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in book on Nanotechnology: Risk Governance, Risk Assurance and Risk Transfer.

This is part of the Springer series Innovation, Technology and Knowledge Management – 15-20 pages. Abstract due asap, full draft chapter end of August.

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Nanotechnology educational gaps for industry and society

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Abstract

A recent study on the needs of employers in industry and other sectors for graduate employees who have received education in nanotechnology shows a mismatch between the existing offers at European universities and the real needs of the labour market. In particular, industry expects to hire employees with skills in nanosafety, regulation and environmental impact assessment within five years. However, universities appear to have difficulties incorporating these topics into their curricula. Here, results of our study are introduced. Moreover, the outlines of interdisciplinary model curricula spanning the bachelor, master, and PhD levels of academic education that can support efforts to address the mismatch between study contents and skills needed in the nanotechnologies job market and minimise its possible impact, are discussed.

1. Introduction

The risk governance of nanotechnologies that is the topic of this book can only have a chance to succeed if the professionals implementing it are well trained and possess the relevant knowledge and skills. Nowadays, many of these professionals have not come across nanotechnology in their education and struggle to find suitable courses or access to expertise to fill their knowledge gaps.

The community who need to deal with potential risks of nanotechnologies in their daily practice is a more diverse group than one might think. It includes managers and employees of companies and research organisations where nanomaterials and nanotechnologies are handled, and also government officials involved in regulating these materials and their applications, and promoting innovation (Malsch et al, 2015), as well as involved in transporting of nanomaterials and nano-containing products, in remediation of contaminated sites etc. The dialogue on risk governance and regulation engages an even more heterogeneous community including politicians, civil society organisations, industrial representatives, media and the general public (Malsch, 2014). In reality, all citizens, old and young, are already exposed to products incorporating nanomaterials and nanotechnologies, but most people are unaware of this.

On the other hand, the first generations of students who have come across nanotechnology in their curriculum have graduated and entered the labour market since around 2010. Universities all over the world are now offering nanotechnology courses at bachelor, masters and PhD level, either as fully interdisciplinary nanotechnology curricula or as a specialisation within a traditional discipline, such as nanophysics, nanochemistry, nanomaterials or nanobiology. This chapter presents recent findings on the current offering of nanotechnology education at secondary and tertiary levels. Furthermore, this offer is contrasted with the results from the surveys carried out among employers and students regarding their needs for nanotechnology expertise and job opportunities available for graduates with nanoskills.

2. Reaching out to new generations: nano at secondary schools

One of the main objectives of introducing nanosciences and technologies to the secondary school system is to invite students to learn and discuss scientific knowledge of social interest relative to nanomaterials (among others), allowing them to evaluate critically what they read in newspapers or see on TV from a more objective perspective. In this manner, it is expected to inspire more students to become interested in nanotechnology and other natural sciences and to pursue science, technology, engineering or mathematics courses at University. Since nanotechnology curricula are flexible, it is easier to let the teacher adjust allocation of hours to workshops, labs or discussions, compared to other classical disciplines. One key approach to nanotechnology is to expose students to the Ethical, Legal and Societal Aspects (ELSA) through discussion and debate. ELSA draws attention to the relevance of nanotechnology to all students and invites them to investigate further 'under the hood'. Taking this perspective of nanotechnology, participation of non-science and technology learning students is also achieved (Talesnik et al, 2013).

We have explored the state of the art of secondary education in nanotechnology in European Union Member and Associated States through an online survey carried out between April and July 2013. In total 36 science teachers answered it, from eight countries. They were approached through the European Schoolnet (EUN)[1], the Association of Secondary Teachers in Ireland (ASTI) and our own contacts.

In addition, we held in-depth interviews with ten leading persons from ministries of education and academia and several senior teachers. This semi-qualitative study demonstrates that the teaching of nanotechnology at secondary schools is in its infancy. Only few students are exposed to nanotechnology in their education, ranging between a few thousands in most countries, to 20% of all students in Ireland, and to all students (until aged 15/16) in the UK having at least some exposure to nanomaterials and their properties in KS3 and KS4 science curricula.[2] In all the countries investigated, several nanotechnology programmes implemented since 2008 were identified, yet most included no more than a few schools and the project ended within a year or two. It was expected that teachers would continue the nanotechnology teaching in schools by themselves, even though many projects reviewed here needed significant cooperation with universities and research centres. We found a great variety in the numbers of hours and ways of teaching sciences in general and nanotechnology in particular in the six countries that were the focus of more in depth case studies: Ireland, Spain, Austria, Italy, the Czech Republic and Israel. There appears to be little information about the requirements of universities and few contacts between schools and universities (Talesnik et al, 2013).

A subsequent study of best practices in nanotechnology education at the secondary school level covered twelve projects including EU funded projects (NanoYou and NanOpinion), initiatives of national (Spain, Austria) and regional governments (Baden Württemberg, Germany), an Israeli school network, academia (Italy, Ireland), industry (Czech Republic), a science museum (Germany) and a local initiative of an individual teacher (Germany). This semi-quantitative study was based on interviews with eleven key persons and an online questionnaire circulated among the teachers involved in the selected programmes, as well as internet sources and reports on the programmes. The selected programmes represent the best practice of teaching nanotechnology in secondary schools. Each programme achieved at least one of the following threshold requirements:

- Programmes that are widely implemented – In terms of the number of participants, the geographical area, etc.
- Comprehensiveness – How rich and innovative the programme was in terms of content, new teaching methods, etc.
- Involvement of the community, industry and academia – Whether there was any collaboration with different stakeholders in the school’s immediate surroundings.
- Award winners – Programmes, which were acknowledged through national or local awards.
- Growing programme – Programmes that grow every year, even if the initial phase has been concluded.

[1] European Schoolnet is a network of 31 European Ministries of Education, based in Brussels, Belgium

[2] Secondary education in the UK was not covered by our study. However, in the UK, there are some nanotechnology aspects in both Key stage 3 (11-13, 3 years) and Key stage 4 (14-16, 2 years up to and including GCSE exams) science curricula, with science being a compulsory subject for all students at these stages. Key stage 3 chemistry covers aspects of materials properties, looking at properties of ceramics, polymers and composites. Key stage 4 chemistry covers aspects of structure, bonding and properties of diamond, graphite, fullerenes and graphene.

We compared the programmes on six parameters in order to outline and compare the various profiles, strengths and weaknesses. They shared similarity in three of these parameters:

- Most programmes were compulsory. This suggests that relying on voluntary attempts does not reach the audience of secondary school students.
- Nine programmes made use of a virtual platform. However, virtual platforms were not found to have been used very much in practice. Virtual teaching methods could improve projects educationally and help to lower the cost of the activity (compared to a real lab).
- The programmes used more theoretical than hands-on pedagogical approaches and practices, suggesting that introducing hands-on activities to the classroom as a general practice has yet to be undertaken.

The projects greatly varied in the other three parameters:

- The degree of independence i.e. is the project taught as part of an existing subject or as an independent subject?
- The involvement of industry or academia.
- Community involvement varied but was generally scarce. Virtual teaching methods could broaden the discourse and reinforce the reported benefits of community involvement while also addressing hard to reach audiences.

In the framework of this book on risk governance, the aspect of community involvement is most relevant, because it shows how secondary schools may contribute to awareness raising about nanotechnology among the general public: In the Austrian programme “Sparkling Science”, the students presented their project findings to the local community. The programme offered by the Israeli school network ORT included one “Nano-day”, when parents and guests from the local community were invited to the school. The Swedish programme included an exhibition of students’ work that was open to the public. The Czech company Contipro offers lectures by University professors to and for the local community including students. The German Museum hosts an exhibition that is open to visitors including students. The projects undertaken by students of the individual teacher are submitted to national competitions and some of them have won these. No community involvement was undertaken in the following programmes: the EU projects NanoYou and NanOpinion, the Spanish curriculum for the first year of Bachillerato, the programme for high achieving gymnasium students in Baden-Württemberg, the Italian Nano-lab, or the Irish programme “Nano in my Life”.

To conclude, the best practices in NST education is compulsory and hands-on activities (experiments). In addition, virtual teaching (that is, teaching through videos, online-competitions, and so on) increased the attractiveness of science topics and improved the effect of education. The benefits of NST teaching in secondary schools comes in learning about new technologies at an early stage of their development. This provides opportunity to build a highly educated and aware public which is able to discuss and learn about scientific advancements.

3. The current offer of nanotechnology education at European universities

No comprehensive overview could be identified of all nanotechnology courses offered by European universities. Kiparissides and Kammona (2011) identified 27 bachelor courses in nanosciences and technologies, 106 MSc/PhD level courses and 5 other degree courses in Europe and 17 bachelors, 35 MSc/PhD and 25 other degree courses in North America. This gives an idea of the likely size of the present offer of such academic education in Europe also. However, this study is not focused on the quantity, but on the relevance of the current offer to the needs of the labour market outside academia and education.

University survey

From March until December 2013, we carried out an online survey among representatives of universities to collect information on the current offer of education in nanotechnology at European universities and the strategies to implement this.[3] 43 responses, including 35 from European respondents were received. This included six from Germany, four from Denmark, three each from Spain, Belgium, Switzerland and the Czech Republic, two each from Austria, France, Ireland and Israel, and one each from Norway, the UK, Turkey, Poland and Bulgaria.

The questionnaire included 29 questions on general information to identify the course, the programme details, the career of the graduates and the level of cooperation with industry. Ten responses covered BSc programmes, nineteen MSc programmes and six PhD programmes. Physics is included in 32 out of 35 curricula, chemistry and materials science in 27, Biology in 15, Biotechnology in 12, Electrical Engineering in 11 and Medicine in 9. Most BSc and MSc programmes produce ten to twenty graduates per year.

The skills and knowledge developed in the university programmes are included in figure 1. The most popular included subject is characterisation and metrology. Over 70% of the programmes cover nanoelectronics, nanostructures and composites, or nanocoatings and smart surfaces.

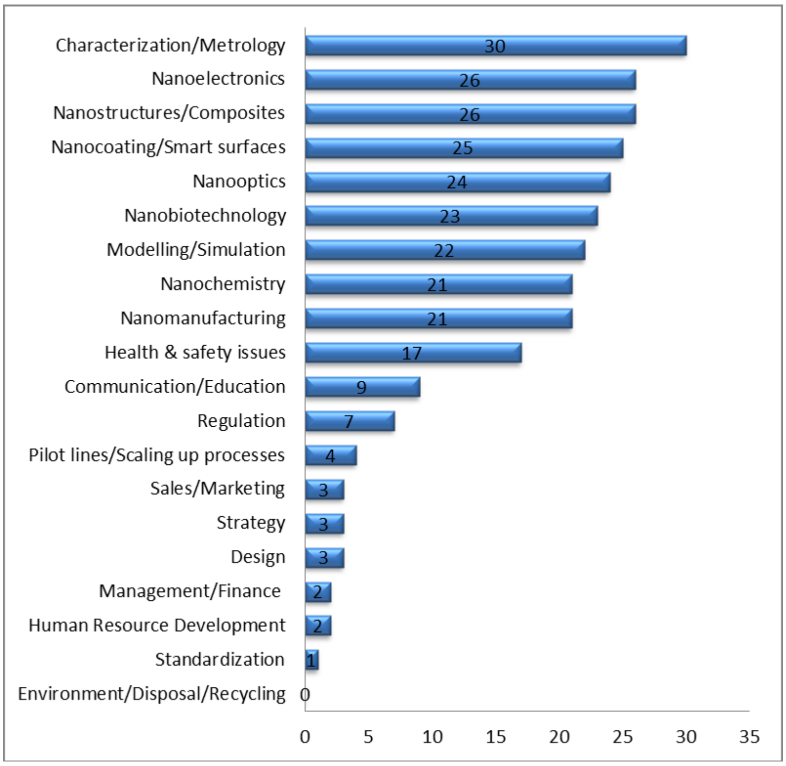

Figure 1: Main nanotechnology related skills and knowledge offered by the university programmes. Number of positive responses for the 35 respondents.

The skills and knowledge that are included in the programme which the university respondents considered would be required by industry are summarised in figure 2 below.

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[3] http://nanoeis.eu/university

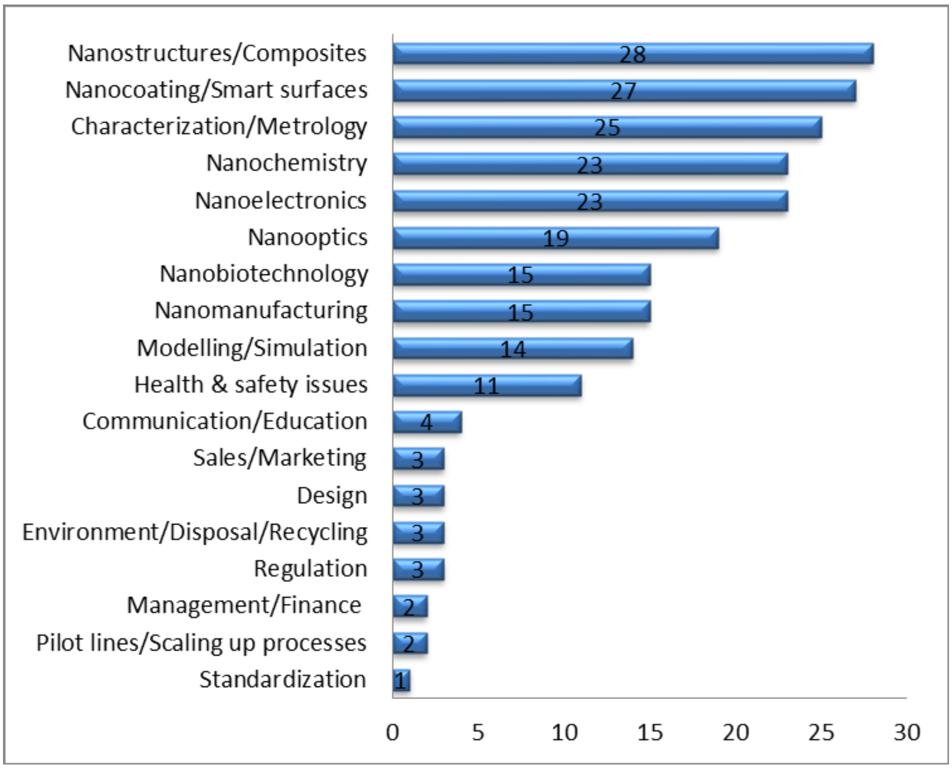

Figure 2: Re-ordering of the main nanotechnology related skills and knowledge offered by the universities according to the universities' perceptions of what is required by industry based on the same 35 responses as figure 1 above.

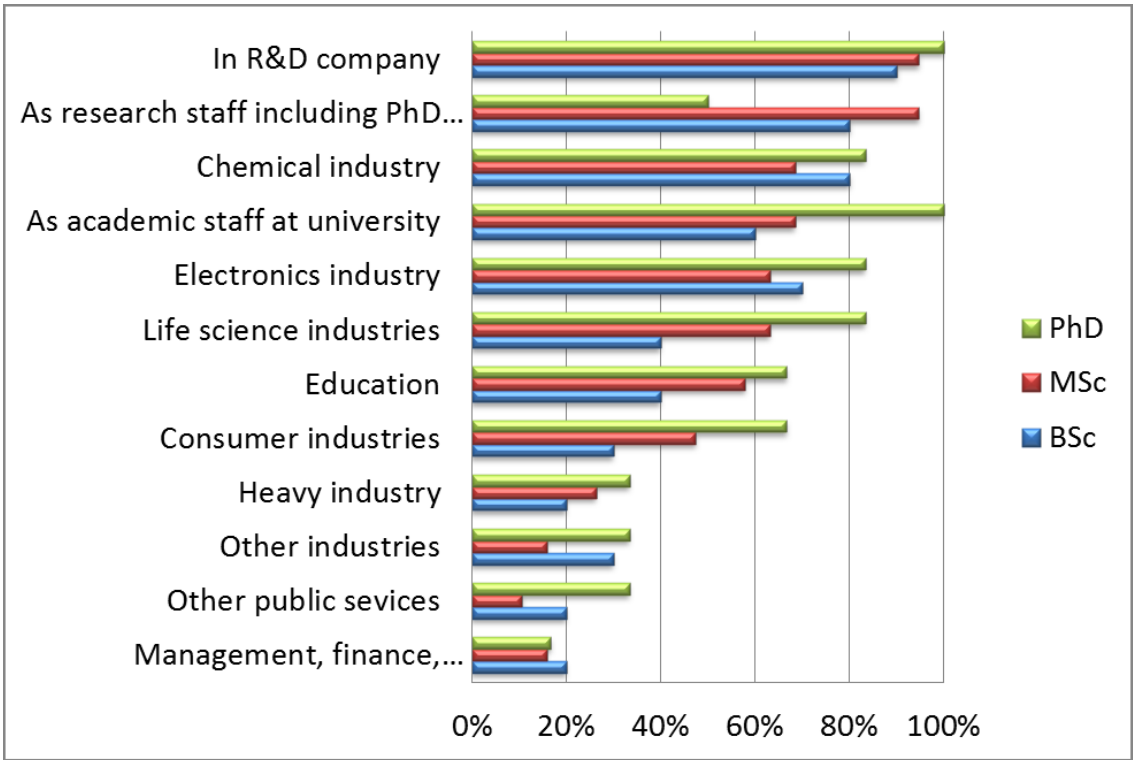

Figure 3: Career prospects per programme level. Note: Percentages do not total 100% because respondents could check all that apply.

All the respondents responsible for doctoral programmes indicate that career prospects for their graduates include R&D companies (companies that offer R&D services to industrial clients) and academic routes (figure 3). Generally, the respondents find that the career prospects are the broadest for the graduates of the doctoral programmes, with one significant exception: only half of the doctoral programmes indicated research staff as the targeted career. On the other hand, 95% of master programmes chose this option–, which included also the PhD studies. The real output figures for the surveyed courses indicate that 54% of graduates ended up in research, academia and education, 23% in industry and 14% in R&D companies.

We also investigated the indicators for a higher likelihood that graduates from a specific programme ended up in careers outside academia. The transfer of graduates of nanoscience and nanotechnology programmes to industry and R&D companies turns out to be most successful when the students participate in cooperation with the industry (e.g. via modules co-taught by industrial experts) or undergo industrial internship training as part of their studies. This factor was established by the present study as the most effective means of providing a productive start towards industrial carriers for graduates. Programmes that include courses taught by industrial experts train graduates that are three times more likely to find employment in R&D companies. Courses introduced to curricula in response to industrial demand increase threefold the flux of graduates to industry but reduce somewhat the number of graduates ending up in the R&D companies. Cooperation with industry in setting up the curriculum has a positive but quite limited effect on the transfer of the graduates to industry and R&D companies (Szafran et al. 2014b).

Case studies

In order to gain a better understanding of the factors that influence the relevance of the curricula to non-academic employers, we carried out a number of case studies at each of the three educational levels (BSc, MSc and PhD).

The BSc courses studied include four-year courses offered by Trinity College Dublin and Dublin Institute of Technology in Ireland, and three-year courses offered by the University of Basel in Switzerland, the iNANO centre of the University of Aarhus, Denmark, and Saarland University in Germany. The interdisciplinary character of the BSc courses is generally perceived as a strong point of the curricula. The representatives of the programmes, in their opinions given in the questionnaire, interviews as well as on the public web pages, indicated that the interdisciplinary character of the education at the first year of the studies is one of the possible factors to motivate the students to enlist on the BSc in Nanoscience and Nanotechnology. Students with a broad interest in natural sciences have an opportunity to study more than one subject, and decide on their specialisation at a later stage. The three year BSc is not considered sufficient to enter the industrial labour market, while the Irish four year curriculum with strong interaction with industry in the fourth year does qualify graduates for such jobs in a wide range of industries. Nevertheless, most graduates prefer to go for a higher degree. In most, but not all, of the BSc courses, direct interaction and in particular, internships are postponed to higher educational levels (e.g. final year or a 4 year programme). The Dublin Institute of Technology and Saarland University programmes emphasize industrial engagement: the former through a compulsory seven months industrial internship in the fourth year, and the latter through an eight week industrial internship before the start of the course. In some Swiss programmes the students visit companies using nanotechnology as a part of the regular programme. BSc theses in general have mostly a scientific character and are done at the university in one of the research laboratories. An option for the students to prepare the BSc thesis with an industrial or R&D company that is encountered in a part of programmes is certainly a practice that should be recommended. The students willingly use this opportunity if offered. In some cases (BSc by Saarland University for instance) more than half of the students choose to prepare a BSc thesis in cooperation between the university and an industrial company.

At MSc level, we studied national courses offered by iNANO (University of Aarhus) and the Technical University of Denmark, the Swiss Master in Nano and Micro Technology and the Spanish National School on Molecular Materials. We also included European Master programmes (Nanomat European Master programme, a Polish-French Master programme led by Univ. Katowice and Univ. Le Manse as well as a Danish-German programme by the Technical University of Denmark and the Technical University Munich), and Erasmus Mundus projects (Monabiphot by ENS Cachan, Master in Nanoscience).

Most of the respondents representing the studied master programmes agree that successful nanoscience and nanotechnology programmes require an environment composed of both scientific laboratories and industrial companies. We found two alternative ways of formation of such an environment. One is based on a formal structure of a consortium or a centre with an advisory board formed by scientists and industrial companies. The other approach is based on a natural synergy between research, experiment, industry and education. For the latter the cooperation with industry does not have to be centralised or formalised, but it is left to the researchers and their contacts with industry, the R&D departments in particular, to implement. Education is adapted to the changing needs of industry by researchers individually. Lecturers suggest new courses or changes in existing ones to their respective study committees. The two approaches (direct and formalised) seem complimentary and not contradictory.

The results of the analysis of the follow-up of the programmes (Szafran et al, 2014b) demonstrate that any form of cooperation with industry has a positive effect on the transfer of graduates to the industrial job market. The more direct in nature the contact of the student with industry is, the more positive the result. The necessary ingredient for effective direct contact is a real pre-existing cooperation of the academic scientists with industry that allows the students to participate in preparing their Master theses in collaboration with industry, or work as interns in the companies, or both. The evident recommendation for university level nanotechnology programmes in this context is: to ensure a successful career for your graduates in industrial nanotechnology an active cooperation with relevant local companies should start before launching a Master degree. A number of public R&D institutions within Europe play a catalytic role as centres of cooperation between the universities and industrial companies. The personnel of these centres combine scientific excellence with awareness of industrial and commercial applications, and their participation in education brings an extraordinary quality to the programmes.

Modules addressing market and commercial applications are largely missing from the nanotechnology programmes. This shortcoming can have a negative effect on the career of graduates in the context of start-up companies or management in particular. One of programmes that aim to fill this gap is the Master of Philosophy in Micro- and Nanotechnology Enterprise at the University of Cambridge that adopts part of the business management course and covers problems involved in the processes of discovery and exploitation. Training in business related modules is also present in Bachelor courses by Saarland University, TUD and NanoFar Erasmus Mundus.

At PhD level, we investigated two programmes. For the Erasmus Mundus Nanofar programme the cooperation with industry is based on a number of companies that are partners of the project, with all PhD students undertaking a mandatory two months internship in one of the partner companies. Some of the Nanofar courses are led by industrial experts (drug delivery systems for instance). The iNano centre in Aarhus organises as one of the options an industrial PhD in the form of a project undertaken by a student on a topic of common interest to the University and a private company. Funding is acquired from a central organisation external to both the company and the university. This course has a remarkably high output of graduates that are employed by R&D companies (about 50%) and industry (about 20%), with only 10% choosing to stay in academic research. This option is chosen by about 20% of the PhD graduates of all iNano programmes.

To conclude, best practice for university level teaching, and alignment with the European Commission Europe2020 vision to boost growth and jobs include the mission of the “New Skills for New Jobs” initiative which sets out to:

- Promote better anticipation of future skills needs
- Develop better matching between skills and labour market needs
- Bridge the gap between the worlds of education and work

The European Commission supports links between university and business at the European level through a series of initiatives. Closer links between business and higher education can:

- encourage the transfer and sharing of knowledge,
- create long-term partnerships and opportunities,
- drive innovation, entrepreneurship and creativity.

Closer cooperation with business helps universities develop curricula that are relevant and meet the needs of students and society. This helps give graduates the right skills and mind-sets for the jobs market.

There are many examples of successful cooperation between academia and industry in Europe. However, the level of co-operation varies considerably between different countries, universities and academic disciplines (Science-to-Business Marketing Research Centre, 2011).

4. Exploring the demand for employees with nanotechnology skills

In order to analyse the needs for nanotechnology skills and expertise in employees, both at the time of recruitment and afterwards, a specific survey was developed. A total of 67 industry representatives replies were received (Queipo et al. 2013). This online survey was carried out during first semester of 2013.

The answers came from 15 European countries, predominantly Portugal, Spain, Italy and Germany. A total of 61% of respondents worked in SMEs, 10% in spin-off companies, 19% in large industrial companies and 9% in industry associations. While 19% of companies were primarily active in manufacturing, 12% were predominantly active in each of nanotechnology or electronics. The companies whose main activity was in nanotechnology were mainly SMEs, and focused on production of nanomaterials or characterisation tools for applications such as textiles, health, environment etc. Other sectors are included in figure 4 below (Queipo et al. 2013).

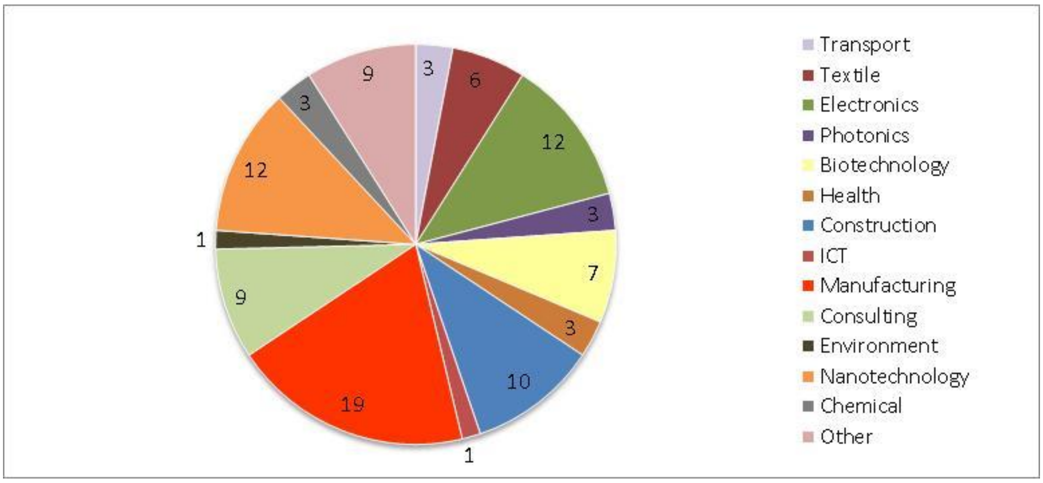

Figure 4: Classification of the companies (in %) responding to the NanoEIS education needs survey according to their main activity area.

Overall, 86.4% of the participating companies declared to have some knowledge in nanotechnology and 9.1% were planning to acquire such knowledge. While all spin-offs possessed this knowledge, 92% of large industry and 83% of SMEs had it. Around 80% of respondents were either users or producers of nanotechnology, including all spin-offs, 78% of SMEs and 70% of large companies. Companies using nanotechnology were mainly active in construction (16.2%), nanotechnology[4] (13.5%), manufacturing, biotechnology and electronics (all 10.8%). The main reasons for not using nanotechnology (15 companies) included: it is not necessary or not in the company's core business (53.3%, mainly consultancies), the lack of technology (26.7%), the lack of knowledge, price and the lack of expertise (6.7% each). In five years' time (i.e. by 2018), 71.4% of spin-offs expect that nanotechnology will bring them a competi-

[4] We did not specify the definition of nanotechnology, so this is according to the companies' own understanding of the term.

tive advantage. Half of the spin-offs expect new nanoenabled products or services, as do 37% of SMEs, 38.5% of large industry and 33.3% of industry associations. (See figure 5 below).

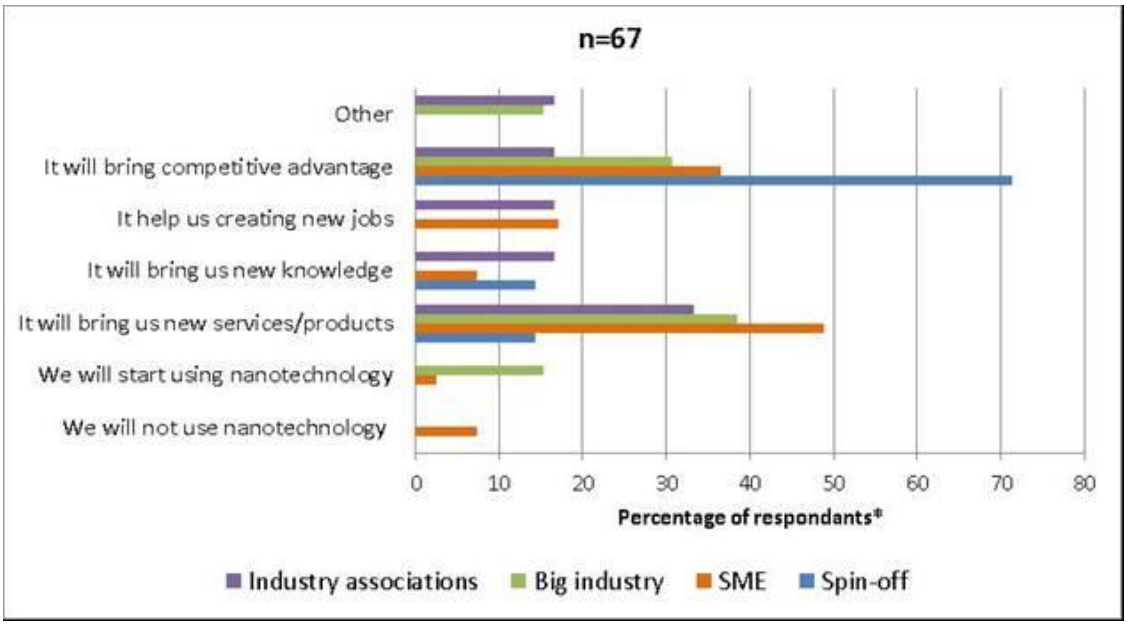

Figure 5: Companies expectations in 5 years' time with respect to nanotechnology *Note: Percentages do not always total 100% because respondents could check all that apply

Three quarters of the companies already had employees with nanorelated skills. This varied between 86% of spin-offs and 76% of SMEs, 70% for large industries and 83% of associations. Spin-offs, large industries and associations mainly employed staff at PhD or MSc level, while SMEs also employed staff with a BSc or vocational training background (see figure 6).

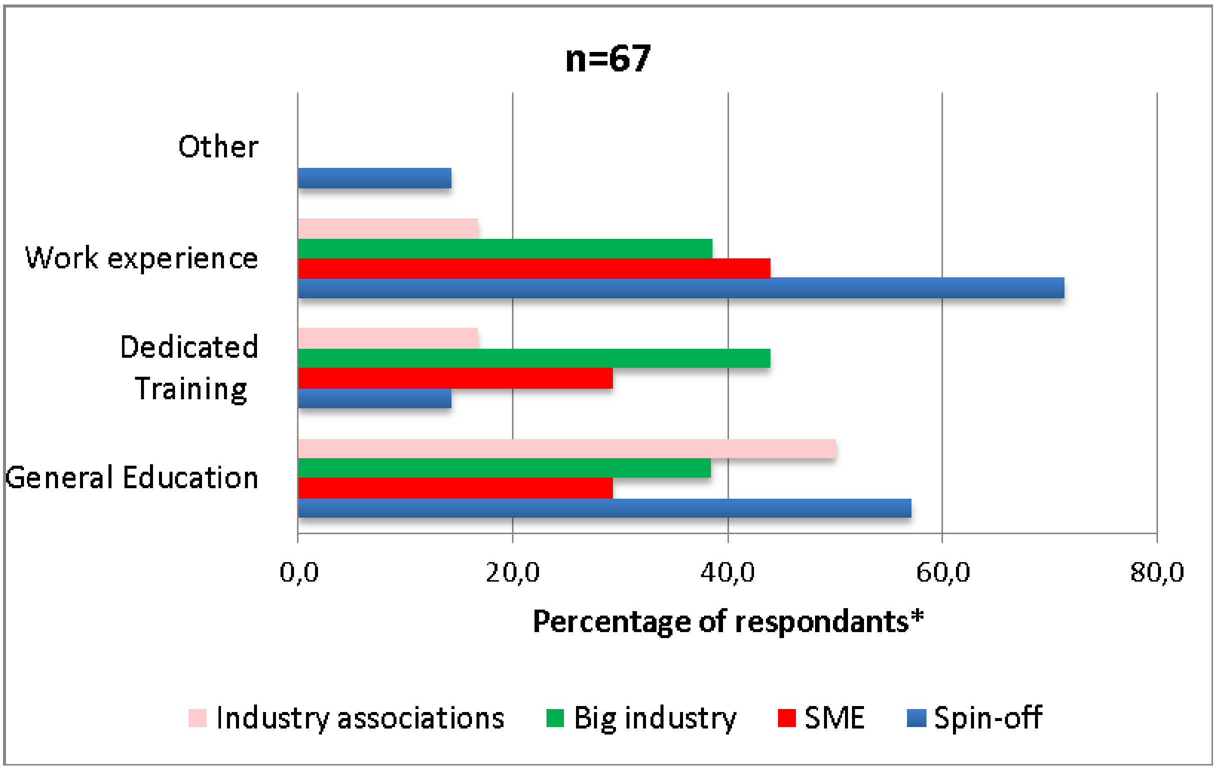

Figure 6: ways of acquiring nanotechnology skills and knowledge. *Note: Percentages do not always total 100% because respondents could check all that apply

Around half of the respondents do not intend to hire nanotechnology experts, especially spin-offs (71.4%) and large industries (70%). SMEs that already employ nanotechnology skilled workers are most likely to hire additional experts within one to three years (56% of SMEs). Out of the ten SMEs without nanoskilled workers, only two are planning to hire such experts. Those that hired nanotechnology qualified staff in the past, experienced the following problems:

- Scarcity of skilled staff with experience in technology transfer
- Lack of nanospecific knowledge
- Education in universities is too theoretical
- The lack of practical knowledge from schools and universities

The respondents ranked the nanotechnology skills they considered necessary now and in five years. This is compared to the current offer at universities in the section below. To acquire these skills, 58.2% of the respondents declared that they are willing to invest in nanotechnology specialised training. This is particularly relevant to SMEs and industry associations where percentages increase to 68% and 67% respectively. On the other hand, 77% of large industry will not be investing in training. 41.8% of the respondents declared that they are involved in education, especially SMEs with almost 58% and spin-offs with 41%. However, the way of involvement varies from giving lectures at universities to sponsoring scholarships. Examples are listed in table 1 below.

Type of employer	Ways of involvement
Spin-off	Provide opportunities to do research for MSc and PhD students
	Lectures (University Masters level) on nanotechnology (particularly nanofabrication and nanofluidics)
SME	Sector environment: Partnerships with Universities
	Industrial training on surface science and nanoparticle-based ma-

	terials
	Tours for University students
	Lectures at educational institutions on life sciences or in masters on Universities (engineering School)
Large industry	General support of education on chemistry, but not necessarily dealing with nanotechnology
	Professional trainings for end-users in the construction sector, but not dealing with nano
	Sponsoring PhD scholarships related to nanotechnology
	Organization of workshops
Associations	Promoting and supporting (by using National projects) Master and PhD tracks specifically oriented to Nanotechnology

Table 1: Ways of industry involvement in education by type of employer.

Comparing the industry needs with university offers

The competences most required by the industry are related to health and safety (risk) issues. These are covered by only half of the surveyed programmes. Environment, disposal and recycling has a ranking in the middle of the industry survey, but is not offered by any university participating in the survey. Universities rank nanoelectronics, nanostructures and composites, nanooptics, nanobiotechnology and modelling and simulation significantly higher than industry. On the other hand, industry respondents rank standardisation and regulation, pilot lines and scaling up processes and marketing and communication higher than universities. Thus, there is a clear disconnect that needs to be addressed as a matter of priority to ensure that those responsible for introducing new products to market have the necessary skills and knowledge.
Universities and industry respondents agree on the relevance of some other subjects: Characterisation and metrology ranks first in the university and second in the industry ranking. Nanocoatings and smart surfaces rank fourth and third respectively, while nanochemistry ranks eighth and fourth.

To conclude, universities should estimate industry needs on health and safety issues as well as on characterisation and metrology. On the other hand, the university respondents overestimate the needs of industry for skills in nanooptics as well as modelling /simulation.
In five years, industry respondents foresee a most pressing need for health and safety aspects, followed by regulation and standardisation and environment, disposal and recycling. There appears to be an urgent need to introduce these competences into educational programmes (Szafran et al, 2014).

Views of students and graduates

In parallel to the survey among university nanotechnology course providers, we also surveyed opinions of students and graduates on these courses between March and December 2013. We received 317 responses including 139 from Europe. The European respondents included 44 graduates and 95 students, 43 females and 96 males, 82 discussed MSc courses, 35 BSc and 22 PhD programmes. Relatively many came from Poland and Germany, followed by Belgium, Denmark, Spain and Switzerland. Fewer respondents came from Sweden, Italy, Macedonia, Lithuania, Israel, the Czech Republic, Finland, the Netherlands and Portugal. The sample contains mostly present or former students of programmes that involved physics (64%). Nearly half of the respondents (45%) declared that chemistry was present within their programme, with lower values for Electrical engineering (31.65%), Materials Science (35.25%) and Biology (21.6%).
The respondents were asked to indicate the acquired competences that they considered useful for their jobs. Nanostructures and composites is on the top of the students list. This is the third most available topic in the curricula and top of the list of useful skills and knowledge as declared by the academic respondents. On the other hand, these topics are in the middle of the list of the industrial needs. Nanomanufacturing, which is the second on the list indicated by students is available in many of the curricula and is in the first half of the industry needs ranking. Quite similar is the relation of the positions of nanochemistry on the lists. Nanoelec-

tronics and nanobiotechnology are high on both the students and academia lists, although on lower positions in the industry needs ranking.
Health and safety issues, which is on top of the industry needs, was declared by only 6% of the students answers, although half of the academic programmes declared covering this topic in their curriculum. None of the students declared that the environment / disposal and recycling topics were covered by their studies. This is consistent with the data provided by universities.

Questions on the competences that the students find missing in their curricula were also included. The students and graduates perceive that the most needed but absent topic is the environment/disposal and recycling issues, in perfect agreement with the data declared separately by industry and academia. Management and finance goes second on the missing list. For the rest, the answers are quite evenly distributed. Nanostructures and composites – found useful but already widely present in the curricula are found missing by only 2% of the answering students and graduates.
Students and graduates were asked which changes should be introduced to the programmes in order to increase the industrial employability. By far the most frequently indicated response was internships at industrial companies and projects. The second change indicated by the students is development of the curriculum in collaboration with industry. This collaboration is frequently declared by the university programmes, but without a very strong effect on the results of education. Quite remarkably, as many as 9% of the answers by students and graduates indicated that a stronger transfer of general knowledge (e.g. project management, presentation skills etc.) can enhance their chances for an industrial career. This is the least popular answer, but still the percentage seems surprisingly high (Szafran et al, 2014).

5. Proposed model curricula

Our surveys showed a mismatch between the existing educational offers and the expectations of potential employers in regards to nanotechnology graduates. As demand for products that incorporate nanotechnology rises, educational institutes come under increasing pressure to prepare a skilled, nano-literate workforce. For a long period of time, most nanotechnology education had been occurring informally in lab environments, as well as through elective courses and not within formal degree programs. It is thus widely accepted that the role of tertiary educational systems should be reinforced. In particular, in order to achieve this goal, the existing training programs should be improved and revised to take into consideration the industrial point of view and match the available training offers with the current and future job requirements of European industry. Surveys, such as that carried out here, should be performed periodically (e.g. every 5 years) to re-assess current and future needs and allow university curricula to evolve continuously to meet the needs of society and industry.

The modern nanotechnology curricula, which are proposed herein, are mostly based on the industry expectations and the outcomes of the surveys done among universities representatives, nanotechnology graduates and students and reflect the emerging nature of nanotechnology itself. It is generally accepted that nanoscience and nanotechnology are interdisciplinary at their very cores and that is why the education requires basic competences in several traditional disciplines. As such, physics, chemistry, materials science, and biology are the most often evoked. On the one hand, conventional educational disciplines and training courses can constrain the introduction of the interdisciplinary approach needed by nanotechnology. It is clearly necessary to overcome such barriers in order to develop the worker skills as demanded by industry. On the other hand, the range of the topics related to the nanotechnology is too wide to be covered in detail in a single universal curriculum, calling for specialization already at the earliest stages of the university education, or the more traditional model of a degree in a core subject followed by nano-specialisation at MSc. or PhD level.

The proposed nanotechnology curriculum is designed for a typical Bologna scheme of education, nowadays adopted by most European countries. The students get specialized in nanotechnology related topics gradually during their 1st degree of studies (Bachelor or Engineering – during 3 years), 2nd degree

(Master - during 2 years), and optionally during their 3rd degree (Doctoral Studies – during 4 years). The emphasis is put on the incorporation of the key skills and knowledge demanded by industry at each level of the education. In such a way, they are not restricted to graduates of higher degrees. Therefore, the courses covering health and safety issues; regulation and standardization; environment, disposal, and recycling; characterization techniques; and “soft” skills are distributed throughout the whole period of studies. Last but not least, the involvement of nanotechnology industry in teaching through shaping curricula and offering internships is emphasized, as one of the factors facilitating the smooth transition between academia and industry.

In the following, the curricula for each educational level will be presented in more detail with the emphasis on building up the skills and abilities necessary to deal with the risk assessment and risk governance in nanotechnology.

Model curriculum for 1st degree studies in Nanotechnology

The presented model curriculum is designed to fit 3 year (6 semester) programmes ending with Bachelor degree diploma work. The graduates of the 1st degree in Nanotechnology are intended to continue their studies for the 2nd degree of studies, or otherwise to find employment on the local job market. They will possess the professional skills, necessary to:

- work in laboratories specializing in nanomaterials synthesis development[5]
- operate laboratory apparatus and equipment
- investigate basic properties of this type of materials
- define usefulness of nanomaterials for specific practical purposes
- develop methods of synthesis of new nanomaterials
- search for information in the field of nanotechnology and related areas

Further, they will possesses general competencies which allow them to:

- work in teams and task groups
- solve simple engineering problems in the field of nanotechnology
- produce reports on issues connected with nanotechnology
- organize work at his/her workplace (e.g. research laboratory or department)
- follow occupational safety requirements
- make use of modern means of communication
- communicate in a foreign language

The starting semesters of BSc courses should include compulsory intensive courses in the elementary foundations of traditional disciplines: physics and chemistry as well as biology and material science supported by a strong training in mathematics, statistics and computer science. It is proposed that the available modules already existing at universities for the classical subjects (chemistry, physics, and biology) are included in the curriculum at the bachelor level, as their value is checked and tested already over a long time. The elements of nanoscience and nanotechnology are intensified in later years, when (often partly) elective courses are introduced. The general education in nanotechnology should be commenced by the introductory lecture on nanotechnology, followed by the more specialized courses, such as: bio-nanotechnology, nanobiology, methods of nanomaterials characterization, nanoparticles and environment, metallic / polymeric / ceramic / cosmetic nanomaterials. The choice of electives naturally depends on the overall specialization of the specific degree program and is dictated by the profile of the university.

[5] this includes basic understanding of issues of safe handling, disposal and related legislation.....

Within the modified curriculum we propose the following non-standard courses during the 1st degree of studies:

- Philosophy/ethics of (nano)science (1st semester)
- Safety at work (1st semester, 3rd semester)
- Cradle-to-cradle product design (2nd semester)
- Information retrieval (2nd semester)
- EU regulations regarding nanomaterials (4th semester)
- Recycling of nanomaterials (5th semester)
- Regulation, standardization, and management (6th semester)
- Public speaking – communication to a wide audience (6th semester)

An integral part of any Nanotechnology program should be the industrial internship, which will enable mutual contacts between nanotechnology students and their potential employers, planned for the 5th semester of the Bachelor degree. Towards the end of the 1st degree studies, the student gets an opportunity to specialize in one of the many possible directions, in the BSc thesis in particular. In Europe, students usually continue their studies in the 2nd degree program, to be fully qualified for the modern job market.

The proposed 1st degree study program should yield a graduate, who will be prepared to assess the main risk factors connected with new products containing nanomaterials, or produced with the use of nanotechnology. This is believed to be the first step towards training in risk governance tasks in future employment.

Model curriculum for 2nd degree studies in Nanotechnology

This level of education in nanotechnology is designed to fit 2 years (4 semesters) and to end with a Master degree diploma work. The graduate of the Master degree in Nanotechnology is intended to be well qualified to work in national/international companies and research institutions, owing to experience gained during the studies and preparation of the MSc thesis, or in a consultancy or regulation establishment as a specialist in nanotechnology and/or nanoscience. The graduates can continue their education via third cycle studies.

The M.Sc. in Nanotechnology graduates will be qualified to work in positions, which require the following professional skills:

- the ability to design nanomaterials with specific properties useful in different areas, e.g. in medicine
- the ability to design, investigate and develop methods of synthesis of nanomaterials
- the ability to develop and plan selection of research methods appropriate for the intended goal
- to supervise technological processes carried out in chemical industry connected with nanotechnology
- the ability to carry out independent investigation of nanomaterials
- the ability to discuss technical and scientific issues connected with nanotechnology

The 2nd degree graduates will possess additional competencies:

- the ability to work in a group and to organize their work
- the ability to use a foreign language
- the ability to define priorities and manage time
- other abilities acquired during research and development projects in their home countries and abroad

In the course of the 2nd degree studies, the student is introduced to specific topics of nanotechnology.

The specialized knowledge is built on the basis of the introductory, background knowledge acquired during the 1st degree courses. It is advised to further augment the knowledge in specific areas, which are relevant for nanoscience, such as physics, chemistry, and biology of low-dimensional systems. Here, by contrast, more time is reserved for nanotechnology-oriented subjects, such as design of nanomaterials (computer-based methods and preparation techniques), advanced methods of nanomaterials characterization, and instrumental analysis of nanomaterials. All these should be supplemented by elective courses, reflecting the profile and specialization of the Master program. Similar to the 1st degree, students are delegated for industry internships, to tighten their contacts with industry environment and to confront their skills and knowledge with their future employers' demands.

Within the 2nd degree in Nanotechnology, it seems advisable to further develop skills and gain knowledge, which are identified of high relevance for the job market. As such, the following obligatory trainings are offered:

- Communication through modern media (1st semester)
- Safety and clean-room good practices (1st semester)
- Regulations: quality management (1st semester)
- Nanoparticles and environment (1st semester)
- Safety at work project (2nd semester)
- Communication with media (2nd semester)
- Life-cycle of nanoproducts (2nd semester)
- Responsible research in innovation (3rd semester)
- Entrepreneurship and communication with customers (3rd semester)
- Communication to a scientific audience (3rd semester)
- Patent law and intellectual property (4th semester)
- Strategy planning in science and business (4th semester)

Following the outcome from our surveys on industry needs, a big effort is devoted to the courses covering safety training, the relation between nanoproducts and the environment, cradle-to-cradle product design, and responsible research and innovation. These will result in an increased awareness of the possible risks connected with the new products incorporating nanomaterials and / or fabricated with the use of nanotechnology. The graduates will be equipped with tools to evaluate the levels of risks and their probabilities. Likewise, the possible solutions to overcome potential problems will be discussed, if possible on the examples from the industrial practice. Moreover, intensive training in communication throughout the curricula is planned. The graduates will have the opportunity to learn how to communicate technical issues to both specialists and non-specialists. The means of communication will include traditional media, such as newspapers, radio and TV, as well as internet with web2.0 tools. It is envisaged that these skills will facilitate better understanding between the producers of nanoproducts, their customers, and society in general. Further, he / she will be given background information of social and ethical issues of new nanotechnology applications through a course in philosophy and ethics and patent law and intellectual properties. These altogether will add to the increased awareness of different aspects of such an emerging area as nanotechnology.

Model curriculum for 3rd degree studies in Nanotechnology

The Ph.D. studies in Nanotechnology are designed to fit 4 years (8 semesters) leading to obtaining the Ph.D. degree. In the course of their 3rd degree studies the student specializes in a specific topic of nanotechnology. Their expertise increases and the holder of the Ph.D. diploma will have a considerable expertise in a particular aspect of nanotechnology. They will be well qualified to work in international companies and research institutions.

The graduate of the 3rd degree studies will be highly qualified to work in positions, which require the following professional skills and knowledge:

- Ability to conduct independent research projects requiring e.g. design of nanomaterials with specific properties useful in different areas; design, investigation and development of methods of synthesis of nanomaterials; characterization of the nanomaterials; testing of the toxicology/ecotoxicology of the produced nanomaterials, etc.
- Ability to develop and plan selection of research methods appropriate for the intended goal

The Ph.D. graduates will possess the following additional competencies:

- the ability to communicate their results to professionals and non-professionals
- the ability to document their work
- the ability to use a foreign language
- the ability to define priorities and manage time (their own and others)
- knowledge of ethical and legal aspects of their work
- other abilities acquired during research and development projects in their countries and abroad

The PhD curriculum is least formalized, since PhD curricula take high levels of specializations into account, so a common model curriculum is not as relevant here as it appears to be in the 1st and 2nd degrees of studies.

It comprises the introductory lecture on nanotechnology, with the objective to give the students knowledge of the basic concepts and definitions in the field of nanotechnology, the most important properties of nano-objects, selected preparation methods of nanoparticles, and selected applications. Such a general course should be supplemented by the elective courses, whose role would be to deepen a certain area of knowledge, and their choice should be left to the Ph.D. student and his or her supervisor. It is advisable that the work done by the Ph.D. student should be enriched either by an industrial internship or by a scientific exchange. An essential part of the Ph.D. program should be devoted to the training in soft skills. As such, at the Ph.D. level the following is suggested:

- Communication and presentation
- Communication to non-professionals
- Science and the media
- Information retrieval
- Exploitation and commercialization of research
- Entrepreneurship
- Project management
- Social media in/for science

All these will contribute to the education of the nanotechnology specialist, who will be in a position to identify and evaluate risks connected with emerging nanotechnology issues, and will be ready for risk governance tasks. An important part of such a training will be given during the course on project management, as risk evaluation and governance will constitute its essential part. Further, due to the compulsory training in communication to the wide audience, they will be prepared for public engagement through e.g. participation in consultancy boards, policy making bodies, etc.

6. Conclusions

We have investigated the current mismatch between the offer of secondary and higher education in nanotechnology in Europe and the needs of the labour market. A remarkable finding is that employers in industry foresee a need for training in health and safety aspects of nanomaterials, followed by regulation and standardisation and environment, disposal and recycling aspects. Similar needs were mentioned in interviews with non-industrial employers (reported in Malsch, 2014) and by students themselves on the skills they are most lacking in their current roles. In the current offer by universities, these topics are hardly addressed. While many university professors demonstrate awareness of these gaps, it proves difficult to adapt the already full curricula and incorporate these topics at the expense of other more traditional subjects. The model curriculum proposed in this chapter may inspire discussion about reorganisation of current or setting up of new curricula. Their modular organisation could also be useful for picking short courses that target training needs of employees in industry and other sectors dealing with nanotechnology.

Placing our chapter in the wider scope of this book on risk governance, risk assurance and risk transfer, we reflect on the strategic importance of interdisciplinary education in nanotechnology to further those goals. First, experiments with nanotechnology in secondary education show that these can help raise awareness of the potential benefits and risks among the new generation as well as their parents and the wider community. The main bottleneck is the limited outreach and *ad hoc* character of the experiments that have been carried out so far, which limits their potential to be embedded and sustained within schools. Standardisation and dissemination of best practices in secondary education in nanotechnology may be improved by making available practical materials through the European platform Scientix. This should stimulate more democratic decision making on risk governance of nanotechnology as it enhances the capacity of non-experts to form their opinion on these issues, and raises public awareness of the issues more generally.

Secondly, responsible risk governance of nanotechnologies leans heavily on the cooperation of well-trained nanotechnology experts in industry, government and civil society organisations. This calls for integrating courses on health and safety aspects of nanomaterials, followed by regulation, standardisation and aspects of environmental impact assessment and disposal and recycling considerations into the current nanotechnology curriculum within five years. In addition, tailor made short courses and other forms of training on the job should be made available on short notice to professionals overseeing risk governance of nanotechnology.

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