DESIGN AND IMPLEMENTATION OF AN INDUSTRIAL MATHEMATICS DEGREE COURSE

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ABSTRACT

The reform of the Italian academic organisation gave the to mathematics community the opportunity to create new degree courses where elements of informatics and computational mathematics are introduced together with the classical mathematical courses.

The aim is to give the students the necessary tools and methods to apply their mathematical knowledge to the solution of real problems arising from scientific and industrial applications; in the third paragraph we briefly describe the economic and industrial situation that characterises Bologna and its geographical area and some of the connections of mathematics with local industries and their demands. A three-year course of Informatics-Computational Mathematics started in Bologna at the beginning of the current academic year (2001-2002): all the teaching and research skills of the mathematicians of Bologna (in particular in the area of computational and applied mathematics) converge towards the local industrial demands and the needs for a new interdisciplinary research. In order to achieve a high level characterisation, it is necessary to create collaboration among the teachers in the definition of the courses programs and in their realisations, because the solution of real problems requires a unitary knowledge of different mathematical and informatics instruments. We report in particular the experience of the informatics and computational courses.

Keywords: informatics and computational mathematics, industrial mathematics, new degree courses.

1. The Italian Academic Organisation

From the beginning of the academic year 2001-2002 almost all the Italian universities adopted the new organisation disposals defined by the Italian government in compliance with the joint declarations of the European ministers for Higher Education (May 1998 and June 1999). They proposed the adoption of a system essentially based on two main cycles, undergraduate and graduate. Access to the second cycle shall require successful completion of first cycle studies, lasting a minimum of three years. The degree awarded after the first cycle shall also be relevant to the European labour market as an appropriate level of qualification. The second cycle should lead to the master and/or doctorate degree as in many European countries. (MIUR, 1999).

In order to follows these guidelines, the Italian Government enacted two decrees, one regarding the first cycle studies and the other regarding the second cycle studies where specific guidelines are given for the new organisation of the University courses. In these documents it is established, for example, that the new courses must be based on the system of credits and that one credit corresponds to 25 hours of work per student.

2. Applied mathematics at the University of Bologna

The Italian Universities have created new undergraduate three years degree courses that prepare the student to enter the job market with a high level of qualification. In the area of mathematics, many new mathematical courses started in the present academic year. These courses contain elements of financial mathematics, computational mathematics, informatics and applied mathematics. The aim of these courses is to apply the theoretical mathematical knowledge to the solution of real problems.

The research of applied and computational mathematics developed in Bologna ([2]) is nationally and internationally acknowledged. The interest and application in the study and solution of real problems characterise the Numerical Analysis group. An overview of the most recent results is collected in (D. Trigiante, 2000). We quote in particular:

- the works in the field of medicine for the reconstruction of tomographic and magnetic resonance images, in collaboration with the public health institutions of Bologna and Florence, and for the reconstruction of echocardiografic images in collaboration with a leading appliance manufacturing industry;
- the research on geometrical modelling, in collaboration with local shoes industries;
- the activities of VisLab (Visual Laboratory) in pattern recognition and involvement in European projects, in collaboration with ESA.

Many of these activities are also part of the MIUR, Italian Minister for the University and Research, research project “Inverse problems in medical imaging” 2001-2002 ([4]).

The strong point is represented by the competencies in parallel computation, acquired since the 80s, with the CINECA university consortium, one of the largest computing centres in Europe. It was a pioneer centre for parallel computation with a Cray I in 1985 and since then it has always offered parallel and distributed architectures with very high performance.

The pressure on academic researchers to help industry and launch new enterprises has changed the “ivory tower” attitude of the 80s and the most important universities established liaison offices with the industry to help the companies get a better insight in academic research.

This diffused culture and attitude towards the applications of mathematics gave rise to the following activities, promoted by the numerical mathematicians:

- the degree course of Computer Science, that started in 1987, and one of the most attractive in Italy;
- a master one-year graduate course in Industrial and Applied Mathematics where faculty members give lectures with an application flavour;
- cooperation activity between Departments focused on engineering applications;
- at the national level, a leading role in the activation of several applied projects of the Nation Research Council namely on parallel computing, information systems, mathematical applications.

In this context, a new mathematical three-year degree, named *Informatics-Computational Mathematics,* stemmed from the described experience and collaborations; it started in the Academic year 2001-2002 in Bologna. Its program contains new and interesting elements of informatics and computational mathematics. The computational mathematics studies aim to show how to efficiently use mathematical knowledge combined with the power of digital computation.

It is a relatively new discipline, expanding very fast with the extraordinary increase of information technologies and it is very attractive for society as an effective instrument to solve new scientific and industrial challenges.

The creation of pedagogically sound applications modules that show how mathematics is used to solve real world problems is an enormously challenging task. The task of introducing new materials will become simpler as an effective dialogue between mathematicians, users and problems providers is developed.

3. Fields of interest and connection with the local industrial demand

Emilia-Romagna region has 4 millions inhabitants, about 446.000 small and medium enterprises (SME) and is the 13th - over 190 regions in Europe - for gross per capita product. Bologna is its capital city.

Emilia-Romagna produces 17% of the national scientific outcome according to OCSE reviews ([5]); there are four public Universities and a private one, and a few centres of the National Research Council and of the National Energy, Environment and new Technologies organisation.

The economic development model is characterised by a dense network of subcontracts and a local sector specialisation inside the industrial districts that had been studied world-wide for its characteristics of productivity, flexibility and specialisation. The districts traditionally deal in the textile, clothing, industrial, shoe, ceramics, motorcycles, agrimechanics, packaging, bio-medical and wood machinery sectors. In the last ten years, in accordance with the information and communication technologies (ICT) growth, there have been plans and initiatives for a multimedia virtual district and general improvements of the use of ICT in the innovation of processes and products for the traditional districts. At the same time several ICT regional companies have grown considerably and have been acknowledged on an international level.

There are many connections between the research environment and the regional SMEs represented by joint ventures, consultancy, spin-offs, research and demonstrational activities often in the European research framework.

The mathematical community has not always been an active partner in these initiatives, at times due to a poor demand (e.g. the widespread use of software packages, use to solve engineering problems, restrain the user from entering the algorithmic and modelling representation of its products) or because of the academic indifference to the local demand, many times inaccurate and not paying in the research arena.

The formulation of the SMEs' needs is now more accurate, the attitude of the renewed university is more inclined to co-operation with industry, the students, often computer-literate since their teens, desire to enter the job market with stronger determination.

What the University has to guarantee is the scientific level and quality of the co-operation: application tools and methods must be at a state of the art level, both in research and tools availability.

Moreover the research community follows the objectives of:

- pursuing the dissemination of the results in the industrial and service sectors;
- promoting the technological transfer towards the local economic bodies.

According to (NESTI, 1963) we use the term Research and Development (R&D) if there are remarkable indications of novelty and the reduction of scientific and technological uncertainty.

The innovation process is based on the following phases: design, R&D, equipment and knowledge acquisition, engineering, production, deployment, marketing .

The scientific and technological activities include: education, R&D, scientific services.

In figure 1 the interconnections between the phases and activities are graphically represented; the circle intersections have the following meaning:

- on the vertical axis there is the border between prototypes and pilot products;
- on the horizontal axis there are advancements in an area (e.g. software tools) or in the knowledge provisions for an application area (e.g. improvements to a simulation numerical technique).

We have a tradition of co-operation with some SMEs and we have collected (in our opinion at a high level) industrial R&D demands that are useful to structure the courses especially regarding their final steps when industrial seminars, stages, joint research projects are possible and desirable.

We provide a list of the current requests to provide an insight of our point of view, rather than to discuss the mathematics behind the proposals.

Modelling and analysis software for fluid flow and heat transfer in the processes of atomisation, water reduction and reshaping of the particles constituting the "casting slip" (mix of different powder clays and other materials) take place before the phase of **forming ceramic articles**. Nowadays, manufacturers of fluid flow-machines design their equipment relying on the knowledge of a small number of cases practically tested. The simulation software and the use of parallel computing will make possible to carry out a large numbers of simulation runs, studying different geometric configurations, with different sets of parameters, in order to approach a design solution close to optimal behaviour in all operating conditions.

The multibody simulation is a well-established technique to help in the study of new mechanical systems; it is called "virtual prototyping" methodology. Several general-purpose programs for cinematic and dynamic analysis are available; they are not design tools but rather analysis tools. Analysis programs can perform the simulation of a system once its geometric and inertial characteristics have been designed. However, in the design problem, the desired response of the system is known and the designer wants to find out the values of the design parameters that better satisfy the design requirements. To solve this problem the designer needs to know how changes of the parameters affect the systems behaviour. The **suspension design for shock absorber** manufacturers of two-wheeler vehicle is a difficult task because of the complexity of the mechanical system, the influence of the rider, the presence of a passenger that can increase the static load of the rear suspension.

There is a strong demand of tools for simulating the **percolation phenomenon** in a variety of applications like the design of new products in the coffee industry, the experimentation of elasticity properties of batches of tyres and the monitoring of chemical contamination of soils. Cellular automata, running on parallel platforms, are a promising software technology.

There is a need by the motor automotive industry to design better transient air and fuel film compensation algorithms capable of improving the performance of **automotive exhaust emission** control system by dynamically compensating for the transient response of the engine during thermal, speed and load transients. The reduction of engine emissions, during cold starts and dynamic operations conditions, is essential to ensure compliance with future regulations.

The **rapid prototyping** techniques to reproduce objects in the mechanical and furniture industry allow a generation of manufactured articles starting from a mathematical definition based on a three dimensional geometric description; selective laser sintering, fused deposition, solid ground curing and laminated object manufacturing are the most used techniques.

The **geometrical modelling** is a fundamental sector for household appliances industries, in the design of products. It is based on mathematical knowledge and graphical representation. Moreover, a growing sector in the software development is represented by CAD techniques that are the fundamental instrument for creating new shapes.

4. Objectives and organisation of the Course

The aim of the Informatics-Computational Mathematics Course is to give to the student solid base of mathematics together with an adequate competence in developing and applying the mathematical and informatics instruments necessary to solve real problems.

The professional and scientific profile of the graduate in this course should be that of an applied mathematician with high critical ability, a good knowledge of the mathematics used for the description of models typical of technological and industrial processes and the ability of applying it using informatics tools. If the student enters the job market, his/her profile answers the demand of the local industrial reality; if the student intends to continue his/her studies to the second level degree and in a doctorate/master, she or he has good basis to go into the research. The competencies in computational mathematics are required not only for an academic research, but also in high level scientific research developed in projects involving physics, engineering, biology, medicine. Many scientific challenges of our times need computational mathematics: let us think of the large and complex computations in biological research on human genome, where huge amounts of data must be accurately processed. Trace of it is the relevance that some widespread journals, such as *Scientific Computations*, give to these researches and to the role of numerical mathematics.

The premise we start from is that what would motivate someone to learn mathematics might not be only the intrinsic beauty of mathematics itself, but something quite different arising from concern and dedication to another subject altogether.

The studies are organised in compulsory and optional courses. The student gains the credits correspondent to a course by attending classes (8 hours per credit in the classroom, 9 hours in the laboratory) and by passing the exam. 180 credits are necessary to achieve the degree.

In the definition of the computational and informatics parts of the curriculum, the directions given in the *ACM Computing Curriculum 2001* (The Joint task force, 2000) have been deeply considered. It identifies a set of knowledge areas in the field of Computing and in each area has defined the body of knowledge. Among them, the area of Programming Fundamentals (PF), Algorithms and Complexity (AL), Programming Languages (PL), Computational Science (CN) and Graphics, Visualisation, Multimedia (GR) have been regarded as essential in the curriculum of the our degree Course.

In the Italian university organisation, these areas are labelled as Informatics (PF, AL, PL) and Numerical Analysis (CN, GR).

About 80 credits of the whole 180 are assigned to the characterizing courses of Informatics, Numerical Analysis and Statistics.

The first year courses started in October 2001; their plan is reported in table 1.

The Multimedia Laboratory is the first course of informatics attended by the students. The aim of the course is to introduce the student to future courses of Informatics and Numerical Calculus, thus sewing the seed for a new mathematical culture, not only confined to abstract spaces, but also applicable to real phenomena. In this context, the terms "informatics" and "computational" should become adjectives of the term "mathematics" in the everyday student language. We plan a laboratory-based on application-oriented instruction and thus diverging from traditional computer science approaches that are often model-based and research-oriented.

In the second semester, the course of Informatics I starts a systematic approach to algorithms and programming with the C language.

The course of Numerical Calculus I introduces the student to the concepts needed in the numerical problem solution: the floating point numbers, the conditioning of a problem and the stability of an algorithm and presents some examples of simple numerical methods. The aim is to give some instruments for problem-solution and mainly to develop a critical ability to the numerical approach to a problem. Really, it is not sufficient to find a resolution algorithm, because many factors affect the efficiency and precision of the method. Some practices are planned in collaboration with the "Informatics I" course; they rely on numerical topics but they make use of the programming language and instruments dealt with in Informatics.

In the following years, in addition to a deeper insight to the informatics (software engineering, net-centric computing, information management) and classical numerical analysis topics, some optional specific courses are proposed. We mention the courses of image processing, parallel computation, computational graphics and geometric modelling.

We are giving a "doing-centred" approach to the students' problem solving skills.

We think that industry increases the communication between the people in charge of hiring applied mathematics graduates and those in charge of educating and defining the curricula. Most of the jobs taken by just completing undergraduate level involve software design and development. But students are weak in a number of areas such as general communication skills, team development experience, user-oriented development practice, analysis of the design experience. Hence we stress the importance of work and experience in the computing laboratories.

With regard to the management of labs activities, we encourage the following behaviour that, we know and experienced, can lead to a virtuous circle:

1. students' aggregation and demand are to be encouraged;
2. students' community awareness are to be developed and strengthened;
3. students' motivation in the courses is to be sought and monitored;
4. students' help and suggestions for the services of the labs are to be considered and accepted;
5. information is to be widely distributed and discussed;

6. services are to be improved on the assumption that the users are involved in the operation and management of the labs.

For the success of 1 and 2 the factors of importance are: the positive attitude by the teachers and instructors, the motivation of the students, the quality of the computer systems and an appropriate credits award.

For the creation of 3 the success factors are: effective information updating, qualified technical assistance, organisation of the students into groups and evaluation of the groups' results.

For the issue of 4, the feeling of belonging to a scientific community strengthens positive behaviours and, as by-products, hackerism and stealing are hopefully eliminated.

Points 1 and 5 concern teachers, instructors as well as technicians and porters.

Point 6 stresses the vision of the labs activity as a core line in the education process.

5. The first semester experience

So far we have only experienced the Multimedia Laboratory course in the first semester of this academic year.

At the beginning of the course, the students compiled a questionnaire on their basis informatics knowledge; the questionnaire showed that about the 30% of the students (60 altogether) had never used a computer and of the remaining 70%, more than 50% had used a computer only for writing with a word processor.

Hence the program course contained some basic knowledge of informatics (the concept of algorithm, network and internet, the Web, multimedia data, data bases, hardware components, operating systems) together with examples and simulations, taken from the Web, of real applications based on mathematics in the area of image processing, astronomy, geometrical modelling, fluidodynamics. We consider a by-product of the course the capabilities of the first modules of the European Computer Driving License [8] that students learnt in the labs and through homework.

The students never imagined that mathematics was so important for these applications and they were fascinated by this fact. In the last ten hours we introduced the concept of a programming language, its main structures and its representation with some examples. Finally, we implemented some simple algorithms, in order to show how a program runs, the possible errors so as to point out the difference between the result obtained with the same method in the real arithmetic and in finite arithmetic on the computer.

We always give lessons with the help of multimedia instruments, both in the classroom and in the laboratory and the course material was distributed through the Web.

At the exam, not all the students showed a full understanding of the informatics concepts, but they all could write some C programs, and they had understood that this is the instrument to create numerical simulations.

6. Conclusions

We are experiencing the first year of a new three-year degree course of Informatics-Computational Mathematics. Our main effort is to prepare the students to enter the job market, with a high level of knowledge, with a particular attention to the demand of the local industry and, at the same time, we want to provide the students that intend to continue their studies with a good level of knowledge. We picked out the essential features for achieving a high scientific level: the definition of a good curriculum, the collaboration between the teachers and the work of the students in computing laboratories following some experienced behaviour. The curriculum should contain, together with basics and advanced classical mathematical courses of analysis, geometry and mathematical physics, basics and advanced courses of informatics and computational mathematics. As far as the informatics and computational courses are concerned, the teachers have planned a jointed action in order to practice on computers, sharing the different knowledge for the common objective of making the students aware that mathematics is an essential instrument for studying and solving many real problems.

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Course (semester)	Credits	Hours of lesson
Algebra I (I)	7	56
Geometry (I)	7	56
Analysis (I)	7	56
Mathematical Physics (I)	7	56
Multimedia Laboratory (Informatics) (I)	4	36
Geometry II (II)	6	48
Analysis II (II)	6	48
Informatics I(II)	6	48
Numerical Calculus (II)	6	48

Table 1 : the first year courses of the Informatics-Computational Mathematics degree plan.

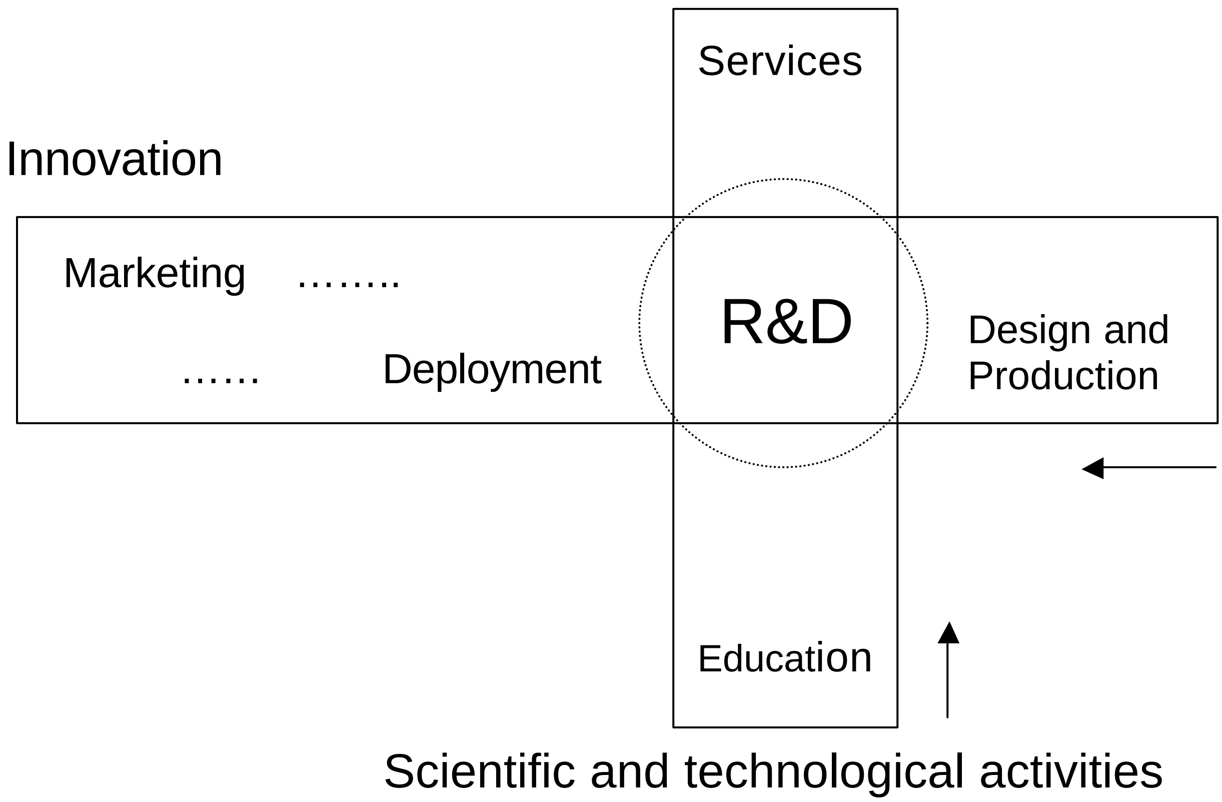

Figure1: Innovation and Scientific and technological activities.