education, in particular on the qualifications of candidates for PhD studies.

• The engineering studies at the Faculty have became more flexible and thereby more suitable to the needs and expectations of the candidates. Therefore, despite diminishing interest in engineering studies among secondary school graduates in Poland, in the period of 1993-1997, the number of candidates who applied for the studies at the Faculty has increased by almost 80%. As a consequence, with an unchanged enrollment limit, capabilities and performance of the students have significantly increased. The grade point average for the group of students who entered the first-stage studies on October 1, 1994 (the first group admitted to the restructured program), was - at the end of their third year of study, when they could switch from the first-stage to the second-stage studies - significantly higher than that of the students who entered the Faculty earlier (before restructuring of the system of study).

• As only those students entering the Faculty who perform well during the first-level studies are admitted to the second-level studies, the MS degree requirements can be made more demanding without the risk of dismissing a large number of students. Compared to the traditional 5-year MS program, the new curriculum of the second-stage studies contains much more advanced courses, and it has become more research oriented. Thus, the education at the Master's level provides now a better starting point for those who decide to continue with the PhD program.
• A possibility to receive the PhD degree in 8 years (or, in an extreme case, in 7 years) after the graduation from a secondary school makes an education path leading to the PhD degree quite an attractive prospect for gifted young people. In particular, for the best MS graduates, a perspective to stay 3 more years at the Faculty to get the PhD degree may look like a reasonable investment in future professional career.

4. CONCLUSION

The essence of the deep restructuring of the system of study at the Faculty of Electronics and Information Technology, Warsaw University of Technology has been the departure from the traditional system of engineering education in Poland to make it more compatible with the emerging international standards of engineering education. We believe that this will contribute to an increase in the number of recipients of the PhD degree, turning into highly qualified engineers and researchers much needed for the future development of the country.

Early experiences with the new system indicate that the qualifications of MS students, being primary candidates for PhD studies, have improved. An integration of the MS and PhD curricula, resulting in a significant reduction of time required to receive the PhD degree, is another factor that would positively affect both the number of candidates for PhD studies and their quality.

It should be mentioned that the integration of the PhD program into a new system of study has not been without difficulties. According to the Polish law, PhD studies are not considered an integral part of the system of higher education - the requirements and formal procedures associated with awarding a PhD degree are stated by the Act on Scientific Title and Degrees, and not by the Act on Higher Education. Those who pursue PhD programs do not have the same rights and privileges as students of the higher education institutions. Also, at the University level, academic regulations for PhD studies differ from those for the other (BS and MS) studies. Therefore, a significant organizational effort was required to deal with incompatibilities in the existing regulations. This work will continue as essential changes in the Act on Higher Education are expected.

A good news is that other institutions of higher education in Poland are moving in a similar direction. In particular, several faculties at the Warsaw University of Technology, encouraged by the recent decision of the University Senate, are working on an introduction of a three-stage (BS-MS-PhD) system of study, similar to that introduced at our Faculty.

References

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