Some Reflections on the Needs of Mathematical Education for Engineering Studies: the case of ISEP

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Abstract – **There is no doubt that for engineers, mathematical knowledge and skills are an essential background. In last years, the teaching of mathematics in universities and polytechnic schools had suffered great changes, due to issues like technology advance, new disciplines and different perception of needs. In Portuguese educational system, these changes had become more evident with the implementation of Bologna agreement. For instance in ISEP, the Oporto Polytechnic School of Engineering, a reduction on the duration of engineering programs from a calendar of 3+2 years, to a programme of 3 years, was made. In respect to mathematics curriculum, a compression and a weakening process had occurred, resulting, simultaneously, from the reducing of mandatory present learning hours in the student's schedules, in order to stimulate independent learning, and also from the introducing of new subjects. In this paper, the results of a survey on the comparison between mathematic schedules in engineering studies, before and after Bologna, as well some reflections on the changes that occurred in mathematics engineering programs, is presented. The results obtained so far, allow us to admit that student's failure rate is going to increase, with the reducing of learning lectures, since students can't adequately manage new concepts due to their deficient mathematical background, and they aren't mature enough to work for themselves, outside mandatory classes. Furthermore, some proposed methodologies to measure mathematical acquired knowledge and skills, of former students in their professional environment, are proposed.**

Index Terms – engineering education, ISEP, learning, mathematics

INTRODUCTION

During last years, engineering graduation programs had suffered many changes, not only in Portugal but all around the world. These changes were due to factors like global economics, quick diffusion of information, technology development, new disciplines and different perception of needs. For that reason, engineering schools had been adapting their curriculums to face the new challenges placed by technology advance and global economy [1]. More recently, in 2006, a new occurrence has brought important changes to Portuguese University and Polytechnic Schools: the implementation of Bologna Declaration. Accordingly to the meeting that took place in Bologna, Italy, in 1999, the Ministers of Education of 29 European countries, subscribed a political declaration, whose main objective was to raise international competitiveness and attractiveness of European Higher Educational System [2] in the global market, taking in account the pressure made by USA education system. For that purpose, the subscribers of that Declaration commit themselves to build a harmonic European Higher Educational System till 2010, in order to enable and stimulate the mobility of students among University programs. In respect to Portugal, the transposition of Bologna Declaration to the national law system, and the implicit obligation of achievement described goals, led Portuguese Universities to the necessity of implementing a completely new organization of their undergraduate and graduate programs [3]. These changes included, for instance, the implementation of a new credit system analogous to the European credit transfer system, in order to ensure student mobility, and, above all, the design of the two-cycles model of education: the undergraduate cycle that qualifies students to achieve an immediate employment; and the graduate cycle designed to give a better scientific background and pointed out to master and doctorate degrees.

However, this process has brought in some difficulties, especially among traditional Polytechnic Schools. Until 2005, engineering undergraduate programs lectured in those schools followed a two-stage model. The first stage with a standard duration of three years provided the degree qualification of Bachelor. The second stage of education offered students a graduate diploma, after the completion of a standard two years program.

The implementation of the Bologna Declaration in Portugal, and particularly in the Polytechnic Institutions, ended the Bachelor qualifications and the two-stage undergraduate models as described above, converted into one-stage program, with an unique standard duration of three years.

MATHEMATICAL PROGRAMS

In respect to mathematics courses in engineering degrees, a compression and weakening process had occurred, essentially due to two main reasons: the reduction of mandatory presence learning hours in the student's schedules, in order to stimulate independent learning; and the introducing of new subjects, namely seminars and embracing projects.

Engineering can be described as the use of mathematical, physical and technological knowledge, *to find solutions to* *challenging problems*. And there is no doubt that mathematical skills are fundamental and indispensable, to the practice of engineering professionals. However, there is no consensus among practitioners on the way it should be done, that is to say what topics are necessary to develop the essential mathematical skills, which of them are relevant to the core business of engineering technical subject and how profound and theoretical based should lectures be. Therefore, some authors encourage that mathematical learning should essentially be based on techniques to solve problems; while others sustain that it must be more supported on its own principles and concepts.

Until 2005, before the implementation of Bologna agreement, the accomplishment of mathematics curriculum defined for engineer programs in ISEP, experienced increasing difficulties, due to the poor mathematical background of the new students, felt year after year.

However, it doesn't seem that changes recently introduced in the mathematics curriculum, aren't enough to solve, only for themselves, the referred educational problems. For that reason, something else must be done to assure that Portuguese engineering students will graduate gathering the suitable mathematical background needed to compete in the European global market.

Against this background, this paper presents some reflections on the changes that occurred in mathematics accomplishment in the ISEP engineer programs, due to the implementation of Bologna agreement. Furthermore, a comparative study on the changes that took place in each engineering curriculum lectured in ISEP, particularly those ones occurred in mathematics courses, is presented, in order to conclude that feedback about mathematical acquired skills and professional practice needs to be measured.

SCOPE OF RESEARCH

Updating existing courses to the aims of Bologna Declaration includes new challenges. For instance, the requirement to evaluate educational programs based on the students outcomes, in spite of using barely the curriculum syllabus. For that reason, it is now necessary to demonstrate the effectiveness of the educational programs. And, the temptation to reduce contents in order to help weaker students in getting success, and fight the increase failure rate due to mandatory changes in curriculums, should be avoided once it has the greatest disadvantage of failing the preparation of more able students for engineering subjects.

So, in order to suit this requirement, it will be necessary, not just to evaluate student's knowledge and ability, but also to identify what must be measured and by what organizations: the universities, the employers or the professional boards.

In fact, the accreditation of engineering educational programs in the professional associations is very important and a matter of concern, whenever changes in curriculum's are ready to be performed. To have engineering programs recognized by Professional Boards is a gold standard for any institution, and the recognition of the quality of their engineer's graduation students, by their future employers.

The competencies acquired by an engineering student, are achieved by the educational program he/she followed. And this program should establish the necessary links between different courses, and the specific bodies of knowledge in order to develop the right skills.

The assessments of students outcomes is, perhaps, the most profitable way of evaluating curriculum and at the same time, verifying the courses syllabus [4]. Evaluate students' knowledge and their aptitude it's implicit in the process of verifying the curriculum, and scrutinizing how changes in curriculum and in the courses contents interact with the outcomes. For instance, the study carried out in the Arizona State University [5] establishes a methodology in order to provide the taxonomy of the gaps in the engineer programs:

- Curriculum gaps;
- Course gaps;
- Program gaps.

The conclusions pointed out from the study indicate that knowing and classifying these gaps allow Departments to identify most important areas where the improvements should be made.

It is well known that mathematics have a place in the engineer program, and engineers need proficient skills in mathematics. For instance, when we look through the ABET Engineering Criterion, criterion number 3 specially refers that engineer students must show *an ability to apply knowledge of mathematics, science, and engineering* [6].

Unfortunately it's not an easy task to develop the required mathematical skills, which are recognized as essential for the future engineering practice. As a matter of fact, in Portugal it is common to hear engineers' professionals claiming, the little use of mathematical knowledge in their daily activity. However, mathematical skills are embedded in the engineer conceptual frame and are used in an implicit mode, anytime and anyway the practice occurs. What we mean is that, even without notice, every engineer (and why, not to say, every professional), uses mathematics in his (her) daily routine, since the abstract knowledge lasts for many years.

The concern of mathematical learning in engineering education, and how can it be more attractive for students or more integrated in theirs curriculum, has been object of reflexions and studies during last years ([7],[8] [9]).

Another problem that deserves particular attention is the definition of the topics that should be taught and what level of performance is needed. In a study carried out by the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology [10], the most important mathematics competencies for the engineering programs, were identified, and what topics have a flow of learning and utilization in the future engineering practice. The conclusions of the study pointed out a list of mathematical topics, as well as the engineering course in which each mathematical skill is used, review or taught. The referred investigation also presents some suggestions for curriculum adjustment with the inclusion of new subjects. Furthermore it identifies essential mathematics concepts for engineer problems, where students reveal more difficulties, like functions, linearity, and the performing of vector products in conjunction with integrals.

This study also made some recommendations to the educational authorities, civil society and professional boards, in order to enhance the communications between mathematics and engineers. This problem is so relevant that European Society for Engineering Education (SEFI), had recently created a task group to study what are the most convenient mathematics for engineer curriculum in the twenty-first century [11].

ENGINEERING CURRICULUM IN ISEP

Introduction

ISEP (Oporto Superior School of Engineering) has a long tradition in graduating engineers in Portugal. In fact, ISEP, the former Industrial and Oporto School, was established in 1852 and graduates bachelors in engineering since 1926. Many changes in educational programmes had occurred since then. Although, through the years, the number of students had quickly increased, especially in the last 30 years following the national trend, the precedent educational mandatory system, completed by students in high school, had been strongly changed and weakening student's mathematical knowledge. This statement is easily recognized by international studies that always place Portugal in the tail of the developed countries, whenever mathematical knowledge is measured (OCDE-PISA 2006). On the other hand, following international tendency, health related sciences, management learning and media studies had become much more popular, with larger increase in demand in the Portuguese Universities, absorbing almost all the well-qualified students. In the meantime, engineering studies had suffered strong decreases on the average qualification needed to access public Polytechnic Schools, with an increase in the numbers of students, but a decrease on their qualifications. Furthermore, new students don't have the desired level of prerequisites, especially in mathematics, whose fluency and background is reduced, contributing to undermine engineer degrees, as mathematics weakness normally lasts till the end of the graduation.

Transferring mathematical acquaintance to engineering students, involves building and consolidating concepts acquired in High School studies, and linking them together in order to assemble a coherent mathematical knowledge, which can be used confidently in the engineering subjects that come forward in the graduation program.

However, recognizing the worst preparation of students when accessing universities, a diagnostic test to evaluate their actual mathematical competences and identify main gaps, was implemented in ISEP [12]. The results of those tests, especially designed to measure students' background, had shown insufficient knowledge in basic and fundamental mathematical areas, like arithmetic operations with fractions and algebraic manipulation, as well as lack of information about trigonometric functions.

The shortfall of knowledge associated with the underperformance in such areas, is of great concern since those topics are the key to enlarge mathematical knowledge [12]. Simultaneously, the task of acquiring the mathematical skills required for an engineer turns to be very difficult.

To overcome this situation, and help less prepared students in their mathematics deficiencies, three different measures were implemented in ISEP: the conception of a support centre, where students could get additional tuition; the aid of computers in the teaching; and the reducing of more advanced syllabus contents, by introducing revisions of the basic ones. However, as it is well documented in SEFI report [11], each one of these measures had its own inconveniences, and without other schemes, they are not enough to build a coherent mathematical body of knowledge.

Engineering Studies until 2005

With the challenges of Bologna declaration, some changes in the structure of engineering studies of ISEP were necessary to be performed. Until 2005 graduation studies follow a two-stage model lasting 3+2 years. In this model the mathematics courses were mainly centred in the first year of the opening stage, and were composed of the following subjects: Calculus I and II, Linear Algebra, Statistics, and Numerical Analysis. Figure 1 shows the numbers of hours per week of the mathematics courses through the first 6 semesters of the different engineering programs:

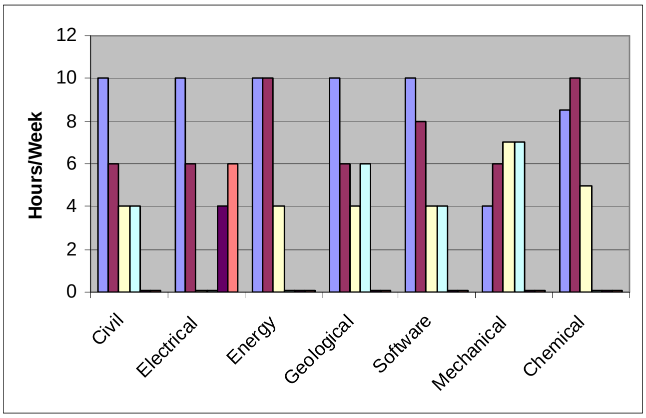

FIGURE 1
MATHEMATICS SCHEDULE IN ENGINEERING STUDIES

Meanwhile some of the engineering studies enhance the mathematical skills with a second mathematic involvement on the two last years, of the second stage. At this level the models adopted were biased with respect to mathematics. Figure 2 illustrates the number of hours per week for the mathematics courses in each engineer degree, in the last 2 years of the 3+2 model:

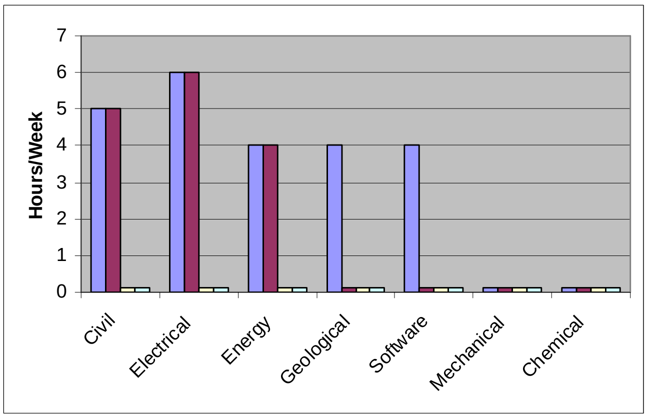

FIGURE 2
MATHEMATICS SCHEDULE IN THE LAST TWO YEARS

These courses were taught mainly in the first year of the second stage, covering a variety of mathematical topics, like Operations Research, Forecasting, Advanced Calculus, Optimization, among others, all of them comprising different mandatory learning hours.
In order to obtain comparable results, the ratio of mathematical lectures in relation to the total weekly schedule, was measured, in respect to the first stage, second stage, and the full 3+2 years of graduation. The results obtained, as illustrated in figure 3, show that the average of mathematics intervention is about 15% in first stage, 4%, on the second stage, with an average of 10% along all graduation programs:

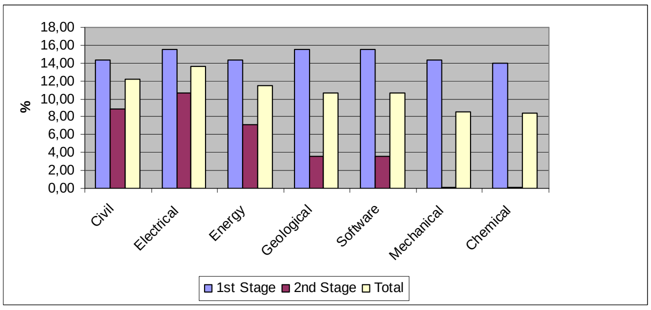

FIGURE 3
WEIGHT OF MATHEMATICS IN ENGINEER PROGRAMMES

Implementation of Bologna agreement

The adoption of Bologna agreement required changes in the curriculum degrees, the most important of all related to the duration of cycles in graduation programs. In fact, it had forced a reduction in the duration of engineering programs given by ISEP, from a calendar of 3+2 years, to a programme of 3 years, and the obligation that, after this 1st cycle, students ought to get a diploma, and the necessary skills to face the labour market.
The changes performed in the curricula due to Bologna Declaration, were enormous. First of all, the obligation for students to be capable of entering in the labour market required the introduction of new subjects, with the consequent decrease in the duration of schedule lectures, in order to develop self learning skills, information search skills, and individual working ability in research projects. In respect to mathematics courses, in addition to the reductions and adjustments that occurred in the subjects scheduled and in syllabus contents, the most obvious change was the reduction of the lectures, as illustrate figure 4.

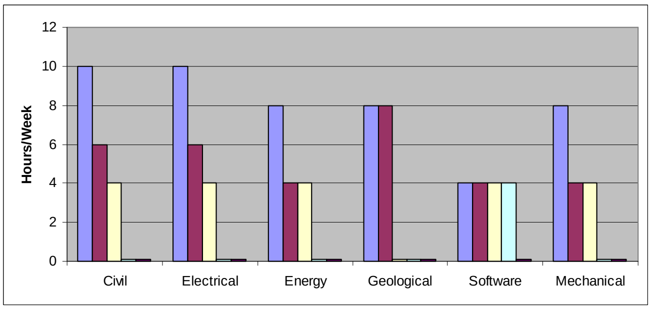

FIGURE 4
HOURS PER WEEK OF MATHEMATICS SUBJECTS

Besides these reductions, some others changes had been performed, namely the withdrawal of specific courses, like Numerical Analysis, that managers decide it wasn't necessary for students of the 1st stage, and the embedding of some of its topics, in other courses.
Making the same comparison as before, between the weight of mathematic lectures all over the six semesters, in relation to the total weekly schedule, we denote that the requirements of mathematics fluctuate between 10 and 13% of the overall mandatory learning schedule, as can be seen in figure 5.

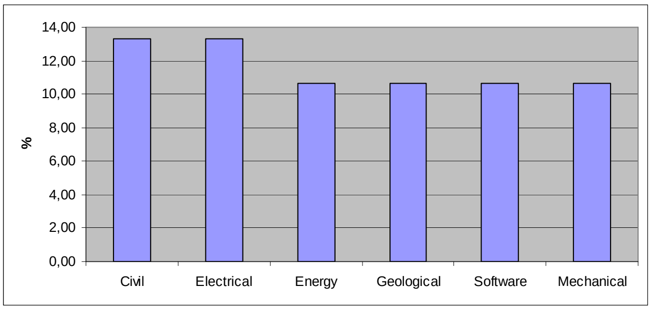

FIGURE 5
WEIGHT OF MATHEMATICS IN ENGINEER PROGRAMMES AFTER 2005 IN ISEP

A comparison between these values, and the ones obtained for the weight of mathematic schedule in engineering programs before 2005 (figure 2), denotes the weakness of mathematical knowledge and skills, while measured up the influence in the three first years of the last degree model. Nevertheless, when analysed all formation model (3+2), the weight is almost the same, varying from 8% through 13%, in the programs before Bologna, and from 10% till 13% in the ones adapted to Bologna agreement.
These comparative studies show that the overall rough weight of mathematics, before and after 2005, is similar and haven't decreased, like top managers like to state. However, a deeper analysis carries out the opposite conclusions: the cutback of learning lectures is increasing the failure rate, since students can't manage adequately the new concepts due

to their weak and deficient mathematical background. As we all know, mathematics courses are built in a way that all concepts are needed during the duration of the studies, as well as the relations among them.

The solutions to overcome this situation are not easy to implement, and normally produce postponed effects.

As referred before, the most popular solution among mathematics lecturers is the extra tuition. However, it normally doesn't help less prepared students, who need an organized program in order to build a coherent mathematical body. Of course that the ideal and well known solution stands for the implementation of the basic mathematical knowledge before the access to the university degrees, particularly during high-school studies (report [11]). Unfortunately this solution depends on political issues that simply are beyond the control of the lecturer body of ISEP.

Throughout the years of teaching I have noticed that students reveal a lack of mathematic self-confidence that professors are supposed to develop.

In terms of personal characteristics, each student has his own pace of acquiring mathematical knowledge. Schedule tasks they ought to achieve, allow students to work at their own speed, and to interfere on their work if, only and when they ask, is the better way to deal with different backgrounds. Simultaneously, the encouragement of students to stay after lectures, if necessary in professor's office, and ask for help if they need assistance with their problems, is the key to make them understand their weaknesses.

In fact, our students aren't mature enough to work for themselves, and beyond the mandatory hours attended in lecturers, simply ignore recommendation books or complementary readings.

FUTURE ACTIONS

Due to the implementation of Bologna agreement, some transformations had to be performed in the engineering programs lectured in ISEP, which will necessary lead to inherent changes in the mathematical component of those programs. Dealing with the whole range of details related with these transformations requires time, and can't be done in just one or two years. To really analyse the effectiveness of the actual educational programs, it is necessary to measure at what stand does students acquired the mathematical skills required to adequately perform their future professions.

The proposed methodology to measure the degree of achievement of mathematical knowledge acquired in university by former students is divided in the following steps:

- inquiries to students at the end of the graduation program, about their feeling on the use of mathematical knowledge, on the engineering subjects;
- employers evaluation after one year of employment, in respect to the expectations about mathematical knowledge of former students;
- inquiries to students about their acquaintance and use of mathematical knowledge, in their daily professional routine;
- accomplish of a diagnosis test, to evaluate the preservation of required knowledge;
- repeat this measures 3 years after the graduation

The results of the inquiries should point solutions to improve means and methods of teaching, in ISEP, and improve mathematical knowledge of students.

CONCLUSIONS

In this paper, an analysis of mathematical curriculum in ISEP, before and after 2005 due to the implementation of Bologna agreement, was made. The compression of the calendar of 3+2 years, to a programme of 3 years, nominated the 1st cycle of studies, and the needs to get the necessary skills to face the labour market, lead to reductions and adjustments in the mathematical subjects scheduled, as well as in the syllabus contents.

To acknowledge how deep these changes were, a survey has been carried out. The conclusions indicate that, in despite of a reduction in the scheduling hours occurred in the first stage, the comparison with the complete formation model before Bologna agreement (3+2), reveals almost the same weight of mathematic hours in engineering programs.

However, it has been noticed that failure rate is increasing, because students had a weak and deficient mathematical background, which frustrates the acquiring of new concepts.

To overcome this situation some measures had been put into practice, namely extra tuition classes, without any practical results. In the opinion of the author based in the experience collected in about 18 years of teaching graduate students, each one of them has his own pace of acquiring mathematical knowledge. So, only mandatory lectures with effective tutoring, where students are allowed to work at their own speed, and teacher's interference on their works occurs only and if they ask, can be the key to achieve success.

On the other hand, it is decisive that mathematical knowledge acquired in university by former students, can be measured, to better understand the weaknesses and strengths of the present system, and the degree of satisfaction of employers. For that reason, a methodology based on inquiries addressed to graduated students and their employers, is proposed, whose results shall be presented in a near future.

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