The Development Of Education And Training Systems In The Field Of Nanotechnology

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ABSTRACT

The paper presents the dynamic development of nanotechnologies in the world and – on this basis – the educational demand for scientists, engineers and didactic staff. Proposed and created forms of education and development related to nanotechnology in theoretical and practical aspect are shown as well. The potential and educational possibilities within nanotechnology are presented with regard to the university studies, postgraduate studies, doctoral studies and training courses in the selected countries. Special attention is paid to characteristic educational systems, both with regard to the organizational and methodological aspects related to nanotechnology in the United States, Japan and EU countries. Compared to these countries, the situation in Poland within education and training in the field of nanotechnology is characterised.

INTRODUCTION

Nanotechnology constitutes one of the key aspects of the contemporary trends of science and advanced technologies in the world. At present, the United States, Japan and the European Union, (particularly Germany and Great Britain) are dominating the field with regard to the directions of following research works: the size of budgets allotted to the growth of nanotechnologies, the range of initiatives undertaken, the number of governmental and university research centers, the development of the education and training system, and the influence of the achievements in the field of nanosciences and nanotechnologies[1] on the growth of economies.

Nanotechnology funding in the last decade on the global scale and in the most developed countries has been growing dynamically (fig. 1).

The total investment in areas connected with nanotechnology has grown in the recent decade to over twenty times its initial size, and the spending from public sources has grown to over ten times its previous level. In total, the outlays of governmental, private enterprises and venture capital funds on research and development in nanotechnology amounted to approximately 8.6 billion dollars in 2004 [2] and to over 9.6 billion dollars in 2005, which constitutes 10 percent growth compared to the previous year. About 4.6 billion dollars from public funds was spent globally on nanotechnologies, which constitutes a 3 percent growth compared to the previous year, whereas the private sector allotted 4.5 billion dollars, which constituted a 18-percent growth compared to year 2004. The expenditures of venture capital funds reached the level of 0.5 billion dollars in 2005, which is characterized by a 17-percent growth compared to the year 2004 [3].

[1] Terms nanosciences and nanotechnologies according to [Report of the COST Strategic Group on Nanoscience and Nanotechnology: Strategy of COST Interests in the Multidisciplinary Field of Nanosciences and Nanotechnologies within the European Research Area, COST *ad hoc* Strategic Group on Nanoscience and Nanotechnology (NanoTech), June 2005] can be recognized as equivatent to the term nanotechnologies

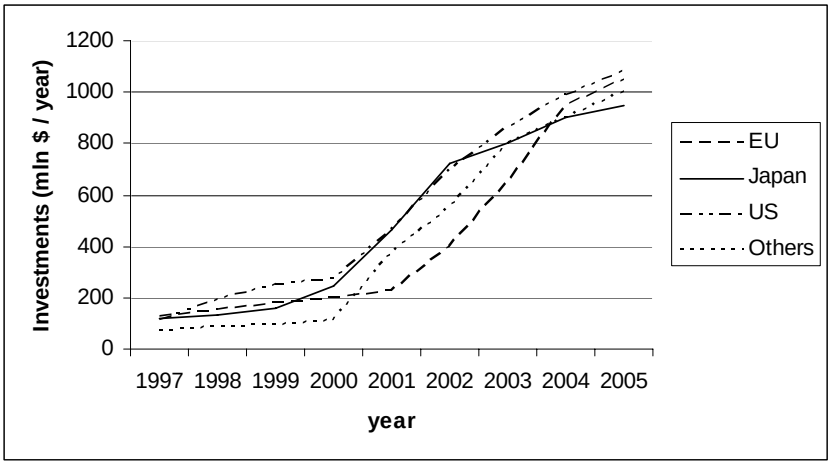

Figure 1
Public Investment In The Nanotechnology Research And Development Sector In The Period 1997-2005 (Million Dollars)[1]

Thus, a more and more important and dominating source of funding development work in nanotechnology is the means generated directly by business activity, which indicates the dramatically increasing economic importance of this field of scientific and application activity. Of the 4.5 billion dollars that enterprises spent in 2005 on research and development in nanotechnology, 41% constituted the share of companies from the United States, 38% was the share of Asian companies, mainly Japan, and 19% stemmed from European companies (fig. 2).

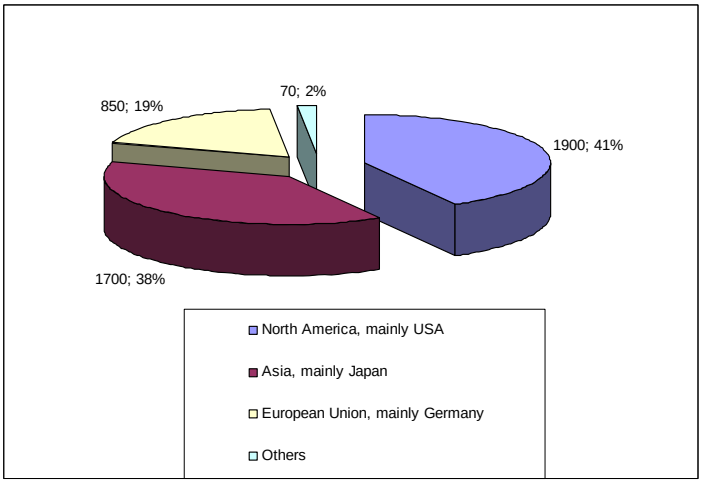

Figure 2
The Level Of Expenditure On Nanotechnology Development From Means Generated By Business In Particular Regions Of The World In 2005 (Million Dollars) [3]

In the United States and in the European Union there are a comparable number of enterprises applying nanotechnologies. Almost half of nanotechnology companies in Europe are German companies. In 2004, about 1500 companies worldwide (80% of them are start-up companies) implemented research and development works in the field of nanotechnology into their strategies. Presently a trend can be observed that, in the majority of highly economically developed countries, research and development is largely conducted by transnational companies.

Forecasts claiming that, within the next 10 years, the global scale of products obtained as a result of nanotechnology application will amount to over 2 trillion dollars and generate 1-2 million new jobs [4], proves the potential of nanotechnology and the possibility of its practical application.

The participation of the world economies that are the most meaningful for nanotechnology development (USA, Japan and the European Union) in global investments are comparable; although, the position of the USA becomes increasingly more dominant (fig. 3). In 2005, the greatest investments among the European Union countries were borne by Germany, Great Britain and France. Moreover, meaningful investments also took place in China, Russia, South Korea, Canada and Australia [5].

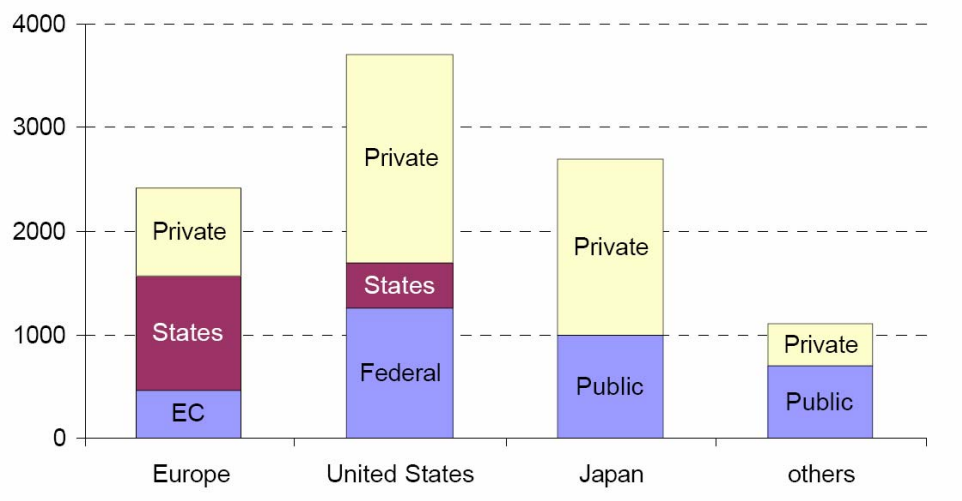

Figure 3
Estimated Public And Private Funding For Nanotechnology R&D In 2005 By World Regions (Million Dollars) [3].

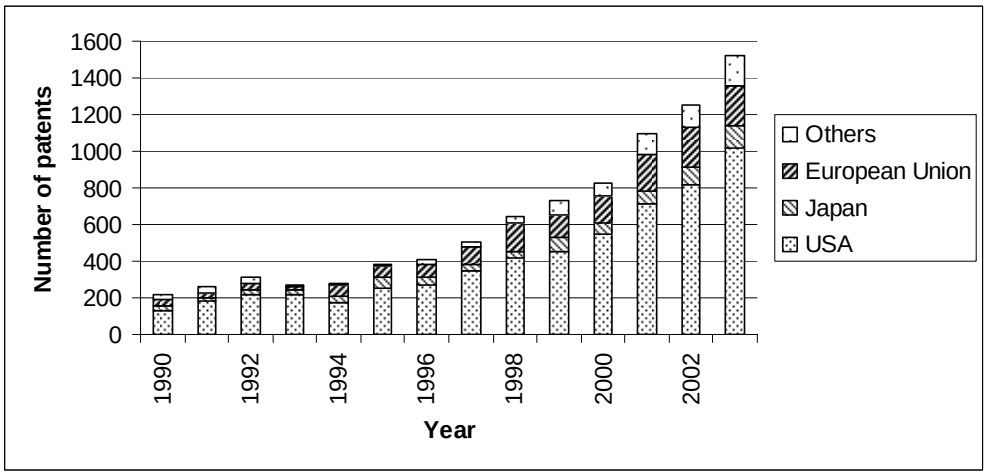

Figure4
The Number Of Patents Applied For In 1990-2003 In Selected World Economies [6]

Another indicator of research dynamics and economic demand for nanotechnological products is the number of patents and publications in particular countries (fig. 4). The greatest number of patents in the field of nanotechnology were filed for the USA, Germany and Japan. The next positions are held by France and Great Britain.

As far as the number of scientific papers dealing with nanotechnology is concerned, the European Union is at the first place (41%) [7], next are the USA, Japan and China. If we take into consideration the number of papers and the frequency of them being quoted, the order is as follows: USA, European Union, and Japan [8].

Due to the fact that nanotechnology constitutes a considerably new and dynamically developing knowledge area, there is a vast shortage of specialists in this field, which requires intensive training of scientists, industry workers and didactic staff. Furthermore, nanotechnology requires continuing development of theoretical knowledge as well as improvement of practical skills by specialists carrying out development work in this area. To meet the systematically growing demand for nanotechnologies and nanotechnology products, modern research and industrial infrastructure as well as a continuously trained, educated, and experienced staff must be provided.

The need of implementing changes in the education system was indicated in strategic governmental documents that concern nanotechnology development in the leading world economies, for example, in the *National Nanotechnology Initiative* [9] in the USA, in the *3rd Science and Technology Basic Plan* [10] for Japan, or the EU Commission's Communiqué *Towards a European Strategy for Nanotechnology* [11]. The need for the modification of the educational system, primarily within masters and doctoral studies was indicated in the national strategy for Poland [12] as well. Attention was also paid to the necessity of organizing training courses and educating scientists and academic staff in units abroad. An urgent need of creating integrated educational internet service was also indicated.

With regard to the dynamically growing demand for nanotechnology specialists and the shortages in education within the regular educational systems, works in the field of nanotechnology are run first of all by scientists specialized in fundamental sciences, such as natural sciences, physics, chemistry and mathematics. Scientists, apart from conducting research, are also involved in didactic activity. They conduct training and development courses. Staff education, primarily staff specialized in technical sciences who are involved in running research in the field of nanotechnology, is mainly carried out within numerous **scientific seminars and conferences**. In addition to training staff, they aim to stimulate nanotechnology development which can occur, thanks to the exchange of experience and the presentation of scientific results, both on national and international arena. Activities of this kind are undertaken in all of the most economically advanced countries.

Training courses are another form of education which is effective and easy to organize. Trends in the United States and the European Union are leaning toward generating diversified educational and training courses offered by both universities and R&D centers. Educational systems in the European Union promote training courses e.g. in the field of surface engineering, molecular physics, quantum effects, nanoanalytics and nanometrology, as well as the manufacturing of devices in nanoscale. The majority of European nanotechnology centers possess a laboratory infrastructure which enables them to organize training courses and coordinate training projects. Polish training offered in nanotechnology is in its initial, although dynamically developing, phase.

A diversified training offer is necessary for rapid staff development in the field of nanotechnology, in addition to the system of regular and continuing education within bachelor and master mode studies. At present the education in the nanotechnology area, apart from training courses, is realized in the majority of countries in the system of **postgraduate and doctoral studies**, mainly due to the fact that the foundational knowledge related to nanotechnology is included in the standard curricula of university studies. The first curriculum of doctoral studies in nanotechnology in the United States was implemented in 2002 at Washington University. In Great Britain, the first enrollment for postgraduate studies in nanotechnology for the academic year 2007/2008 was announced at Oxford University. Oxford and Cambridge Universities also organized doctoral studies, which included 50 doctoral titles in nanosciences.

In Poland, the best and the most advanced education offer in the field of nanosciences and nanotechnologies is provided in doctoral studies, where there is a wide spectrum of theoretical subjects and well-equipped laboratories used for experimental work. Benefits of these studies are usually close relations with the world science community and the quality of studies which are effectively verified by doctoral theses and the publication achievements of the PhD students [12]. In the last 8 years, from 1998 to 2006, 9 habilitations and 64 doctorates were obtained in nanosciences and nanotechnology in Poland. The subject of all habilitations were structural nanomaterials. The majority of doctoral studies concerned technical sciences (39), nanotechnology in the area of physics (15), and nanotechnology in the area of chemistry (9) (fig. 5).

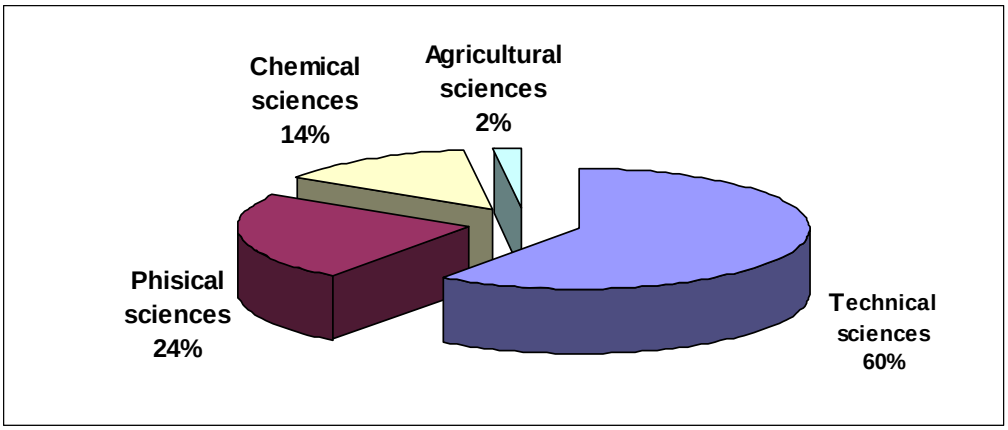

Figure 5
Doctorates In The Field Of Nanosciences And Nanotechnologies In Poland In 1998-2006 [12].

The access to **specialist literature**, i.e. papers, journals, monographs and specialist publishing series is of great importance in the educational process in nanotechnology. Worldwide literature in this field is very extensive, but it mainly comprises papers and books in the English language. The greater part of specialist literature is available on the Internet, which additionally facilitates the realization of the priority of knowledge dissemination in the nanotechnology field. Literature dealing with nanotechnology published in the Polish language is rather scarce, both with regard to monographs and papers. Therefore, foreign-language materials are the main source of information on conducted research and scientific achievements in the field of nanosciences and nanotechnologies. However, the situation is changing rapidly, as more and more new publications in this domain appear, e.g. at present a new monographic publishing series *World of nanotechnology* is introduced in Poland.

Although presently nanotechnology is primarily a specialization area in doctoral studies, it is implemented into regular **educational systems** in many countries, and in some has already been introduced at primary school level (e.g. Japan) and secondary school level (e.g. Taiwan). In many technologically advanced world economies (the United States, Japan, Germany, Great Britain, Australia) nanosciences and nanotechnologies are lecture topics at university level.

The actions for education undertaken in the **United States** are coordinated by Nanotechnology National Infrastructure Network (NNIN) consisting of 13 universities e.g. Cornell, Howard, Stanford, Washington, Michigan and Harvard. The priority of actions undertaken in the USA is striving to take up cooperation between academic units and research centers and to encourage students to specialize in nanotechnology. Each university belonging to NNIN implements educational curricula and runs training courses in different disciplines connected to nanosciences and nanotechnologies. University educational programs in the USA aim at achieving the following research purposes:

- gaining skills of characterizing and measuring nanostructural properties,
- enhancing the abilities of synthesizing and processing nanostructures and nanocomposites,
- developing the skills of designing, analyzing and simulating nanostructures and devices at nanoscale.

Nanotechnology National Infrastructure Network initiated in 2004 an educational research program for students (*Research Experience for Undergraduates – REU*) enabling participation in laboratory tests and research projects in the field of nanotechnology, the application of advanced laboratory techniques and testing apparatus at a worldwide level. An example of activities undertaken by universities is the realization of nanoscience initiative (the elaboration of curricula *Nanoscience K-12 Curriculum Development)* at Stanford University. The initiative consists in the creation of educational modules in the field of nanosciences and nanotechnologies destined for secondary schools. Postgraduate curricula and a training program destined for secondary school teachers have been developed as well (*The Research Experience for Teachers – RET*).

Numerous initiatives aiming at the development of educational systems were undertaken in **Japan**. *The Nanotechnology Researchers Network Center of Japan* realized at the Ministry of Education, Culture, Sport and Technology coordinates the following undertakings:

- *Summer Nanotechnology School* – students learn quantum mechanics, the knowledge of which is necessary to operate electronic and optic nanodevices applied in computer science and communications. Issues dealing with physics of organic semiconductors and the theories of quantum information processing are also introduced. The curriculum encompasses classes in nanomedicine, nanobiology and nanophysics.
- *Multidisciplinary school* – the main discipline is nanobiotechnology. The classes comprise problems concerning living organisms at molecular level.
- *Exchange Program for Young Scientists* – the scientific and technical cooperation in the field of nanotechnology is promoted on international arena. Countries involved in this project are the United States, Great Britain, France and Sweden.

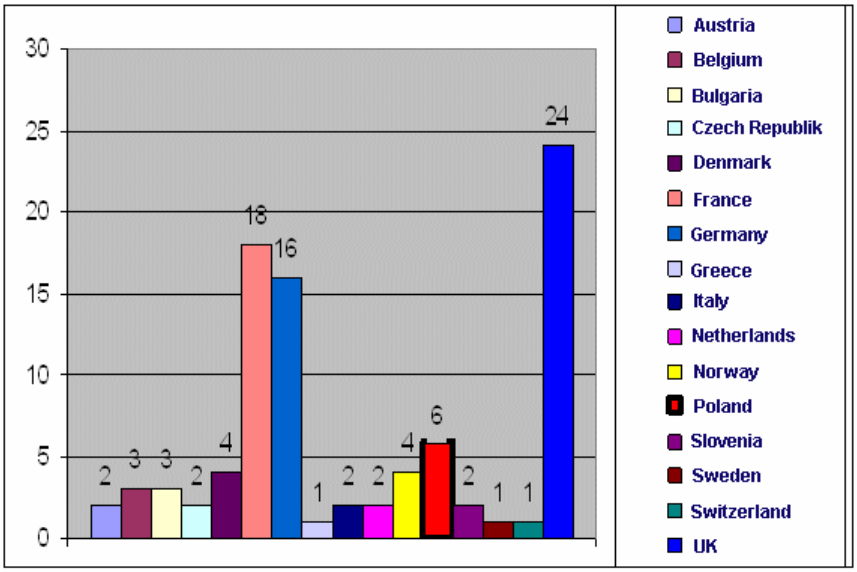

Figure 6
Number Of Majors Connected With Nanosciences And Nanotechnologies Offered At Masters And Doctoral Studies In Selected UE Countries.

The promotion of education is one of the priority objectives of the **European Union** strategy for the development of nanosciences and nanotechnologies [13]. Particular attention is paid to the need of educating new generations of specialists in the field of nanotechnology with the use of modern devices supporting the educational process, as well as conveying knowledge and skills by experienced scientists.

Among the European countries, the leading role in the respect to the number of majors connected with nanotechnology offered at masters and doctoral studies is played by Great Britain, France and Germany (fig. 6).

The offer of masters studies in the field of nanosciences and nanotechnologies provided by European universities is very differentiated. The greatest number of masters studies programs is run in Great Britain, France and Germany (fig. 7).

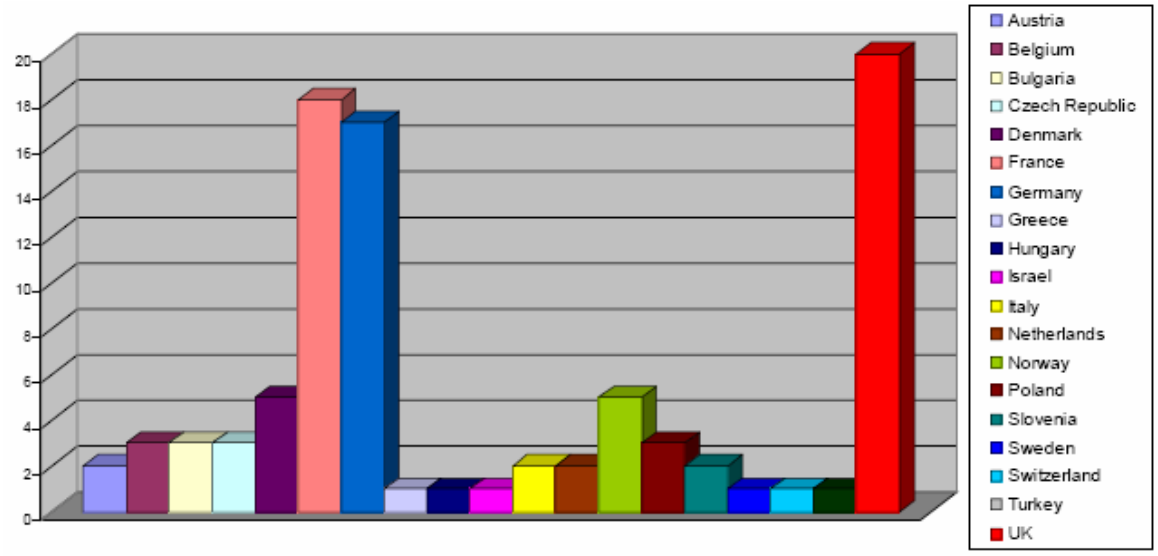

Figure 7
Master Studies In The Field Of Nanosciences And Nanotechnologies
In Poland Compared To Selected European Countries [14].

Among the European countries **Great Britain** has the most differentiated educational offer in the field of nanotechnology. In order to adjust the educational system to the needs generated by research and industry sector, the educational system has been changed recently, in particular at the level of masters studies, postgraduate studies and in continuing vocational development. At the level of higher education, several universities elaborated educational modules in the field of nanotechnology which constitute educational elements in the system of masters or doctoral studies. Further undertakings in this area will enable the universities to offer attractive educational packages concerning education in specialized disciplines, as well as multidisciplinary nanotechnology programs destined for masters studies, modules for engineering studies and short-term training courses.

The education offered by **Polish** academic institutions comprises a dozen or so specializations in the field of nanotechnology which finish with a B.Sc. or a M.Sc. According to European trends aiming at introducing education in the field of nanosciences and nanotechnologies at lower levels of academic education, presently an offer of engineering studies and bachelor studies is being formulated in Poland (fig. 8).

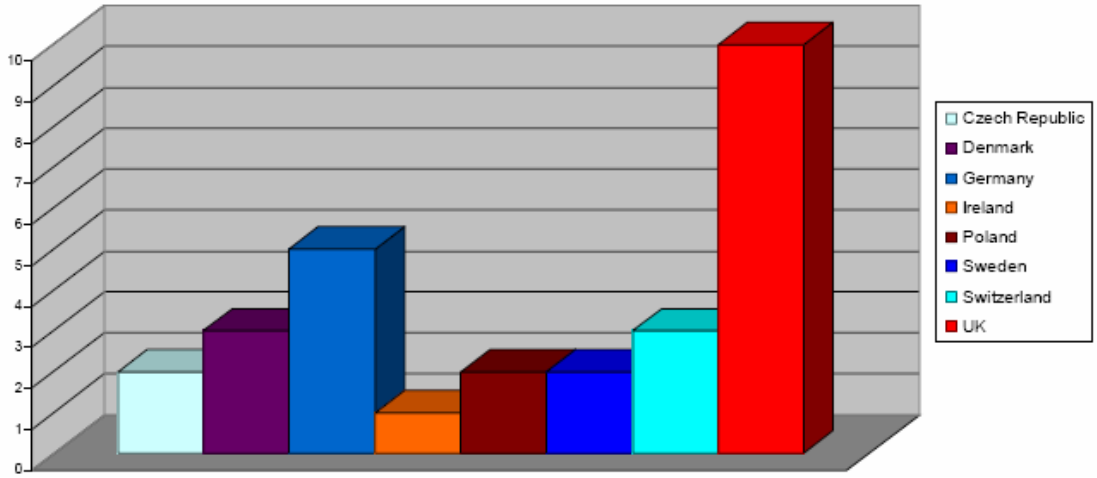

Figure 8
Engineering Studies And Bachelor Studies In The Field Of Nanosciences And Nanotechnologies In Poland Compared To Selected European Countries [14].

Many universities offer only fragmentary education in the field of nanotechnologies that consists in the lecturing of only selected subjects related with this issue, mainly in physics and chemistry departments. The analysis of subjects offered at Polish universities has revealed that the most extensive offer encompasses nanostructures, nanomaterials and nanocomposites. Moreover, the specializations in the area of basic phenomena and processes, nanophotonics and nanoelectronics have been identified.

Education in the field of nanosciences and nanotechnologies is supported by advanced communications techniques and multimedia in form of information portals, Internet databases, on-line seminars, training via Internet, education with the use of multimedia, etc. This system is particularly well developed in the United States. An example of an information system is a complex Internet service coordinated by the National Nanotechnology Infrastructure Network consisting of educational portal, thanks to which it is possible to access the educational offer, training courses, seminars and presentations on nanosciences and nanotechnologies on-line. On websites, various training programs, lectures on nanotechnology, educational materials, e-books, and on-line seminars can be found. Another example of such educational activities undertaken in the USA is an initiative of Cornell University comprising, among other things, the administering of a website *Nanooze* [15] destined for children. Also, in the European Union countries, education in the field of nanotechnology is supported by advanced information technologies. Thanks to the Internet, on the website of the European forum on nanotechnology, Nanoforum [16], the user can obtain access to the recent publications, lectures, training materials, information on organized conferences, seminars and other forms of vocational training, as well as lists of academic centers providing education in the field of nanosciences and nanotechnologies in the European Union. An example of an Internet system devoted to nanotechnologies provided in Japan is *nanonet - Nanotechnology Researchers Network Center of Japan* [17]. Within this service information on the possibilities of training in the field of nanotechnologies are in the form of conferences, seminars, courses and also selected papers published by *Japan Nanonet Bulletin – JNNB* is available.

Figure 9
Internet Portal POLnano

In Poland an information system comprising an extensive range of educational offers called ”POLnano” is just being intoduced (fig. 9).

CONCLUSIONS

The comprehension and application of phenomena occurring in the nano-scale requires solid knowledge of the foundations of natural sciences, physics, chemistry and mathematics. Therefore, the most significant education in the field of nanotechnology takes place at the university level. Many universities take the challenge of our time and offer more and more subjects with ‘nano’ in name at different education levels. Three types of approaches to nanotechnology education can be identified worldwide. Within the first type, short specialized modules, are offered the graduates and student as a modest addition to the existing curricula concerning the behavior of materials. Within the second type, master programs within nanosciences are offered to the graduates who are already quite familiar with the behavior of materials. Within the third type, devoted to initial students, new three- or four-year programs are created in which the problems of nanotechnology are deeply-rooted from the beginning of education. The greatest doubts and problems are related to the third type in which the knowledge of phenomena in the nanoscale is conveyed to the students at the first stages of learning when their knowledge of materials at a macroscale [12] is very limited.

The reaction of the academic sector to the creation of the possibilities of educating an appropriate number of nanotechnologists is too slow, when taking into consideration a rapid development of this domain. At present, in the USA, Europe and Japan only selective educational curricula are offered which do not comprise the whole nanotechnology area. A lack of cooperation between the research sector and industry sector can be observed with regard to the preparation of scientific and technical staff of a selected profile adjusted to the market needs. The educational outlines encompassing nanosciences and nanotechnologies are predominantly realized in the programs of postgraduate and doctoral studies, assuming that the foundations of nanotechnology knowledge are integrated in the curricula of masters studies. In the majority of academic units, nanotechnology is lectured within the framework of a major at universities. However, a significant lack of specialization and specialist university structures within nanotechnology can be observed.

Techniques supporting educational actions have been extended by the use of computer tools, such as Internet portals, Internet databases of publications, multimedia presentations etc. in the majority of countries promoting nanosciences and nanotechnologies, in particular, in the USA and the European Union.

In Poland, universities and technical universities play a very important role in the creation of solid knowledge foundations in the field of nanosciences and nanotechnologies. Especially important and efficient is the interdisciplinary approach in the creation of the educational system in this domain.

As a result, it has to be stated that educational activities in the area of nanosciences and nanotechnologies constitute a basic activity for the development of these disciplines. Therefore, it is necessary to synchronize the educational initiatives with funding mechanisms, as well as establish wide research cooperation with economy representatives, including the SME sector, as a leading sector in this domain, in order to ensure the compliance of educational initiatives with economic practice in the field of nanotechnology.

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