Nano-education from a European perspective

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Abstract. At a global level, educating the nanotechnology workforce has been discussed since the beginning of the new millennium. Scientists, engineers and technicians should be trained in nanotechnology. Most educators prefer training students first in their own discipline at the Bachelor level (physics, chemistry, biology, etc) followed by specialisation in nanoscience and technology at the Master's level. Some favour a broad interdisciplinary basic training in different nanosciences followed by specialisation in a particular application area. What constitutes a good nanoscience curriculum is also being discussed, as well as the application of e-learning methodologies.
The European Union is stimulating the development of nanoscience education in universities. The Erasmus Mundus programme is funding nanoscience and nanotechnology education programmes involving universities in several European countries. The policy debate in Europe is moving towards vocational training in nanotechnology for educating the technicians needed in industry and research. The EU vocational training institute CEDEFOP published a report in 2005. The EU funded European gateway to nanotechnology Nanoforum has stimulated the accessibility of nano-education throughout Europe with reports and online databases of education courses and materials. For university education, they list courses at the Bachelor, Master's, and PhD level as well as short courses. The EU funded EuroIndiaNet project also reviewed Nano-education courses at the Master's level, short courses, e-learning programmes, summerschools and vocational training courses.
In this presentation, I review Nanoforum and other publications on nano-education in Europe and highlight current trends and gaps.

1. Introduction

The central question of the session on nano-education at ICNT2007 is "Do we need a nano-education?" To answer this question, we should first find out who needs a nano-education? Who has expressed the need for a nano-education in the past? What is the interest in nano-education from the people who have expressed a need? What kind of education is needed (expertise, skills, level)? For which jobs are knowledge and skills of nanotechnology needed? After analysing the demand side, I will review the response by European education institutes since 2004 as presented in several reports. Finally, I will compare expressed needs and measured response and suggest an answer to the central question about the need for a nano-education.

2. Who needs a nano-education?

2.1. USA

Mihail Roco has probably been the strongest advocate of "educating the nanotechnology workforce". He believed "training people is a key component for long-term success", and foresaw a need for a multdisciplinary trained nanotechnology workforce in 2010-2015 of 8-900,000 in the USA, 5-600,000 in Japan, 3-400,000 in Europe, 1-200,000 in Asia-Pacific outside Japan, and 100,000 elsewhere. In total about 2 million persons. He based his estimate on the 2001 market for instruments. (Roco, 2001) The National Nanotechnology Initiative in the USA has identified the need to "develop educational resources, a skilled workforce, and the supporting infrastructure and tools needed to advance nanotechnology", as one of its four major goals, since 2001 and invested considerable resources into developing nanotechnology education at all levels from PhD to secondary schools and public outreach. (NNI website, 2007) Also the 21st century Nanotechnology Research and Development Act (USA, 2 December 2003) states "The activities of the [National Nanotechnology] Program shall include […] providing effective education and training for researchers and professionals skilled in the interdisciplinary perspectives necessary for nanotechnology so that a true interdisciplinary research culture for nanoscale science, engineering, and technology can emerge."

2.2. Europe

In 2004, the European Commission highlighted the need to "promote the interdisciplinary education and training of R&D personnel together with a strong entrepreneurial mindset" (EC, 2004). The European Action Plan for nanosciences and nanotechnologies (EC, 2005) included several measures to foster interdisciplinary human resources for nanoscience and nanotechnology. These measures included a workshop on Research Training in Nanosciences and Nanotechnologies in April 2005. The predicted need for nanotechnology trained personnel of Mihail Roco (2001) was taken as starting point for the workshop. The validity of this prediction was not discussed. There appeared to be a surplus of trained nanoscience researchers in Greece and Sweden and a shortage in France and the UK. Participants expected China to educate over 1 million engineering graduates per year, the coming 5-10 years, which could mean there would not be a shortage of trained nanoscience researchers worldwide. The skills needs in industry and the profile of trained researchers did not match quite well, partly because the needs of industry had not been investigated. (Monk & Rachamim, 2005)

2.3. World

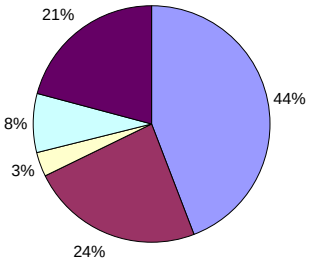
ICS UNIDO organised an Expert Group Meeting North-South Dialogue on Nanotechnology Challenges and Opportunities, 10-12 February 2005. The participants developed an action plan for a comprehensive nanotechnology education from primary until post-graduate and life-long learning. This standardised education should be developed between 2006 and 2010. (ICS UNIDO, 2005) During this meeting, the American nano-education expert Judith Lightfeather claimed: "experts have estimated that future demands will require 15 trained technicians for each scientist in a nanotechnology manufacturing business" (Light Feather, 2005). She did not give details about the source and motivation for this estimate. The results of the meeting have probably been used in USA and EU nano-education strategy development, as discussed above.

It appears that the main drivers for nanotechnology education are US and EU officials responsible for funding nanotechnology RTD. Little information is available on the actual or perceived needs of potential employers of nanoscientists, engineers and technicians.

2.4. Demand side

In Europe, in 2004, 44% of 733 respondents to the "Open Consultation on the European Strategy for Nanotechnology" expected a shortage of trained staff in nanotechnology within five years, 24% in five to ten years and 3% after ten years. Only 8% believed such a shortage would never occur.

The respondents believed the lack of highly skilled staff to be the main difficulty for SMEs and start-ups in nanotechnology. Almost half thought this was a crucial bottleneck, and about 30% thought it mattered "a lot". Apart from nanotechnology knowledge, interdisciplinary skills were considered much more important than awareness of societal issues, communication/presentation, entrepreneurial skills or interpersonal / management. Respondents considered interdisciplinarity crucial according to over 60%, compared to less than 20% for the other skills. More than 60% of respondents worked in the public sector. Furthermore, 12% worked in an SME (<250 employees), 11% in a large company, 3% was self employed and 2% worked for an association. (Malsch & Oud, 2004) The survey results don't enable analysis why respondents expect the shortage of trained staff and for which jobs.



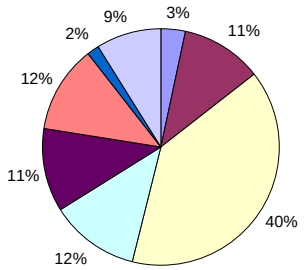


Figure 1: When will a shortage of trained nanotechnology staff occur? 44% < 5 yrs, 24% 5-10 yrs, 3% > 10 yrs, 8% never, 21% don't know

Figure 2: Professional environment of the 733 respondents: 40% university or higher education institute, 12% public research institute, 11% government, 12% SME, 11% large company, 3% self employed, 2% association, 9% other

Source: Malsch & Oud, Open Consultation on the European Strategy for Nanotechnology, Nanoforum 2004, www.nanoforum.org

The European Nanobusiness Association surveyed the opinions of 142 respondents from business and other organisations interested in nanotechnology in 2005. They found that about a third of respondents considered graduates with a PhD, or a first degree in a scientific discipline with a masters degree in nanotechnology, respectively, most useful for their company, 22% needed a first degree in a scientific discipline and a tenth a first degree in nanotechnology.

Need for trained staff, ENA 2005	PhD	1st degree scientific disc. MSc in nanotech.	1st degree in scientific disc.	1st degree in nanotechnology
142 respondents	34%	34%	22%	10%

Main hurdle in nanotechnology development, ENA 2005	insufficient government funding	lack of defined markets	lack of trained personnel	Other
142 respondents	23%	21%	16%	40%

Respondents to the ENA survey considered the lack of trained personnel only the third main hurdle in the development of nanotechnology after insufficient government funding and lack of defined markets. (ENA, 2005, quoted in Abicht et al, 2006)

CEDEFOP analysed skills needs for nanotechnology, based on literature review and qualitative analysis of the needs of German nanotechnology companies for intermediary level qualifications. A theoretical background of natural sciences (mathematics, physics, chemistry and biology) should be integrated with applied sciences. Students should also acquire interdisciplinary knowledge, entrepreneurial and management skills and life long learning abilities. They concluded that identification and development of required human resources for nanotechnology is lagging behind investment in R&D. (Abicht et al, 2006)

Nanoforum and IoN have conducted an online survey of skills and training needs of industry in May 2007. The results have been published online mid 2007.

3. Response by European Education institutes

3.1. Academic education

Country	PhD 2004-2005	Short 2004-2005	MSc 2004-2005	Undergraduate 2004-2005	*English MSc 2007+*
International					*5*
Austria			2		*1*
Belgium			3		*1*
Bulgaria	1		2		
Czech Republic			3	2	
Denmark	2	13	3	3	*1*
Finland					*3*
France		2	18		*1*
Germany	4	5	13	5	*2*
Greece			1		
Hungary	1		1		
Ireland				1	
Israel	1		1		
Italy		2	2		*2*
Netherlands			2		*3*
Norway	5		0		
Poland	1		2	2	
Slovenia	1		1		*1*
Spain		2			
Sweden			2	2	*5*
Switzerland			4	3	*2*
Turkey			1		
UK	3	1	17	10	*19*
Total	**19**	**25**	**78**	**28**	***46***

Nano-education courses by country. Source: Nanoforum, 2005 and EuroIndiaNet, 2007

In academic year 2004-2005, Nanoforum found 19 PhD programmes in nanotechnology in the EU and associated states, in Norway, Germany, the UK, and Denmark; and in some other countries. In that year, 25 nanotechnology short courses were found, including thriteen in Denmark (all offered by iNano), five in Germany, and one or two in other countries. Nanoforum identified 78 secondary

(Masters) degree programmes including eighteen in France, seventeen in the UK and thirteen in Germany; and one to four in other countries. Nanoforum found 28 undergraduate nanotechnology programmes in the UK, Germany, Denmark, Switzerland, Czech Republic, Poland, Sweden and Ireland.

In 2007, Nanoforum published an analysis of three types of nano education: type A offers a limited supplement of short specialised modules to graduates or students. Type B consists of Master degree programmes, and type C are full nanoscience education programmes for undergraduates. The authors take a stance against type C. The report also includes additional information on nanotechnology higher education in Poland, Slovenia and Romania. (Kulik & Fidelus, 2007)

EuroIndiaNet (2007) identified 46 Nanotechnology Masters courses being offered in 2007 or later in the English language in Europe. Five of these courses are international, involving universities in several European countries. Almost half take place in the UK, one to five in Sweden, Finland, the Netherlands, Germany, Italy, Switzerland, Austria, Belgium, Denmark, France, and Slovenia. Of course many more programmes are held in the national language. Several short courses, summerschools and e-learning programmes were also listed. The results of Nanoforum and EuroIndiaNet are not comparable, because they measure different things. The Institute of Nanotechnology IoN has launched a Nanotechnology Masters Course Recognition Scheme during EuroNanoforum 2007 in Düsseldorf, 19-21 June. The aim is to allow industry and students to compare and assess the quality of European nanotechnology Masters Courses. (IoN, 2007)

3.2. Vocational training

EuroIndiaNet (2007) collected information on vocational training in nanotechnology in several European countries. The development of individual courses or study paths specialising in nanotechnology for technicians is clearly just beginning. Germany is most active in this respect. Different organisations including the isw Institute for Structural Policy and Economic Development and the FreQueNZ network are stimulating this development and the technology centre of the German Engineering Association VDI-TZ is centralising information on courses in an online database. Other initiatives for vocational courses in nanotechnology have been identified in Belgium, Denmark, The Netherlands, Switzerland and the UK.

3.3. India

About 12 Masters courses in nanotechnology were identified in India in 2006, but many more are being developed. The Indian Department of Science and Technology is funding the development of post graduate nanotechnology teaching programmes. There are also many PhD programmes and several short courses and summerschools. A significant number of scientists are active in nanotechnology in India, but there is a lack of trained engineers and technicians. In industry and at management level, there is a lack of awareness of the potential of nanotechnology. To address this, workshops and conferences are being organised. There is a need for more fellowships for students. (EuroIndiaNet, 2007)

4. Discussion

Nanosciences and nanotechnologies have until recently been mainly publicly funded areas of research. In 2005, worldwide total public and private investment was approximately €9.7 billion, including almost half from private sources. About €2.4 billion was spent in Europe, including a third from private sources, about $3.5 billion in the USA, including 54% from private sources, about €2.7 billion in Japan, including two thirds from private sources. Only recently is the worldwide private investment in nanotechnology R&D overtaking the public investment. European private investment is lagging

behind compared to the USA and Japan (Hullmann, 2006). The US National Nanotechnology Initiative, German competence networks of nanotechnologies and European Union Framework programme are key drivers of nanotechnology development on a global scale. The main rationale and incentive for education in nanosciences and engineering also originate from governments, EU and UN organisations. According to two European online surveys of opinions of people interested in nanotechnology development held in 2004 and 2005, public and private actors also see a need for educating the nanotechnology workforce. The exact demand for skills and knowledge from European industry has only been investigated quantitatively, mainly in Germany (Abicht et al, 2006).

The response from European higher education institutions to the expressed need for nano-education focuses mainly on Masters courses, but other forms of education including short courses, formal PhD programmes and undergraduate education programmes are also being offered. More recently, vocational training courses in nanotechnology are also being discussed and developed. Again, the drive appears to be top-down rather than in response to clear needs from industry. To conclude, the time is right for systematic investigation of the needs for nanotechnology education from employers.

European or international standards for good quality education in nanosciences and nanotechnology should be developed and initiatives taken for sharing best practices between professors and vocational trainers. The EU can stimulate this under the People programme in FP7 for university graduates funded by DG Research and the new Lifelong Learning programme funded by DG Education (2007-2013).

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