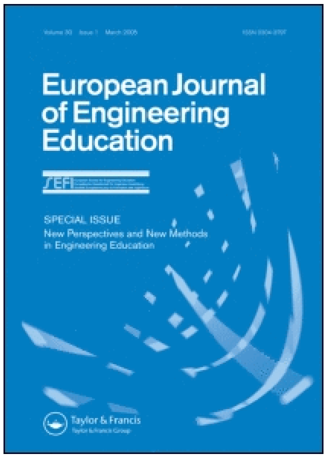


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# The future for industrial engineers: education and research opportunities

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# The future for industrial engineers: education and research opportunities

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EU graduation and the recruitment of industrial engineers (IEs) have been investigated. An increasing demand is observed for graduates in almost all industrial engineering (IE) subjects. The labour market in the EU is evolving towards the service sector even if manufacturing still represents a significant share of both IE employment and gross domestic product. On average, IE in the EU is still within the framework of the 'market-driven' paradigm, which contrasts with the knowledge society aims pursued by the 'Bologna process'. R&D resources and human capital are identified as major success factors to overcome current limits for IE development in the EU. With reference to both factors, a comparison between the EU, Japan and the US is provided. In the EU, the attractiveness of universities and the social dimension are recognized as major forces attracting human capital. Patent maps outline current and future IE research and education fields of interests. Finally, EU higher education opportunities are briefly described.

*Keywords*: European Higher Education and Research; State of the art; Future trends

## 1. Graduation and recruitment of IEs in the EU

The wide spectrum of industrial engineering (IE) subjects led us to limit discussion to graduation and recruitment of engineers for industry in the European Union (EU) to engineering courses that are consistent with the definition of industrial engineers provided by 'The Institute of Industrial Engineering' (Kelling *et al.* 1996):

> 'Industrial Engineers design, improve, and install integrated systems of people, materials, information, equipments, and energy'.

Particular attention is paid to the Italian situation. In Italy (figure 1, source: MIUR, 2006), graduations significantly increase (first and second cycle) in the 2003–2005 period and are mainly concentrated (about 80 % in 2005) in a few courses including information technology (IT), mechanical, management, telecommunication, and electronic engineering.

In Spain (INE 2005), a slight general increase (about 3%) in the total number of graduations in IE courses of the 1$^{st}$ and 2$^{nd}$ cycle was observed over the 2001–2003 period; the

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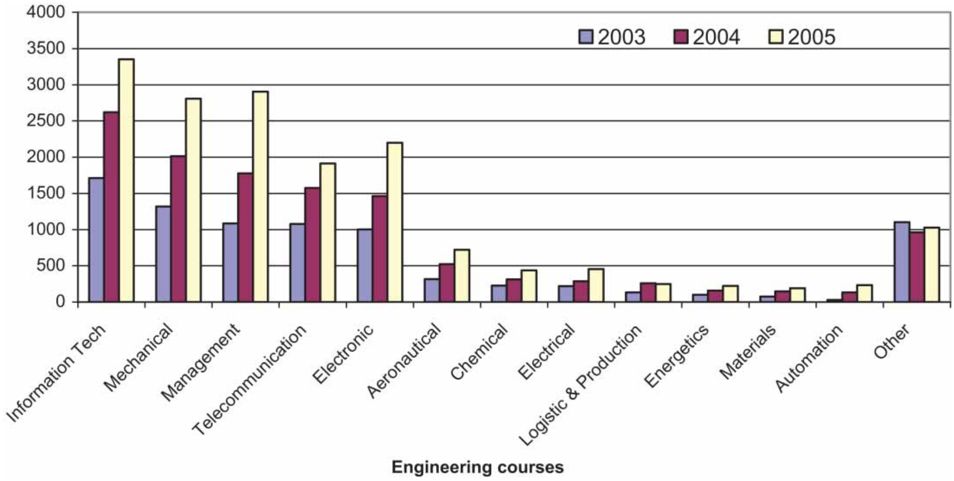


Figure 1. IE graduations in Italy in 2003–2005 (Source: MIUR, 2006).

sample considered includes industrial (i.e. mechanical, electronic, electrical, textile, chemical), IT, telecommunications and aeronautical engineering; the highest increase (32%) occurred in telecommunications engineering graduations. In the UK (HESA 2005) mechanical, electrical/electronic engineering students prevail both in the first and in the second cycle with a positive trend in electrical and electronic engineering post-graduate qualifications during the four academic years 2000/01–2003/04 (figure 2). In Germany, after a negative trend in graduations in mechanical and electrical engineering during almost all the 1990s an opposite trend has been observed since the end of that decade.

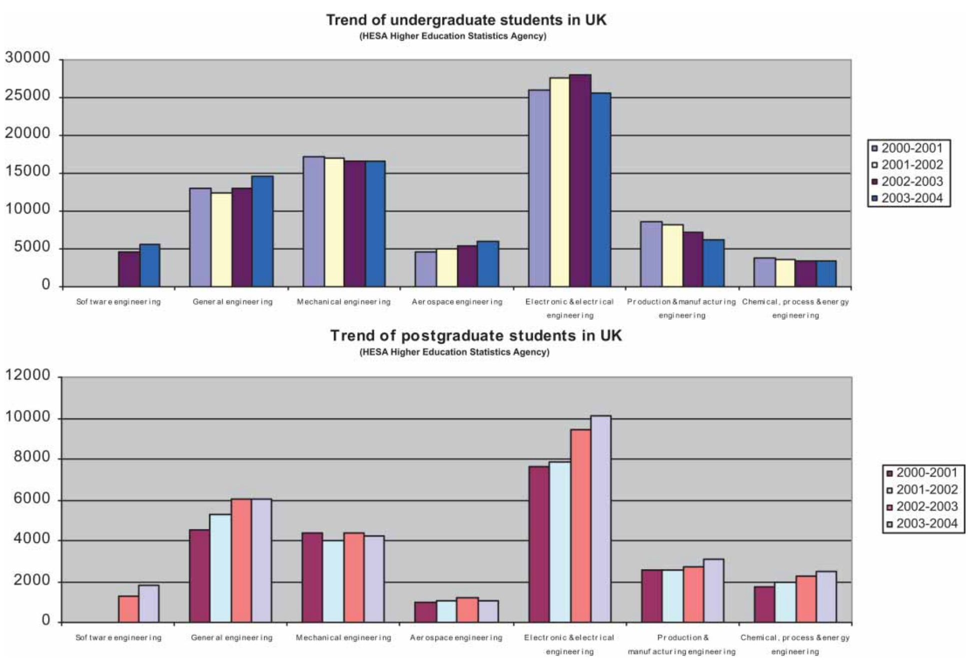


Figure 2. UK undergraduate and post-graduate students in 2000–2004 (Source: HESA, Higher Education Statistics Agency, 2005).

On average, EU demand for IE education tends to consolidate some engineering courses such as electronic and mechanical engineering. However, increasing attention is being paid to new IE courses (e.g. bio-tech and materials engineering), which are expected to show an increase in interest in the very near future.

As far as recruitment of industrial engineers is concerned, in Italy an increase was observed in the 2003–2005 period for almost all IE graduates (L'ingegnere Italiano 2005, Centro Studi C.N.I. 2005). Major positive increase in the 2003–2005 period is in the recruitment in IE area including Mechanical, chemical, electrical, nuclear, aeronautical and biomedical engineering (+431 %). Despite the crisis of the information and communication technology (ICT) sector and of a reduction in demand for IT engineers, the overall recruitment of the electronic and IT engineers increases (+26.1%) in the 2003–2005 period.

Most of the recruitment of IEs in Italy is in the service (industrial and public) and manufacturing sectors, with the former sector having the highest impact on recruitment (from 49.4% in 2003 to 54.0% in 2005).

In the EU, despite a general positive trend in recruitment in the tertiary sector, manufacturing (Manufuture WG 2003) still plays an important role both in economic terms (about 22% of gross domestic product (GDP)) and in terms of the work force required (18% of employment).

However, manufacturing is increasingly challenged by global competition and, mainly, by Asian manufacturers. It is worth noting that in the 1990s, the greatest increase in direct foreign investment was in low wage (less regulated) economies and higher increases in market share were basically observed in low technology intensive production.

In the EU, examples of excellence in research and education, mainly in northern countries (e.g. Finland, Sweden and the Netherlands), are recognized as a world reference (Florida 2005). However, on average, the EU Research and Education (R&E) system (i.e. the system of universities as well as public and private research centres) tends to follow a development policy basically driven by market needs. According to a 'market-driven' paradigm (figure 3), R&E and industry systems tend to behave as 'followers' of market needs which are characterized by high uncertainty and dynamic behaviour; production is constrained by low time-to-market and high labour costs, as well as safety, quality, and environmental constraints.

R&E system tends to follow industry needs which, in turn, are more oriented to low-risk and mature technologies since most industrial production in the EU is carried out by SMEs which are less inclined to pursue innovation and have less resources to do so. The major consequences are 'low intensity' knowledge demand by industry and an education system mainly engaged in mass education.

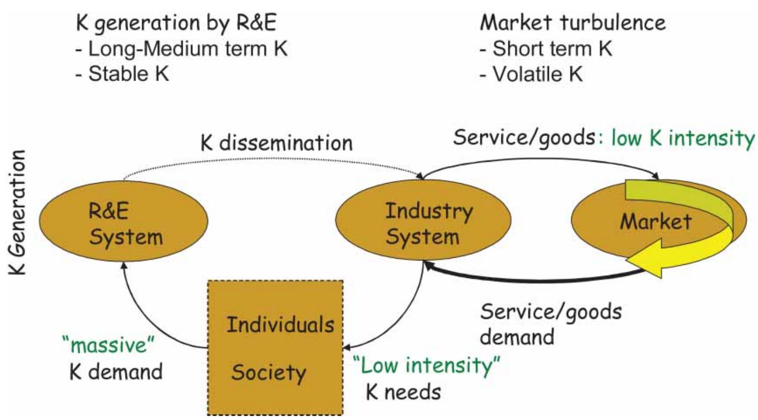


Figure 3. The 'Market-driven' paradigm.

## 2. The European higher education and research areas

In order to tackle the abovementioned limits of a 'market-driven' paradigm, European countries identify the 'knowledge society' as the most effective road for sustainable development. An in-depth transformation of the higher education system in Europe has been planned since the end of the 1990s. This transformation is aimed at harmonizing the architecture of the education system by pursuing a common degree-level system based on two cycles (undergraduate/graduate).

The Sorbonne (1998) and Bologna (1999) declarations, Prague Communiqué (2001), Lisbon Council (2002), Berlin Conference (2003) and Barcelona Council (2004) represent intermediate stages of what is known as the 'Bologna Process', in the perspective of constructing the 'European Area of Higher Education' by 2010. However, more than five years after the beginning of the 'Bologna process', the 'market driven' paradigm is still the prominent reference framework for both the education and industrial systems.

The most tangible effects are in the increase in the number of students and in new university centres. In many cases, IE education tends to be more oriented to operational than design and creative factors.

The education system shows inertia in updating engineering programmes to market needs; consequently, asynchronous flows occur between educational needs expressed by industry and IE course updating. A prospective mid/long-term education policy is needed to anticipate industry requirements and reduce delays.

Recurring debates on the quality of education often give rise to doubts about the effective capability of the new higher education system to fulfil the contrasting targets of reducing time for education and increasing its quality consistently with the needs of a knowledge-based economy.

The prominent goal for the EU university system, as stated by the Lisbon and Berlin Conferences, is pursuing excellence both in education and in research by integrating the European Higher Education Area (EHEA) and the European Research Area (ERA). The main success factors consistent with a knowledge-based society are identified as:

(a) financial dimension of R&E system
(b) competition for human capital

In 2003, R&D investment in the EU-25 accounted for less than 2% of GDP while the same figure was 2.59% in the US and 3.15% in Japan (Duchene and Hassan 2005). Moreover, governments still represent, for many EU countries, the largest source of R&D funds, mainly in countries where low intensive technology production is prominent.

Despite the Barcelona council declaration of the heads of the EU states, which fixed at 3% of the GDP the minimum threshold of R&D expenditure to be reached by 2010, structural constraints in the R&E funding system significantly limit the actual capability of the EU to fulfil such a goal. In the EU-25, R&D expenditure is expected to reach about 2.2% of GDP in 2010.

A low demand for innovation as well as for a research workforce is expressed by industry. A major limit is represented by the structure of the industrial sector in the EU where small and medium-sized enterprises (SMEs) perform a large part (22.4%) of business R&D (usually funded by public resources) against 14.1% in the US and 7% in Japan. Research efforts are basically oriented to mature and low-risk industrial sectors and the total percentage of exports in technology-intensive manufacturing is lower in the EU-25 (20%) than in Japan (25%) and the US (25%).

With reference to human capital (Duchene and Hassan 2005), even if the EU-25 is producing more 'science and technology' graduates (24.2% of overall graduation) than Japan (23.1%) and the US (185 %), EU-25 makes available only 5.4 researchers (in full-time equivalents) per thousand of the labour force, against a doubled availability in Japan (10.1%) and in the US (9.0%). The percentage of researchers in business sectors is significantly lower in the EU (49%) than in Japan (67.9%) and the US (80.5%). Moreover, an ageing process is eroding the current S&T workforce: 34.7% of researchers are in the 45–64 year-old group and only 30.8% in the 25–34 year-old group.

According to this scenario, demand for innovation by industry has to be stimulated and the EU higher education system should improve efforts to increase the availability of researchers in business sectors, also by encouraging woman in research careers. Factors for creating a woman-friendly culture in institutes of higher engineering education are investigated in Daudt and Salgado (2005).

European Master and PhD courses as well as life-long learning represent a large and not fully expressed demand for IE higher education in Europe. Attracting top talent from more advanced research centres is one of the most effective actions to create and develop excellence in research and education. Creativity has become a crucial issue in industrial and management engineering education (Chi-kuang Chen *et al.* 2005). The major question is how to attract knowledgeable and creative people.

### 2.1 *The social dimension as a factor for attracting creative people*

Up to the 1990s many students interested in higher education were more attracted by the US university system than by the EU one. About 50% of EU people who obtained qualifications in the US stayed there for a long time and many of them remained permanently. All over the world, out of 150 million of people living outside their native country about 20% lived in the US. After the events of September 2001, a decrease of about 30% in foreign students occurred in the US and increasing attention was paid to the social dimension.

Recently, the phenomenon has been investigated in-depth by US researchers. Taxonomic and statistical studies (Florida 2002, 2005a, 2005b) provide a procedure for ranking countries based on their capability to attract creative people. The procedure refers to a composite '3T' index, the global creativity index, which considers talent, technology and tolerance as attraction factors. Talent factors are conventionally evaluated (e.g. they are based on the percentage of people holding a bachelor's degree, the number per million population of creative people working as architects, artists, engineers, musicians and researchers). Technology indexes are based on R&D expenditure as a percentage of GDP and on production of patents. Finally, tolerance is 'measured' by a sample analysis of people's opinions on traditional and current values (God, religion, nationalism, family, …) as well as on individual rights (quality of life, democracy, the environment, immigration, homosexual rights etc.). Indexes are normalized using a (0, 1) scale.

The study was performed on data from 45 countries all over the world; eight EU countries are ranked in the first top 10. Northern countries (see table 1) are evaluated as having high '3T' performance in the EU.

**2.1.1 The role of the cities.** The scenario depicted in Florida (2005b) outlines the role of the cities for attracting and retaining 'creative' people. The choice of spending a long study and research period or of carrying out a 'knowledge-based' job is based on social values offered by a city more than a country. As a consequence, new cities all over the world are competing to become more attractive than others.

Table 1. Ranking of EU countries according to the global creativity index (Florida 2005).

| | Talent | Technology | Tolerance |
|---|---|---|---|
| 1 | Finland | Sweden | Sweden |
| 2 | The Netherlands | Finland | Denmark |
| 3 | Belgium | Germany | The Netherland |
| 4 | England | Denmark | Finland |
| 5 | Sweden | The Netherland | Germany |
| 6 | Ireland | Belgium | Austria |
| 7 | Germany | France | England |
| 8 | Spain | England | France |
| 9 | Denmark | Austria | Belgium |
| 10 | France | Ireland | Italy |
| 11 | Greece | Italy | Spain |
| 12 | Austria | Spain | Greece |
| 13 | Italy | Portugal | Ireland |
| 14 | Portugal | Greece | Portugal |

**2.1.2 The Austin area.** The emblematic case is represented by Austin, where focused investments in research activities along with social policies of local authorities made the city one of the most attractive both for industry and for 'creative' people.

In the 1960s, Austin was a college town of 200 000 residents mainly employed in the University of Texas and in the state government. Federal research funds in electronic research programs were able to attract industry (Department of Defense's Joint Services Electronics Program). The Microelectronics and Computer Technology Corporation (1983), a high technology consortium created to promote US technological leadership in electronics, as well as the *Sematech* consortium (1988), involved in research into semiconductors, were located in Austin. Prior to 1980, R&D expenditure in Austin was less than 200 million dollars.

Now, the private and public sectors spend 1.4 billion dollars on R&D annually. At present Austin is in one of the most advanced high technology regions in the US where about 1800 technology companies employ 115 000 people out of a population of 1 million. In the Austin region there are seven area colleges and universities with more than 100 000 students. The government and the universities provide financial incentives and an attractive business environment for prospective arrivals.

**2.1.3 The Boston area and the emerging 'Global Austin' cities.** Another case of success is represented by the pharmaceutical industry in the state of Massachusetts. The state has changed its cultural identity over time: from excellence in economic history in the 1920s and 1930s, to high-tech research and productions in 1970s and 1980s, to financial-services in the 1990s. Nowadays, the world leadership in biotechnology research and industrial production is concentrated in the state of Massachusetts. Boston is the center of what has become a 310 billion dollar industry of 280 biotechnology companies. Research is regularly carried out jointly by companies and universities. Social policies are oriented to make Boston and Harvard as attractive as possible. The opinion of Jean-Pierre Sommadossi, CEO and chairman of Idenix Pharmaceuticals Cambridge, is meaningful in this regard:

> 'What makes a company first and foremost are the people…You want to be in a location where you're going to be attractive for a management team to join the company. You want to have access to a scientific pool directly there. It would be extremely difficult for a biotech company to have to recruit everyone from outside and not have a [local] scientific pool to tap into.' (Chemical and Engineering News 2003)

Sidney, Melbourne, Toronto and Montreal are considered as emerging 'global Austins' with Tel Aviv and Bangalore being candidate 'global Austins'.

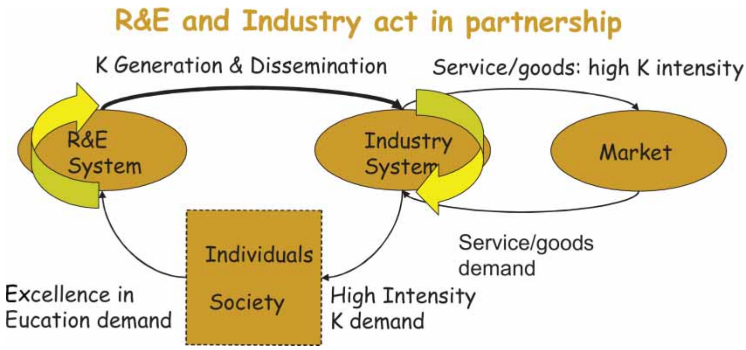


Figure 4. The 'Knowledge-driven' paradigm.

Such highly complex evaluations on the future of our cities could be considered as subjective estimates. However, the cultural and social power of cities to attract knowledgeable people have to be considered as relevant developing factors in the 'Knowledge-based' society. The EU has many opportunities to add value.

Previous remarkable examples make clear the role that Universities can play when talent is attracted from outside by the excellence of R&E centres which, in turn, could give rise to interest from industry to locate both research and production around such centres.

The above mentioned examples represent successful cases in the framework of the 'knowledge-driven' paradigm (figure 4). In the framework, the driving forces of the knowledge generation and dissemination processes are both in the excellence of the higher education/research system and in industry.

According to such a paradigm, flows of knowledge generation and knowledge utilization tends to be synchronous because of the attitudes of industry to value ideas and innovation within a 'low time-to-market' context. There is great potential in the higher innovation rate of process and products and in stronger links between universities and industries: they tend to act in partnership. More and more people in a 'knowledge society' will demand excellence in research and education.

## 3. Trends in knowledge demand: education opportunities for industrial engineers

Planning the education of highly knowledgeable and creative people is a complex task requiring medium–long-term evaluations of topics which will be of interest in the future. Effective techniques adopted to investigate future knowledge needs are patent maps and scenario analysis.

The triadic patent map index (Duchen and Hassan 2005), measuring the number of patents per million population, shows, on average, a significant deficit in patent production in the EU. (Patents taken can be linked together to build triadic patent families: a set of patents taken at the European Patent Office (EPO), the Japanese Patent Office (JPO), and the US Patent and Trademark Office (USPTO) that share one or more priorities.) The situation in 2003 was: 93 in Japan, 53 in the US and only 31 in the EU-25. While patent production in Finland and Sweden is comparable with that in Japan, both Germany and the Netherlands outperform the US; however, in the year 2000 no less than 13 EU Member States produced less than 5 triadic patents per million population. On average, the percentage of the number of triadic patents for the EU-25 accounts for nearly 1/3 of the overall triadic patent families.

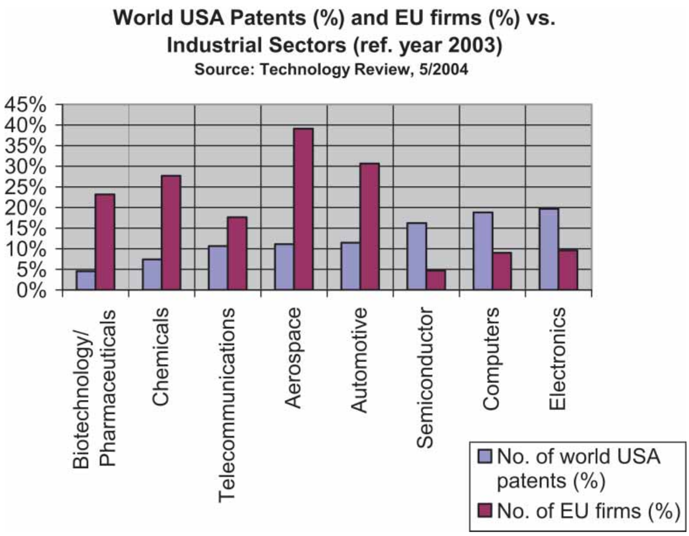


Figure 5. World US patents and EU firms in different industrial sectors.

An overview of the US patents registered by international firms in 2003 is provided in the Technology Review journal (Technology Review 5/2004). The map refers to a sample of the top 150 firms for each of the most knowledge-based industrial sectors. As can be seen in figure 5, the first three industrial sectors producing most of the patents registered in the US are labelled as 'Semiconductors', 'Computers', and 'Electronics'. In these sectors there is the lowest participation of EU companies which, on the contrary, significantly contribute in 'aerospace', 'automotive', and, to a lesser extent, in the 'chemicals', 'biotechnology' and 'pharmaceuticals' industrial sectors. The same conclusions also apply when the 1998 2002 period is considered (graphs have been omitted).

It is also interesting to observe in figure 6 how the technology cycle time, i.e. the average age (years) of patents considered as fundamentals among company patents, tends to be higher in industrial sectors such as 'chemicals', 'aerospace', and 'automotive', than in 'telecommunications' or 'computers', sectors which require dynamic behaviour in generating innovation.

Statistics stress the opportunity of maintaining and reinforcing basic education disciplines (maths, physics, chemistry) in the EU while providing, at the same time, further research and education efforts in innovative and knowledge-based sectors.

In this concern, it is worth noting a recent ranking of firms based on the 'Technology Review Innovation Index' which expresses the attitudes of large companies to R&D investment (table 2): eight bio-pharmaceutical companies are in the top fifteen. Nevertheless, IE courses are not yet adequate, in quality and quantity, to face the increasing demand for knowledge people in the bio-tech and health industry.

### 3.1 *'Looking at the future'*

Forecasting studies based on analysis of socio-economic scenarios are provided by the Institute for Prospective Technological Studies (source: The IPTS, The Future of Manufacturing in Europe 2015–2020. The Challenge for Sustainability 2003).

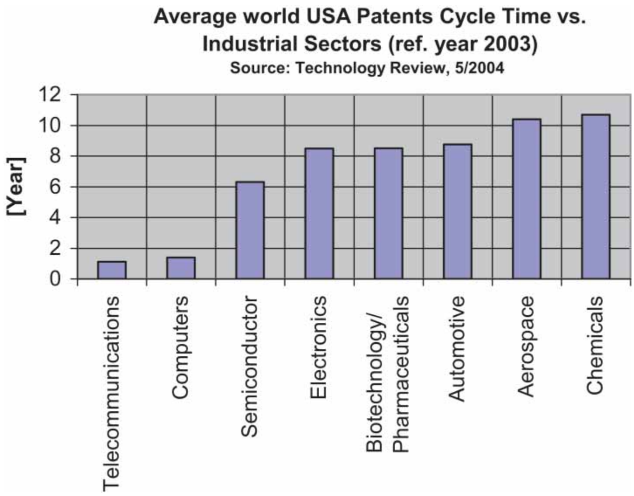


Figure 6. Average world US patents cycle time in different industrial sectors.

Table 2. A patent map according to the technology review innovation index (Source: Technology Review 5/2004).

| Company | Technology Review innovation Index (*) | R&D 2003 [Million $] | Variation in R&D (%) | Variation in R&D [million $] | (R&D/) Sales) (%) |
|---|---|---|---|---|---|
| Pizer | 178 | 7131 | 38 | 1955 | 16 |
| Amgen | 149 | 1655 | 48 | 539 | 20 |
| Nokia | 146 | 4514 | 23 | 850 | 13 |
| Johnson&Jhonson | 141 | 4684 | 18 | 727 | 11 |
| BMC software | 138 | 586 | 20 | 96 | 41 |
| Volkswagen | 138 | 4233 | 22 | 762 | 4 |
| Sony | 136 | 4683 | 16 | 649 | 7 |
| Merck (US) | 135 | 3178 | 19 | 501 | 14 |
| Serono | 134 | 468 | 31 | 110 | 25 |
| Astrazeneca | 134 | 3451 | 12 | 382 | 18 |
| Microsoft | 133 | 4659 | 8 | 352 | 14 |
| Roche | 133 | 3694 | 12 | 396 | 15 |
| Novartis | 133 | 3756 | 12 | 394 | 15 |
| Intel | 132 | 4360 | 8 | 326 | 14 |
| Nissan Motor | 129 | 3225 | 18 | 491 | 5 |

(*)The innovation index is based on R&D expenditures, percentage and absolute variations, and on % of R&D on Sales.

IPTS provides forecasting estimates on the future of EU manufacturing industry over the next 15 years. 'News from the future' seems to confirm and reinforce current trends in bio-nano technology, new materials, digital factories and plant miniaturisation as well as in health, safety, and security of work environments and infrastructures.

In the field of nanotechnology, the crucial questions will be both component reliability, to make 'nano' products market-viable, and standardization of measures and tests in nano-environments. Nanotechnology is a new a frontier for engineering education. It is estimated that about 2 million workers will be needed worldwide in the next decade (Roco 2002).

Smart materials, bio-polymers, and electronic equipped textile materials are examples of new materials that are more environmentally compliant or capable of modifying their performance in a changing environment (e.g. textile materials having different thermo-physiological properties according to environmental temperature).

Energy and environment topics will increase in importance in the spectrum of IE. At current, both energy and 'environment' consumption in China as well as in Europe and Central Asia are lower than in the EU, Japan, and the US (World Bank Data 2005).

Studies of 'plant miniaturization' will be of increasing importance both in research and in industry. Miniaturization is expected to provide low cost plant as well as environmentally compliant industrial processes. The benefits are mainly expected in health and safety concerns of hazardous industries (chemicals, petro-chemicals, pharmaceuticals, steel, nuclear, etc.).

Security of production systems and infrastructure will also be considered with traditional safety problems and the need for new design and operational guidelines will become prominent. The scientific and industrial interest in the concept of 'plant vulnerability' will increase; design and operation guidelines will be more and more safety and security oriented (NPRA Guidelines 2004).

The 'communicative competence' is a further skill required to scientists to create a social base for innovation, beyond the scientific knowledge. The need of communicative engineers is considered a social necessity to reduce the gap between invention and innovation (Ravesteijn *et al.* 2006).

## 4. Towards effective integration of higher education systems in the EU

Integration of higher education systems in the EU should be achieved while adopting solutions consistent with European traditions and values, taking into account the power of talent, technology, and tolerance to attract knowledgeable and creative people.

The integration process of the higher education systems in the EU was started by the Socrates Erasmus, Tempus, and Leonardo programs promoting the mobility of both students and R&E staff. In the academic year 2003–04 about 135 000 EU students participated in the Erasmus program, with an average 10% increase on the previous year. In Italy, the opposite situation occurred from 2001 to 2004 since the percentage of graduates studying abroad decreased from 19% to 11.3% (Almalaurea, Statistics 2005). The main reasons for this are to be found in the new higher education system which is considered too 'intensive' (the education system tends to reduce time required for graduation) and in the system of credits equivalence adopted by each university.

A recent new opportunity is offered by the ERASMUS Mundus program, which came into force on 20 January 2004. It is a five year program (2004–2008) with a planned financial envelope of 230 million Euro for the whole period. Master Courses (MCs) can be offered for both EU and third country students by Erasmus Mundus Action 1. A consortium of at least three EU universities can decide to offer a single or joint diploma. At present, EU universities offer Erasmus Mundus MCs in both traditional (e.g. Mechanical Engineering) and innovative (e.g. Industrial Mathematics) IE areas.

As far as PhD courses are concerned, more effort is required to achieve integration between EU universities to give a European dimension to doctorate programmes. The European dimension in Doctorates was promoted by the 'Confederation of European Community Rectors'. However, a European PhD title still does not officially exist. It is for each university to decide whether the title can be attached as a label to the national PhD title. The harmonization process of doctorates in the EU is under way. European Ministers Responsible for Higher Education (Communiqué of the Conference of European Ministers Responsible for Higher Education, Bergen, 19–20 May 2005) are coordinating efforts to develop common basic principles for doctoral programmes. Results are expected from the Ministerial Conference in London in 2007.

## 5. Conclusions

Current demand for IEs in Europe comes from manufacturing and, to a greater extent, from the industrial and public services sectors; increases in traditional industrial engineering education areas occur with few exceptions. However, new IE course programs are needed to satisfy the incoming demand for knowledge from innovative industrial sectors.

Research and education systems should be considered as belonging to a unique system which has to interact with industry. The paradigm of a 'market-driven' research and education system fails in pursuing effective innovation. The answer lies in the 'knowledge society' and a 'knowledge-driven' paradigm should be followed by education and industry systems.

A leading role is expected from the IE higher education system to bridge the gap between EU economies and the other most industrialised areas in the world.

Major obstacles are recognized in the current deficit of both R&D expenditure and human resources. R&D expenditure is inadequate both in quantity and in efficiency. SMEs contribute to a significant extent in R&D expenditure. This is considered a limitation because of SMEs being less inclined to manage innovation.

The R&E system 'produces' a consistent flow of S&T people but a remarkable deficit in researchers in business sectors still occurs along with the ageing process effecting current research people. Women are still under represented in S&T labour force.

The solution also lies in the capability of the R&E system to attract knowledgeable people. Attracting capabilities relies on both classical (technology) and new (social) drivers. Current patent maps outline the quantitative and qualitative trends in innovative industrial sectors. Nano-bio technologies, new materials, digital factories, energy and environment, safety, security and health are the main topics of interest for IE. The higher education system in the EU must improve efforts in educating people to innovate and IE areas should come first in satisfying the demand for knowledge.

Higher education on these topics requires a high level of integration between EU universities. Recent opportunities are being offered by Erasmus Mundus Master's Courses and by European joint doctorate courses.

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