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From University to Society

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IST Experience in R&D in Portugal and Worldwide

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1. Summary

The objective of this paper is to present the R&D experience of Instituto Superior Técnico (IST) in recent years. Nevertheless, the R&D experience of an Engineering School cannot be dissociated of its educational context and of the country's science & technology system.

This paper starts by presenting the evolution of Portuguese higher education system and giving an overview of IST's position amongst the Portuguese engineering school. Some facts and figures about Instituto Superior Técnico are also be presented.

The situation of R&D in Portugal is then described and the importance of universities in the Portuguese Science & Technology System is analysed.

Afterwards, the experience of Técnico in terms of Research and Development is presented with a analysis of the bibliometric results at IST and a characterisation of the R&D projects developed in recent years, focusing on the connections that IST has developed with the society in order to maximise the impact of the research that is being undertaken.

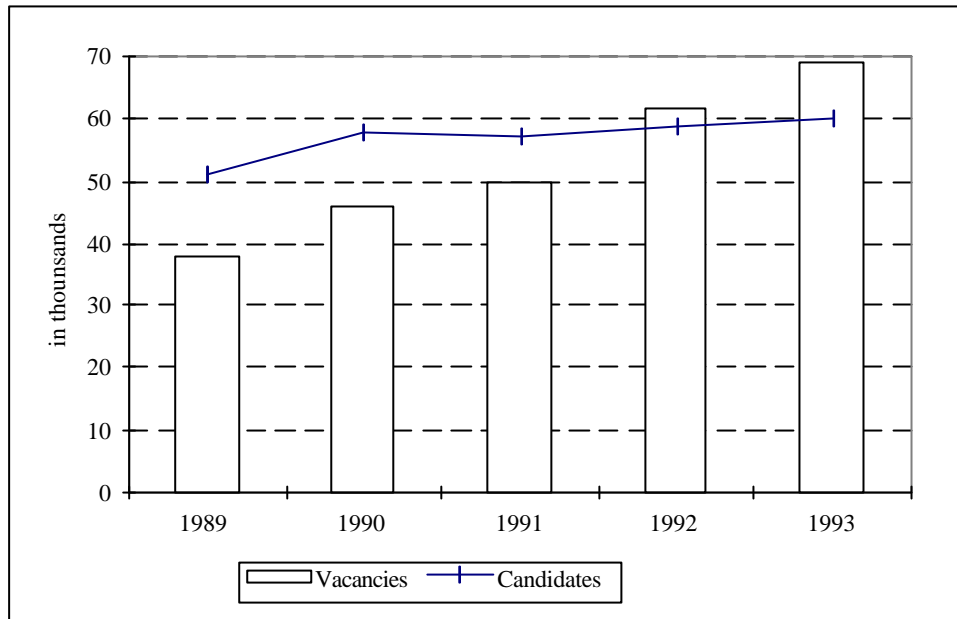
Finally, the importance of fundamental research in Universities is emphasised, with a reference to the importance for Portuguese universities of promoting the cooperation with industry, thus achieving a major contribution to the development of the society.

2. IST's Positioning in the Portuguese Higher Education System

2.1. Higher Education in Portugal

Until the seventies, higher education in Portugal was centred in 4 universities, all of them public. From that time on, higher education was expanded and diversified with the creation of new universities, the development of vocational higher education, the increasing internationalisation (in terms of teaching and R&D) and the development of the private sector (mainly in the social sciences). The number of vacancies grew at an average rate of 19% between 1986 and 1993 (30% in the private sector) which allowed Portugal to close the gap between candidates and vacancies.

Figure 1: Evolution of the Supply and Demand of Higher Education



Source: Portuguese Ministry of Education

Since 1992, the total number of vacancies (including private universities) has been a little higher than the number of candidates, reflecting an excess supply of higher education in absolute terms. In 1995, due to a large increase in the candidates, the situation was balanced. In spite of this situation, in 1993 only 53.3% of the candidates were placed in the course of his/her first choice. This implies that there is no adequate adaptation of supply of higher education to the demand of the candidates. Overall, there is an excess of courses in the area of Law and Social Sciences (due to the large growth of the Private Universities) and a lack of supply in Engineering and Natural Sciences. This represents a structural deficiency of the system.

In terms of expenditure, the higher education system represented 1.4% of the Gross Domestic Product (GDP) in 1993. Its financing comes mainly from the state budget for the public universities and from tuition fees paid by students for the private universities. In recent years, public universities started to collect tuition fees from the students. Nevertheless, this fees represent no more than 10 to 15% of the real cost of each student to the Universities.

Presently, Universities are being encouraged to generate their own resources from services to the Community, particularly from R&D services, but this funds still represent a very small amount compared to the expenditures of the institutions.

2.2. The Engineering Education System

The EES in Portugal represents around 25% of the higher public education system, in terms of vacancies and number of students enrolled. The great majority of the Engineering institutions are of a public nature, funded by the government. Less than 15% of the vacancies are offered by private institutions, representing 5% of the students enrolled.

Table 1: The Weight of the Public EES in the Public Higher Education in 93/94

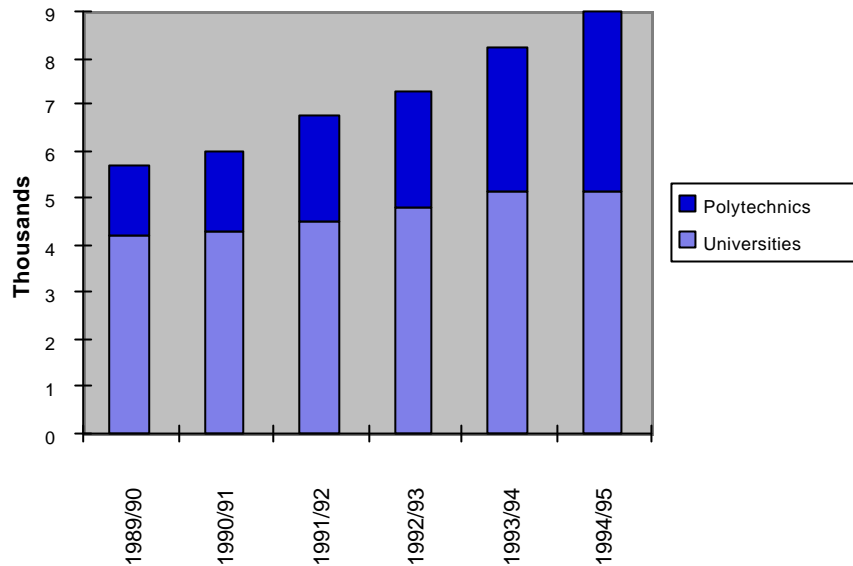
		Higher Education (I)	Engineering Higher Education (II)	II/I x 100
University (5 years)	Number of Courses	371	98	26,4%
	Number of Vacancies	18 261	4 975	27,2%
	Number of Students	99 745 (92/93)	31 122	26,1% (92/93)
Polytechnic (3 years)	Number of Courses	276	54	19,6%
	Number of Vacancies	11 505	3 155	27,2%
	Number of Students	38 040	approx. 12 000	31,6%

Source: Portuguese Ministry of Education

In the scholar year of 1993/1994, the Public and Private Universities offered 52 different specialisations in Engineering Courses, in a total of 119 Courses, for 32000 students in 26 different higher education institutions.

The number of vacancies in the Engineering areas have increased sharply in the nineties (especially in terms of the *bacharelato* degree) representing 12% of the whole higher education system. This resulted from the recognition that there is a serious lack of supply of engineering professionals with more focused technical skills of immediate application (which corresponds to the polytechnic education). It is expected that the number of vacancies in Engineering will continue to grow in the next five years, although at a much lower rate than in the previous years.

Figure 2: Vacancies in the Engineering Area



Source: Ministry of Education

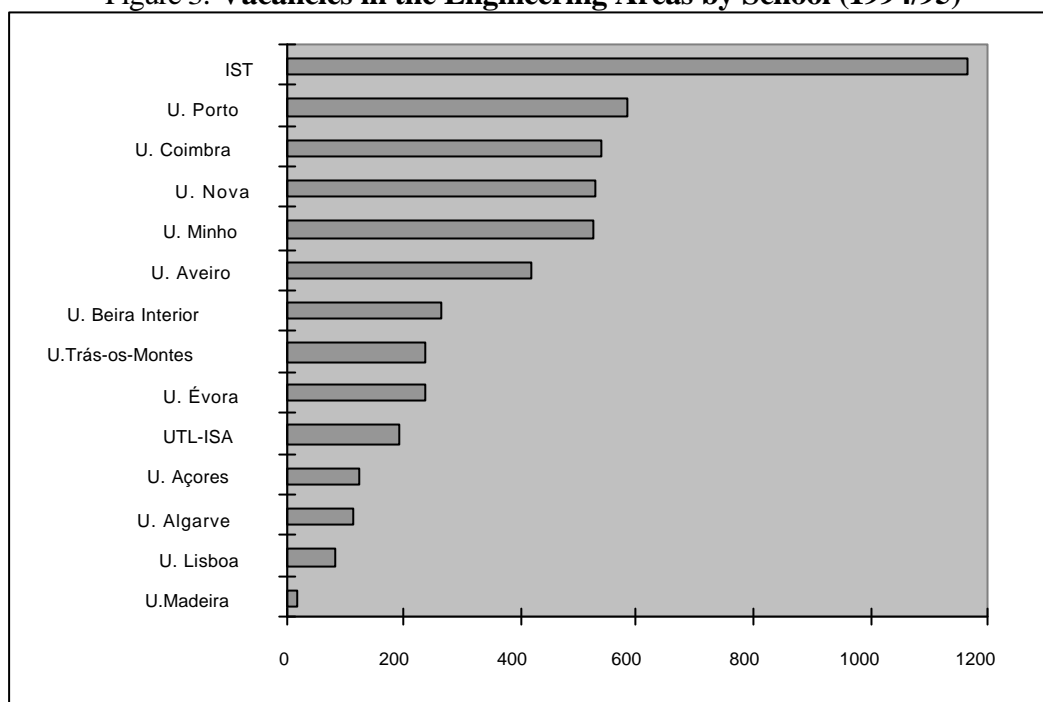
For the Engineering Universities, the next decade will be more oriented to consolidation and quality than to quantitative growth.

2.3. Instituto Superior Técnico

The IST's mission is, on the one hand, to provide excellence and quality in Graduate and Post-Graduate education in the areas of engineering, science and technology and, on the other hand, to undertake the Research and Development activities which are essential for offering education at the highest European standards of quality and for contributing for the development of the society.

Instituto Superior Técnico (IST) is the oldest and most important Engineering School in Portugal. Created in 1991 and located in the centre of Lisbon, IST offers 14 different Engineering Courses, 16 Master Courses and 19 Doctoral Programmes. In 1994, IST represented 23.1% of the total vacancies for university degrees in the Engineering area. In 1993 and 1994, 80% of the new students at IST were placed in the course of their first choice.

Figure 3: Vacancies in the Engineering Areas by School (1994/95)



Source: IST Annual Report - 1994

The position of IST can also be compared with some European Universities in terms of the number of students enrolled:

**Table 2: Students Enrolment:
A Comparative Analysis between IST and Other European Schools**

	Total Enrolment		Undergraduate Enrolment		Post-graduate Enrolment	
	Number	% C&T	Number	% total	Number	% total
IST, Lisbon	8.717	100	7.635	87,4	1.082	12,4
Oxford, UK	14.271	40	10.407	73,0	3.864	27,0
Cambridge, UK	13.935	48	10.217	73,4	3.718	26,6
I. College, UK	7.049	95	4.740	67,3	2.309	32,7
UCL, UK	9.647	55	7.375	76,5	2.272	23,5
Warwick, UK	8.424	30	6.746	80,1	1.678	19,9
NTH, Norway	7.509	100	6.737	89,8	772	10,2
KTH, Sweden	8.800	100	7.500	85,3	1.300	14,7
Chalmers TH, Sweden	7.048	100	6.106	86,7	942	13,3
INPG, France	1.215	100	733	60,4	482	39,6

Source: Estudos de Universidades, Gabinete de Estudos e Planeamento, IST.(1994)

Note: %C&T - refers to science and technology students proportion

Some of the most important figures concerning IST are now presented:

IST MAIN INDICATORS

1. Educational Activities

1.1. Undergraduate

Numerus Clausus	95/96	1.210
Total Enrolment	94/95	7.635
Students admitted in their first option	94/95	80 %
Undergraduate degrees completed (Licenciatura)	1994	756

1.2. Post-Graduate

Master Students	94/95	897
Master Degrees completed	1994	133
Doctorates Started in 1994		144
Doctorates Completed in 1994		44

1.3. Ratios

Ratio Students (Licenciatura) / Teachers (FTE)	Dec/94	9,06
Ratio Students (Licenciatura) / Professors (FTE)	Dec/94	15,98

2. R&D Activities

2.1. Publications

Books published and edited	14
Papers in Scientific Journals and Books	385
Conference Papers	602
Ratio (Total of Publications) / Prof. FTE (Dec/94)	2,09

2.2. Ongoing Projects

Supported by JNICT	85
EC Projects	139
Supported by Portuguese Companies	35

3. Human Resources

Teachers (FTE)	Dec/94	842,6
Non-Teaching Staff	Dec/94	531
Ratio Prof./Teachers (FTE)	Dec/94	56,7%

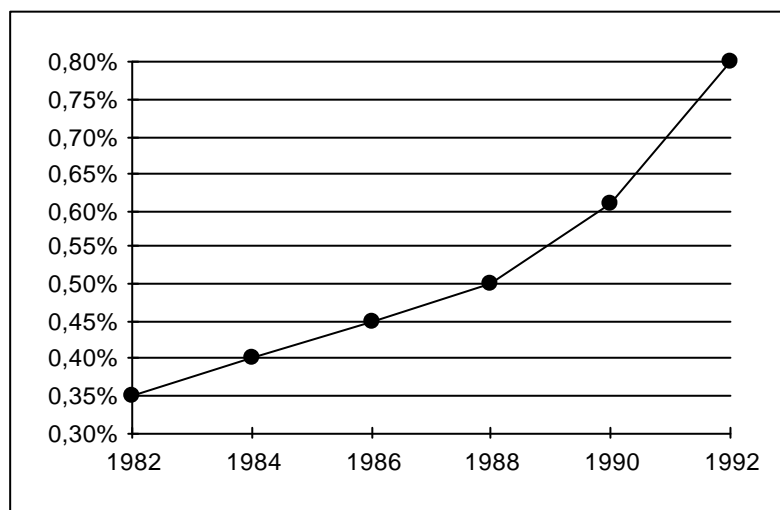
4. Financial Resources (10⁹ PTE)

Staff Expenses	5,433
Operating Expenses	2,885
Subventions to operation and Services Rendered	8,575

3 - Characterisation of the Portuguese Science & Technology System

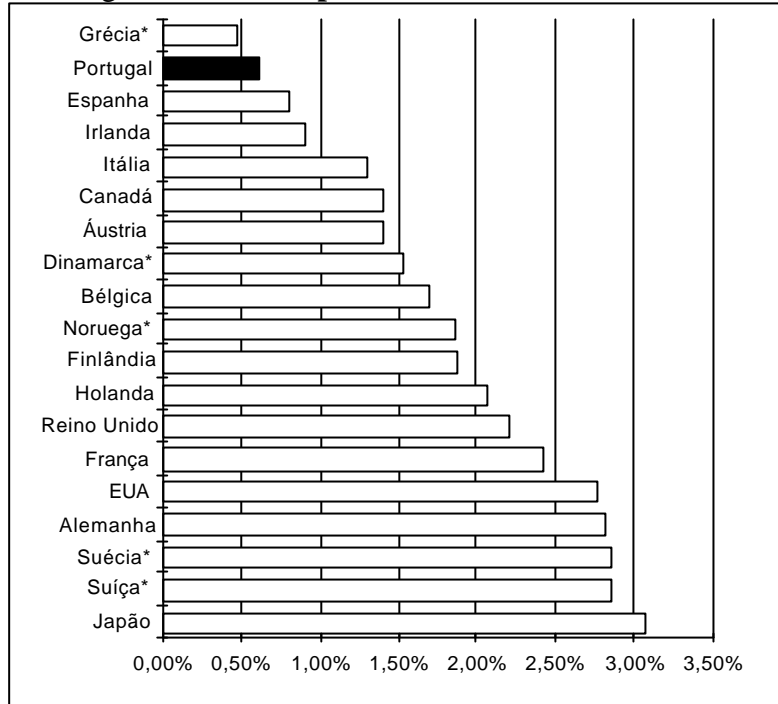
The S&T System in Portugal was historically very weak and only in the eighties it started a period of strategic orientation and development. The membership of the European Community in 1986, and the funds that were received for R&D, allowed the growth and strengthening of the system.

Figure 4: Total Expenditure in R&D as % of GDP - 1982 to 1992



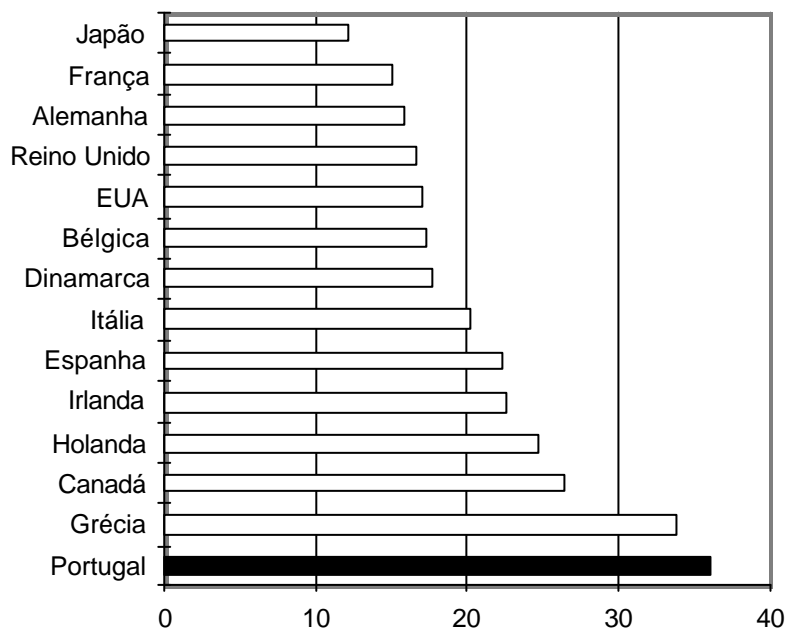
Even after the growth in the eighties, the total amount of R&D expenses in terms of the GDP, when compared to other countries, indicates that Portugal needs to increase its investments in R&D.

Figure 5: R&D Expenses as a % of GDP in 1990



In terms of the execution of R&D activities, the Portuguese Universities have an extremely important role, being responsible for almost 37% of the total R&D in 1990.

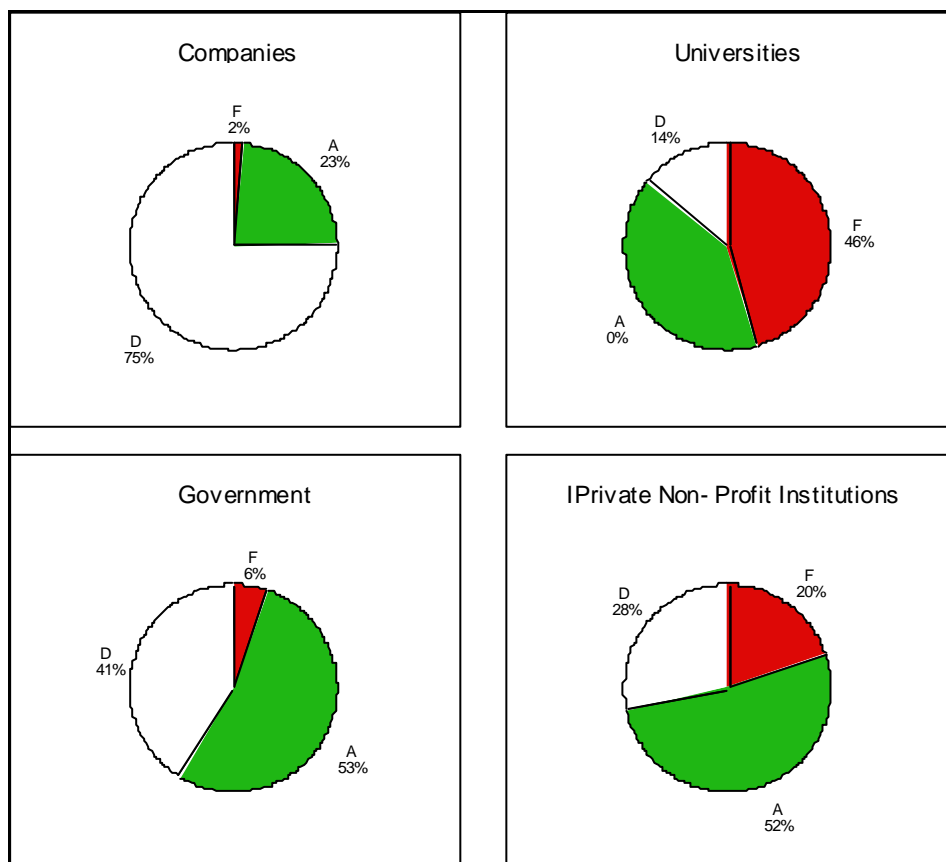
Figure 6: University R&D as a % of Total R&D Expenditure in 1990/1991



Source: OCDE (1994)

The proportion of University R&D in the total R&D for Portugal is one of the largest in international terms and still continues to grow (while in other countries there is tendency to reduce the weight of university R&D). In 1992, Universities were responsible for 43% of the total R&D in Portugal. This figure becomes more impressive if we take into account that Universities are the main responsible for Fundamental Research (companies and the government are more focused on technological development and applied research, respectively).

Figure 7: Total Portuguese R&D Expenditure by Type of Research in 1990



F = Fundamental Research; A = Applied Research; D = Technological Development

Source: JNICT (1993)

In terms of the division of the R&D Expenditure by scientific areas, the importance of the Engineering and Technology area is increasing, representing in 1992 more than one third of all the Portuguese R&D.

Table 3 : **R&D Expenditure by Scientific Area in 1990 - 1992**

<i>Scientific Area</i>	<i>1992</i>	<i>(%)</i>	<i>1990</i>	<i>(%)</i>
Exact Sciences	10415.2	16.6	5873.3	15.3
Natural Sciences	6970.4	11.1	4965.3	12.9
Engineering and Technology	21707.6	34.5	12248.2	31.9
Health Sciences	6871.3	10.9	3504.8	9.1
Agriculture, Forestry and Fishing	8272.9	13.1	5748.9	14.9
Human and Social Sciences	8708.2	13.8	6106.0	15.9
Total	62945.6	100.0	38446.6	100.0

Source: JNICT (1995)

The major characteristics of the Portuguese Science & Technology System are thus:

- **Relatively low level of R&D Expenditure**
- **Major Role of the Universities in the Execution of R&D**
- **Weak Role of the Companies (both in financing and execution)**
- **Heavy Dependence on Public Financing (Government and European Funds)**
- **Almost 90% of the Fundamental Research is carried out by universities**

4 - Research and Development at Instituto Superior Técnico

4.1. Bibliometrics

Research & Development activities are essential for university education. As we have already seen, in the Portuguese scientific and technological context, higher education institutions are responsible for more than

40% of the total spending on R&D activities (as compared to the 16% European average) and almost all of the spending in fundamental research. Consequently, besides acting as highly qualified trainers of human resources, universities assume an essential role in R&D activities carried out in Portugal. IST has carried out, throughout its history, an extensive R&D activity, both in Portugal and in international terms. This has contributed to the creation of an immense scientific potential in the teaching body. One of the ways to measure such a potential is through bibliometrics information (number of publications).

Table 4: Number of Publications Resulting from R&D in IST: 1993 and 1994

<i>Type of Publication</i>	<i>1993</i>	<i>1994</i>
Books (Authors)	6	4
Books (Editors)	17	10
Papers in International Journals	296	288
Papers in National Journals	56	62
Papers as Chapters of Books	42	43
Conference Papers	440	606

Source: IST Annual Reports

This publications are divided between the several Departments and Autonomous Sections that compose Instituto Superior Técnico. The bibliometrics performance of each Department can then be analysed:

Table 5: Number of Publications by Department in 1994

<i>Departments</i>	<i>Nº of Professors (Full-Time Equiv.)</i>	<i>Books (Auth.)</i>	<i>Books (Edit.)</i>	<i>Intern. Papers</i>	<i>Nation. Papers</i>	<i>Chapters</i>	<i>Confe- rences</i>
Civil Engineering	62.	1	1	21	16	11	120
Electrotecnic & Computer Sc.	103	1	1	32	10	4	190
Mechanical Engineering	70	1	2	32	5	10	95
Materials Engineering	12	0	0	13	0	0	9
Mining Engineering	14	0	1	13	0	0	9
Marine Engineering (AS)	2	0	1	0	1	5	7
Chemical Engineering	93	1	2	125	10	8	95
Economics & Manag. (AS)	6	0	0	0	0	0	3
Physics	59	0	0	35	10	0	36
Mathematics	40	0	2	27	1	3	19

Totals	461	4	10	288	62	43	606
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Source: IST Annual Report - 1994

The analysis of the Science Citation Index (SCI - composed of selected international journals) indicates that the Portuguese publications increased at a average of 12% a year between 1982 and 1992. In the same period, IST publications increased at an average of 19%, and IST represented more than half of all the Portuguese publications in the area of Science and Technology in 1992.

4.2. R&D Projects

The scientific potential of a university can also be measured by the number of projects that the institution is involved in. There are usually three different forms of financing for the R&D projects in Portugal: Community funding for European Projects, Government funding (managed by JNICT) and projects funded by Industry. The European projects are particularly important because they promote the internationalisation of the R&D activities. In this field IST has a remarkable track record, being the Portuguese institution with more participations since the first framework programme. In the second framework programme, IST accounted for 13% of all the Portuguese participations, involving 52 European projects.

In 1994, projects under the scope of Community programmes represented a funding of 1 026 million PTE of which 22% in the area of Biotechnology and Chemistry. The areas of Environment (12%), Production (11%), Information Technology (10%), Telecommunications (9%) and Energy (9%) were also very significant.

Particular mention should also be made of the projects carried out under the Partnership Contract agreed between the IST and the European Atomic Energy Community (EURATOM) in which the IST has participated via the Centre for Nuclear Fusion. Around 30 graduates, 6 Masters and 13 PhDs participate in this project, working in the following activities: ISTTOK tokamak; the study of transport properties in the ASDEX-Upgrade tokamak using micro-wave reflectometry; participation in JET (Joint European Torus); studies of non-inductive current generation; X-ray spectroscopy in the TCV tokamak; participation in ITER (International Thermo-Nuclear Experimental Reactor); and participation in the MAST and W7-X projects.

It should also be noted that 1994 was marked by the transition from the Third to the Fourth R&D Community Programme (1994-1998). As a consequence, a series of projects were concluded in 1994, and much effort was put into preparations for the Fourth European Framework Programme for Technological Research and Development, mainly in the preparation of proposals for applied research and technological development.

In terms of projects funded by JNICT, these represented an additional revenue of 254 million PTE of which 25% were dedicated to the field of Biotechnology & Chemistry and 18% to the field of Materials.

The low number of projects with the Portuguese industry is explained, on one hand, by the lack of R&D in almost all the Portuguese companies, with the exception of some of the very large ones, and on the other hand, by the focus of IST on fundamental research activities.

Table 6 - Total R&D Projects being undertaken at IST in 1994

<i>Scientific Area</i>	<i>European Proj.</i>	<i>JNICT</i>	<i>Industry</i>	<i>Total</i>
Energy	19	3	-	22
Environment	16	9	3	28
Information Technologies	12	6	6	24
Materials Engineering	18	11	1	30
Marine Engineering	11	2	-	13
Biotechnology Engineering	21	23	1	45
Production	11	-	11	22
Microelectronics	4	1	-	5
Telecommunications	8	4	2	14
Civil Engineering	3	7	3	13
Aeronautics	5	-	3	8
Physics	10	8	5	23
Applied Mathematics	1	5	-	6
Total	139	79	35	253

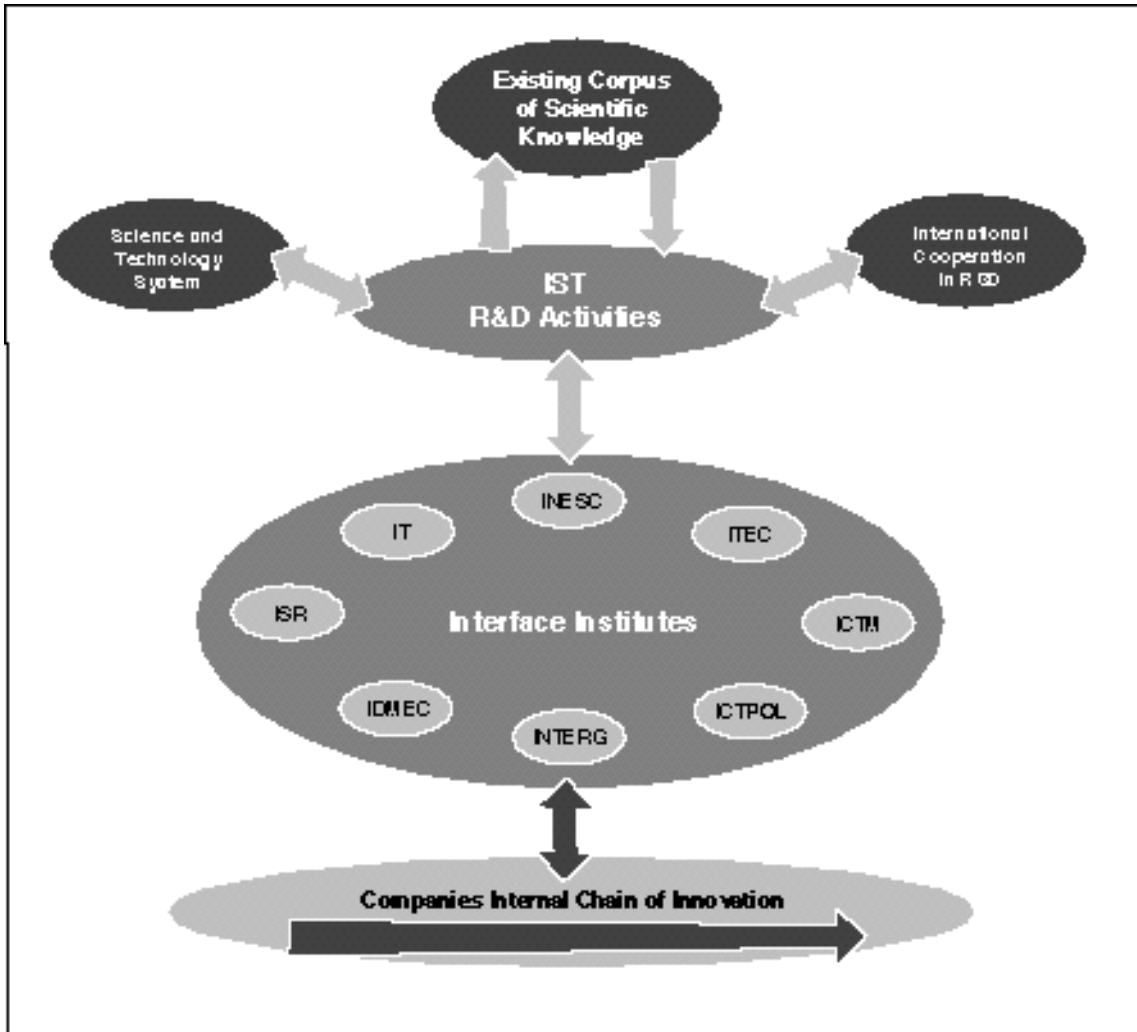
Source: IST Annual Report - 1994

4.3. Link to Society

In spite of focusing its R&D in the area of Fundamental Research, IST has not neglected the connection to society and to the innovation process of enterprises. The consolidation of closer links between the IST and society has come about through collaboration with autonomous R&D and technology transfer organisations. The development and collaboration with these interface institutions, which are more able to establish the connection to industry and perform applied research and technological development, allows IST to strengthen and valorise economically the R&D undertaken and thus contribute to the development of the society

The latest economic theories emphasise innovation as the best means by which to carry out the transfer and endogenisation of technology. The Chain-Linked Model of Innovation (proposed by Kline&Rosenberg in 1986) constitutes the most advanced methodological instrument to explain technological innovation and was the inspiration behind the conceptual framework presented in Figure 8, which shows the position of the IST in relation to interface organisations and their link to the central chain of innovation in companies.

Figure 8: Framework of R&D Activities in IST



In this framework, the R&D Activities of IST are performed by Research Groups and Centres, establishing links with the International R&D activities (through Community projects and specific cooperation) and with the national science & technology system (through Portuguese funded projects). The connection with the industrial sector and with companies is developed and consolidated through autonomous interface institutions, which are described hereafter.

INESC (National Institute for Systems and Computer Engineering)

The activities carried out by IST teachers at INESC fall within four main strategic areas: Telecommunications and New Services, Computers and Computer Science, Electronic Systems and Technology, and Integrated Industrial Systems for Management and Production.

The organisational structure of INESC included, in 1994, 58 Research Groups, of which 26 were headed by IST teachers. Of a total of around 296 university researchers collaborating with INESC in 1994, 114 had contractual links with the IST, while, of the 16 Technology Transfer Centres at INESC, 6 were run by IST teachers. The number of research and development projects in progress rose to 316, of which

141 were within groups and centres headed by IST teachers. In the same year, 176 Master's and Doctoral theses were in progress at INESC, of which 122 were being supervised by IST teachers.

ITEC (Technological Institute for the European Community)

ITEC is designed to act as an interface institution between the academic and business worlds in three specific areas: Knowledge Transfer, Technology Transfer, and Business Valorisation. These aspects are dealt with by, respectively, the Technological Training Centre (Cenfortec), the Institute for New Technologies (INT), and the Centre for the Promotion of Innovation and Business (CPIN).

In the case of INT, 1994 was characterised by the construction of its new premises on the INETI campus at Lumiar, where planning has begun for activities in the following technological areas: Automation and Robotics, Energy, Environment, New Production Technologies, Materials and related Laser Processing, and Industrial Management.

In the area of business valorisation, the process of making CPIN into an autonomous entity, an EC-BIC (European Community - Business Innovation Centre) was completed in 1995. During 1994, CPIN continued its initiatives for the incubation of technology-based companies three companies having completed the relevant incubation period.

With regard to initiatives promoted by ITEC and organised at the IST in 1994, there were 38 training courses in different fields under the Young Researchers for Industry programme. In addition, there were 10 training courses under Measure E of PEDIP, with emphasis on the training of technical managers and directors of companies.

Mention should also be made of the Technological Enhancement Programme for Senior Staff, under which two courses were organised, namely "Advanced Technology in Glass Production" and "Technology Transfer and Management", the latter in collaboration with the University of Texas in Austin. As a result of this course, the signing of a co-operation agreement is expected between the IC2 Institute of the University of Texas, the IST and ITEC.

ICTM (Materials Science and Technology Institute) and ICTPOL (Polymer Science and Technology Institute)

The main aim these institutes is to carry out specific and specialised actions in the field of Materials and Polymers, respectively

IDMEC (Mechanical Engineering Institute)

The aim of IDMEC is to carry out specific and specialised actions in the field of Mechanical Science and Technology, particularly through the promotion of R&D activities, the development of advanced training plans, the promotion of technology transfer, the evaluation of new processes in companies, and the development of integrated management programmes in the fields of energy, logistics and technology.

This institute has two sites, one at the IST and another in the Engineering Faculty of the University of Oporto. The IST site is organised into four Research Centres, which are supported by a total of nine laboratories, related to the scientific fields covered in the activities of the IST site. In 1994, the number of projects in progress reached 64, of which 28 were international. With regard to publications, the activities of the IST site can be seen in 70 papers in journals and 132 articles and chapters published in books and treatises and presented at conferences.

INTERG (Institute for Energy)

The main aim of INTERG is to carry out specific and specialised actions in the field of Energy.

In 1994, there were 40 researchers at INTERG, of which 20 were Doctorates, 18 being IST teachers. In 1994, 12 projects were developed in this institute. The projects are carried out through close collaboration with Portuguese and foreign research centres, in parallel with contacts with companies. A further task of INTERG is the creation of synergy between the various engineering fields which contribute to this sector.

IT (Telecommunications Institute)

The main aim of IT is the promotion of research and development in the field of telecommunications, and it has sites in Lisbon (at the IST), Coimbra and Aveiro.

In 1994, out of a total of 55 researchers at IT's Lisbon site, 49 were IST teachers. Apart from these, IT has around 50 collaborators, a significant proportion of whom are Master's and doctoral students from the IST. there are also dozens of undergraduates who work at IT as part of their final course work.

ISR (Systems and Robotics Institute)

ISR operates in the fields of Robotics, Automation and allied areas, and has sites in Lisbon (IST), Coimbra and Oporto. During 1994, R&D activities were carried out at ISR (Lisbon site) by 82 researchers, of whom 22 were doctorates, 35 were working on Master's or doctoral theses, and 25 were engaged on their final undergraduate work. During this period, special mention should be made of activities carried out in the fields of Autonomous Mobile Robotics (Terrestrial and Submarine), Computer Vision, Artificial Intelligence, and Dynamic Systems, mainly in the following projects: PO-Robot, MARIUS, SOUV, Medusa and MAESTRO led by the IST Site and funded by the NATO SfS programme, by the European Community (MAST Programme) and by Lisbon Municipal Council; as well as the BENTHIC LAB project (MAST programme) led by IFREMER (France).

R&D results for 1994 have been reported through the publication of 3 doctoral theses, 4 Master's theses, 5 articles in books, 16 papers in international journals, 48 international conference papers, 2 papers in Portuguese journals, and 15 papers at Portuguese conferences.

4.4. IST's Participation in Technological Parks

The participation of IST in the technological infrastructures known as technological parks is an important element for the consolidation of IST link to industry. In this context, IST has participated, from the outset, in the TAGUSPARK - Company for the Promotion and Development of the Science and Technology Park for the Lisbon Area - in which IST has an area of 15 acres. In 1994 the discussion process was set in motion at the IST regarding the programme for the IST's installations at the TagusPark, with a proposal to PRODEP being prepared to finance the infrastructures. The architectural project is now being put out to public competition.

Within this framework, IST has participation in two other technology parks, namely LISPÓLIS (Association for the Lisbon Technological Centre), and PTM/A (Mutela/Almada Technological Park), being involved in activities promoted by these parks.

5- The Importance of Fundamental Research in Universities

The R&D activities in the area of science and technology carried out by the universities are suffering a growing pressure from society. Due to their focus on fundamental research, aiming at the creation of knowledge and the improvement of the quality in teaching, the direct role of university's R&D in economic growth has not been impressive. This lack of commercial results is leading public authorities to privilege the funding of applied research activities in universities. This situation is notorious in the fourth framework programme of the European Community, whose main objective is the reinforcement of the technology base of European industry in order to improve its international competitive position.

The main role of universities R&D should be the development of fundamental research activities. This conclusion is supported by the fact that universities have the competence and the means required and a sufficient distance to the market to allow the necessary autonomy and freedom of research. The continuous effort of Universities in fundamental research creates a basis of accumulated knowledge and technological potential which is very important for a subsequent phase of applied research.

Given the specificity of the Portuguese science and technology system, described in this paper (namely the preeminent role of the universities and the weak participation of industry in R&D), the universities should guarantee the connection of their R&D activities with the industrial needs of the country and of Europe.

The Portuguese universities have thus a difficult task at hands since they should be able to develop the interface with industry without losing the necessary focus on fundamental research. That is the commitment and challenge of Instituto Superior Técnico.