EU 7th FRAMEWORK PROGRAMME

Call FP7-NMP-2012-CSA-6

NanoEIS

Nanotechnology education for industry and society

NMP4-SA-2012-319054

Deliverable title: Dissemination of main outcomes to scientific and educational community and general public

Deliverable number: D6.3

Work Package number: 6

Task number: 6.3

WP leader: MTV

Task leader: MTV

Lead beneficiary for this document: MTV

Delivery date (project month): M36

Actual delivery date (project month): M36

The project NanoEIS receives funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 319054.

Document Control Page

Deliverable Title	Dissemination of main outcomes to scientific and educational community and general pub-lic
Author (writer, short partner name)	Ineke Malsch, MTV
Publisher (e.g. journal publisher or the consortium)	Consortium
Contributors (co-authors with participant short name)	-
Nature (peer-reviewed article, report, website, prototype, etc.)	Report
Creation date	11.09.2015
Version number	3
Version date	12.10.2015
Last modified by (person and organisation name)	Ineke Malsch, MTV
Rights (e.g. IPR, copyright, such as copyright "NanoEIS consortium")	Copyright "NanoEIS consortium"
Dissemination level	☐ internal ☒ public ☐ restricted
Review status	Where applicable: ☒ Draft ☒ WP leader accepted ☒ Coordinator accepted ☐ Accepted for publication ☐ Date of publication
Action requested	☐ to be revised by Partners involved in the preparation of the document ☐ to be revised by all partners ☐ for approval by the WP leader ☒ for approval by the Project Coordinator
Requested deadline	30.10.2015

The present document constitutes Deliverable D6.3 prepared in the framework of the project entitled “Nanotechnology education for industry and society” (Project Acronym: NanoEIS; Contract No.: NMP4-SA-2012-319054).

Revision history

Version	Date	Modified by	Comments
1	11.09.2015	Ineke Malsch, MTV	First draft
1-1	14.09.2015	Albert Duschl, PLUS	Overall comments
1-2	14.09.2015	Ineke Malsch	Add annex 3: discussion education session EURONANOFORUM 2015
2	14.10.2015	Ineke Malsch	Incorporate comments by Albert Duschl, add annex 4, finalise draft text
3	14.10.2015	Albert Duschl	Accepted version

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1. Introduction

This document presents the conclusions for the general public of the main outcomes of the NanoEIS project on Nanotechnology Education for Industry and Society. The objectives of the tasks in the NanoEIS project presented in this report are:

- To optimize the exploitation of the project results, in particular ensuring sustainable exploitation beyond the lifetime of the project by integrating key outcomes in ongoing efforts and by providing continuous full accessibility of web-based elements
- To develop and communicate specific recommendation pertaining to the different stakeholders
- To document in detail the relation between education programmes and the different employers, which enables an analysis of strengths and weaknesses in the present education landscape
- To identify best practice examples on many levels, and to identify factors which make some approaches successful

The report summarises the main findings and recommendations from the following two reports (in chapter 2):

- Report on recommendations for secondary schools (D6.1)
- Report on recommendations for universities (nanotechnology education and lifelong learning) (D6.2)

In chapter 3, the main outcomes of discussions at stakeholder workshops held during the project are incorporated. Chapter 4 presents the main conclusions and recommendations for the general public. The annexes include the reports of the stakeholder workshops in anonymised form.

2. Summary of recommendations

The project resulted in recommendations for nanoeducation at the secondary school level and at the level of universities. Both sets are extensively argued and presented in other reports. The recommendations for secondary schools are included in D6.1. The recommendations on nanotechnology education and lifelong learning offered by universities are included in D6.2. They are summarised here.

2.1 Recommendations for secondary schools

The rationale for incorporating nanosciences and nanotechnologies (nanotechnology for short) in secondary school education (specifically for 14-18 year old students) is twofold. Firstly, secondary schools offer a suitable entrance point to raising awareness of nanotechnology among the general public. This is necessary because nanotechnology is a pervasive technology that is increasingly applied in a wide range of products. Workers, consumers and the environment are exposed to nanomaterials and nanotechnologies. Democratic decision making on how to foster and regulate the technology depends on such public awareness. Secondly, as an interdisciplinary subject that touches upon all Science, Technology, Engineering and Mathematics (STEM) subjects as well as societal and ethical aspects, nanotechnology is a very attractive way to interest young people in studying STEM subjects in university.

That said, we recommend developing teaching materials for 60 hours of teaching at secondary schools. In addition, teachers should be trained and secondary schools should be accredited in nanoscience and nanotechnology studies according to European accreditation standards. Good quality education requires access of the students to hands on training in regional labs that are equipped for nanotechnology experiments. Teachers' training centres must also have these facilities, and be coordinated in a European platform. The implementation of this proposal depends on the active engagement of Ministries of Education, the EU, industry, universities and science centres.

2.2 Recommendations for universities

By 2011, universities in 17 European countries were offering at least 138 nanotechnology curricula at Bachelor, Masters or PhD level (Kiparissidis, 2011). Other universities have also been developing such curricula since then. They are faced with two problems: the recruitment of students and the relevance of their education to the ever changing needs of the industrial and non-industrial labour market for graduates.

The NanoEIS project has investigated these aspects and proposes the following recommendations. The recruitment of students can be improved by more intensive cooperation with secondary schools in the region offering nanotechnology education. In addition to teaching traditional academic disciplines, universities should incorporate health, safety, regulation, standardisation, environmental impact and sustainability as obligatory courses, required by employers. Professors and lecturers responsible for nanotechnology curricula may incorporate one or more modules from the model curricula at Bachelor, Masters and PhD level developed in the NanoEIS project. Direct industrial involvement in teaching is essential for improving the numbers of graduates that find jobs in R&D and industry outside academia. From early on, students should be trained in communication to non-experts about their research.

3. Input from stakeholder workshops

Participants in two stakeholder workshops and a webinar and the audience attending a presentation of NanoEIS during the EuroNanoForum 2015 conference commented on the main findings and recommendations. Remarkable input from these events is summarised below. Reports on each event are included in the annexes for reasons of transparency.

3.1 Comments regarding sustainable exploitation of project results

A key issue for NanoEIS is to optimize the exploitation of the project results, in particular ensuring sustainable exploitation beyond the lifetime of the project by integrating key outcomes in ongoing efforts and by providing continuous full accessibility of web-based elements. The NanoEIS strategy foresees dissemination of results via different routes including Nanofutures association, the partners and direct contacts with universities. At European level in Nanofutures, the development of an education roadmap is foreseen that integrates company-specific skills with more general skills to understand the whole value chain and industrial ecosystem where nano-companies operate. This education roadmap should be linked to the Nanofutures product roadmap, according to its president Dr Paolo Matteazzi.

Participants in the first stakeholder workshop in the Netherlands recommended to establish direct contacts with universities offering nanoeducation (including SAXION University of Applied Science, TU Delft, and the MESA+ centre for nanotechnology at the University of Twente). During the course of the project, contacts have indeed been made with these universities, informing them about the project. The final results of NanoEIS will also be communicated to them after the end of the project.

Contacts with the Topsectors that have developed Human Capital Agenda's, in particular the Topsector High Tech Systems and Materials including nanotechnology are also recommended. NanoEIS modules could be offered for integration into the curricula of those universities. There is also a top-talent programme COAST (Comprehensive Analytical Science & Technology), that could be interested. This trains top students from applied sciences together with companies. During the NanoEIS project, contacts have been made with the person responsible for the Human Capital Agenda for HTSM. It appears that this agenda is targeting industrial employer involvement in STEM education more in general, not specifically nanotechnology.

For secondary schools, ministries of education have been contacted by NanoEIS, recommending to them to incorporate the teaching module on nanotechnology presented in chapter 2. Dutch participants suggested that there could be opportunities for nanotechnology modules in the interdisciplinary course "Natuur, Leven en Technologie" (Nature, Life and Technology) that is part of the curriculum at secondary schools. This may be explored in the future.

3.2 Comments targeting specific stakeholders

NanoEIS partners have developed and communicated specific recommendations to stakeholders responsible for the curriculum at secondary schools and at universities, as presented in chapter 2. In addition, the engaged stakeholders mentioned other opportunities as summarised below.

3.2.1 Recommendations for universities

The NanoEIS model curriculum is proposed to universities as an example they can use to improve their education. Draft versions of the curriculum have been presented to stakeholders during the project. Suggestions for improvement of the NanoEIS curriculum included both adding additional modules and more strategic comments. Suggestions for additional modules included project management, entrepreneurial skills, synthesis methods of new nanomaterials, awareness of EHS aspects to all nanotech students and nanoregulation.

More strategic comments included the following. The expected skills for Bachelors were considered too demanding, most jobs foreseen in the NanoEIS curriculum currently require an MSc. In order to target industrial jobs, the curriculum could be divided in three strands: R&D jobs in industry, setting up a start-up company, and sales jobs in industry. The NanoEIS curriculum could furthermore learn from experience with interdisciplinary Science for Society curricula at Dutch universities since the 1970s. In addition, the NanoEIS curriculum and the Dutch SAXION-MESA+ curriculum (under development) may both benefit from exchanging ideas. Outside Europe there is also interest in exchanging best practices in nanotechnology education and in developing online lectures in different languages.

On a more general level, some participants complained that universities are rewarded for enrolling as many students as possible, caring less about the level of the student. It may be better for university administration and government departments to steer more on output of graduates than on enrolment.

Changing the curriculum

A recurrent issue in the discussions with stakeholders touched on the feasibility of changing the university curriculum. The adoption of the model curriculum proposed by NanoEIS is expected to take 2-3 years and must be adapted to local requirements that are different in each (EU) country. Several participants had experienced a conservative attitude among university lecturers who were reluctant to change their lectures or curriculum. This may be different in universities of applied science that are more oriented towards the industrial needs. In academic universities, financial incentives imposed by the university administration may also stimulate changes. Currently, most academics are not financially or career-wise rewarded for changing their lectures.

Nanospecialists or disciplinary scientists with nanoskills?

Is industry better off with nanospecialists or with disciplinary scientists who have followed some nanotechnology courses? If you have a nanotechnology degree, you know a bit of all aspects, but you are not a specialist in anything. In the UK, non-specialised nanogeneralists are preferred at BSc level, who must subsequently specialise at the MSc level.

3.2.2 Recommendations for industry

According to Dutch participants, further study is needed to establish a realistic estimate of the job market for nanotechnology graduates, in particular for Bachelors. In the experience of some participants, most current jobs are fulfilled by Master graduates and physicists and chemists with nanoskills rather than nanospecialists, and there is no current recruitment problem in industry. In five years more demand for nano-BScs and MScs is expected, especially in start-ups that may then be booming. Participants in the webinar suggested that industry representatives could introduce real life cases in the university education, to make the curriculum more relevant to industry needs.

3.2.3 Recommendations for students

NanoEIS has not made explicit recommendations for students. The discussion with stakeholders in the Netherlands suggests that this may be a good choice, because there are still considerable national differences in organisation and culture of the education system, that make it difficult to identify good practices that are relevant for all European students.

3.2.4 Recommendations for the general public

While participants in the workshop in the Netherlands agreed that all citizens should have a basic awareness and knowledge about the pervasive nanotechnologies in society, opinions differed on how this should be taught: at secondary schools as discussed in chapter 2, through nanotechnology minors in other curricula at universities, or in the form of lifelong learning courses that could be offered by commercial training.

3.3 Relations between education programmes and employers

NanoEIS has made an effort to document in detail the relation between education programmes and the different employers, which enables an analysis of strengths and weaknesses in the present education landscape in surveys and case studies reported separately in the deliverables available on the website. Participants in discussions with stakeholders disagreed among each other on several aspects of the preferred relationship between education programmes and employers. This did not lead to shared conclusions. The main issues are highlighted here.

3.3.1 Teaching soft skills versus learning on the job

Some participants have good experiences in interdisciplinary (including several natural sciences) or transdisciplinary (including natural and social sciences) education. With hindsight, others missed training in soft skills including management, communication, internships and EHS aspects. Contrary to these views, some participants stressed that the time for most BSc programmes is too limited to include those skills, that will in any case be trained on the job after graduation or could be offered as short lifelong learning courses after graduation. Furthermore, companies may prefer to offer training on proprietary information in house to their own employees.

3.3.2 Profit or responsible innovation?

Especially during the discussion in Poland, the issue of the mismatch between the ultimate aims of companies (making a profit), the aims of universities (creating new knowledge), and the needs of society (responsible research and innovation) was raised. Firstly, this was a concern for the design of study programmes: e.g. should one include marketing and communication, or epistemology and history of science and technology? Secondly, it raised practical issues for PhD students working in and with industry whose publications were delayed, limiting their chances for a scientific career.

3.3.3 Professional versus academic courses

Some participants stressed the need to distinguish between professional education at universities such as pharmacy or medicine, that trains students for jobs in a particular sector, and more general academic education that focusing on training analytical skills, that can be applied in more contexts. In the first case, internships are a natural part of the curriculum, while this is not necessary in the second case.

3.4 Best practice examples

In the report D3.3[1], NanoEIS has identified best practice examples on BSc, MSc and PhD level, and identified factors which make some approaches successful. In the discussions with stakeholders, more examples of good practices were mentioned. Some of these examples were out of scope of the NanoEIS project, including programmes offered by Universities of Applied Science and commercial courses. Further study is recommended to assess those courses.

Some additional examples did target BSc, MSc and PhD programmes at universities. Time limits prevented their analysis in the NanoEIS project, so further study analysing them is recommended. One such good practice relates to the NanoEIS finding that professional EHS skills are needed by industry, while universities tend to be more conservative. The question is how to get technical faculties interested in this area. The safety and society programme of the Dutch programme NanoNextNL could offer an example. This programme is recently investing more money into a course on business development, including a module on safety and society. Their experience is that it is not easy to get PhD students to join the course, but after they have done it, their reactions are very enthusiastic.

4. Conclusions and recommendations

The findings and recommendations developed in the NanoEIS project have been tested in discussions with stakeholders. Many of the findings have been corroborated by participants. Other outcomes of the project raised questions and may need further study to understand better the underlying causes and context determining them.

Several practical suggestions have been made to optimize the exploitation of the project results, in particular ensuring sustainable exploitation beyond the lifetime of the project by integrating key outcomes in ongoing efforts and by providing continuous full accessibility of web-based elements. These include pan-European networks such as Nanofutures and the EUN network of schools, the partners' own contacts, as well as national and local initiatives in the EU member states. There is also interest in international cooperation in developing a nano-curriculum outside Europe. As a follow-up

[1] Szafran, Bartlomiej, Wojcik, Pawel, Spisak, Bartlomiej, Griffin, Karin, Rutkowska-Zbik, Dorota: Report on factors favouring specific desired outcomes for nanotechnology programmes at universities. NanoEIS deliverable D3.3. October 2014, www.nanoeis.eu

to the NanoEIS project, nano-education at Universities of Applied Science and in commercial courses for life-long learning may also be investigated.

NanoEIS has developed and communicated specific recommendation pertaining to the different stakeholders.

For universities, NanoEIS has developed a model curriculum they could use to improve their own curriculum. This is available as Deliverable D4.1. Stakeholders commented on the circumstances that influence the uptake of this model curriculum. This includes the internal organisational difficulties in changing the university curriculum. Several suggestions have been made to overcome this, ranging from top-down imposing financial incentives to bottom-up cooperation with local employers. Another issue is the eternal chicken and egg debate whether the labour market needs nano-specialists or disciplinary scientists with some nano-courses. The modular organisation of the NanoEIS curriculum caters for both preferences.

For industry, NanoEIS has made some recommendations on how they could get engaged more in education in nanotechnology at universities, based on study of good practices. Stakeholders have suggested additional study to establish the size of the labour market for BSc and MSc graduates with nanotechnology qualifications.

NanoEIS has not made recommendations for students, so this could be the topic of follow-up studies. Awareness about nanotechnology among the general public can be improved as a spin-off from the proposed integration of nanoeducation in the secondary school curriculum. Other good practices for raising awareness of the general public have been studied in other projects such as Nanodiode. This was out of the scope of the NanoEIS project.

NanoEIS has documented in detail the relation between education programmes and the different employers in the different surveys and case studies reported in the series of deliverables of WP 2 and WP 5. This has enabled an analysis of strengths and weaknesses in the present education landscape as presented in D6.1 and D6.2. The stakeholder discussions highlighted the following ambiguous issues on which different views persist. Some prefer teaching soft skills during the formal education, while others believe this can be picked up when the graduate is at work in a company or organisation. While some favour the preparation of students for jobs in profitmaking companies, others prefer to teach them a more critical attitude aiming for responsible innovation. Internships may fit better in professional rather than academic courses that teach analytical thinking.

NanoEIS has identified best practice examples on many levels, and identified factors which make some approaches successful in report D3.3. Stakeholders mentioned additional examples that could be analysed in follow-up study.

Annex 1: report on first NanoEIS stakeholder workshop “Responsive Tertiary Nano-Education”

Location: Business Centre Rudolf Magnus, Utrecht, The Netherlands, 24-11-2014

This report is organised thematically, not chronologically, to be able to identify the main lines and conclusions in the discussion.

Participants: Ted van Hoof, TMC, Kees Groeneveld, MinacNed, Rens van den Berg, STW and NanoNextNL, Pieter van Broekhuizen, IVAM, Peter Schön, Saxion Hogeschool, Gregor Luthe, Saxion Hogeschool, Remke Klapwijk, HOBEON, TU Delft, Freddie Ntow, NIA (speaker), Ineke Malsch, Malsch TechnoValuation (organiser)

1. Industry needs

Industry survey presented by Freddie Ntow (c.f. D2.1)

1.1 Survey methodology

The participants questioned the methodology followed in the NanoEIS survey. One question should have been phrased differently: “does your company have any knowledge about nanotechnology and are you aware of it?” because people often have knowledge but are not aware of it. It is also not clear which answer is expected to the question “does your company have any knowledge about nanotechnology?” The next question was: is your company a nanotechnology user or producer, that could clarify what answer is expected.

The problem with the question is: if you had asked Unilever 20 years ago whether they were doing nano they would have said yes, we are at the forefront. If you had asked if they put nanotechnology in the soup, they would have said no, we have smart food, but don’t put nanotechnology in it. Participants would have asked the question in the NanoEIS survey differently.

About the nanotechnology training of respondents: NanoEIS did not distinguish PhD, MSc etc, but only whether they had acquired it at work, as specific training or as general education. The composition was quite even.

It appears that most of the companies involved in nanotechnology do not consider investing in nanospecific training, but that depends on the country.

How did NanoEIS partners get to the list of the companies: we contacted the members of NIA and other nanotechnology companies outside the traditional EU 15 countries. How representative is it? The survey is more representative of the EU 15.

1.2 Pros and cons of establishing the value chain companies are in

Did the NanoEIS survey look at a value chain for nanotechnology companies? (No, that may be a good question to include if we repeat the survey)

MinacNed organises about 200 companies with different places in the value chain, like instrumentation, nanomaterials developer. All these companies need to know what nanotechnology is about in their own place, but they need knowledge all along the value chain from research to consumer. They asked some simple questions to their members: who are your suppliers and customers, and who are the suppliers of your suppliers and the customers of your customers, this way they established the value chain.

The problem with the methodology used by NanoEIS is that you will not find an analytic instrumentation provider by keyword nano. The results of the survey may therefore be biased. Some big companies like BASF or DSM have the whole value chain inside, the answer to the questionnaire depends on which person inside the company you are asking. This is also the reason why people answer that they are in manufacturing. They produce products, but may also do other things. If NanoEIS had not finalised the questionnaire, it would be recommended to broaden the question to research, development, manufacturing or support.

MinacNed has defined several value chains of nanotechnology for electronics, etc. It has been done from the perspective of a knowledgeable person outside the companies that is now able to apply one external standard for every person he asks. NanoEIS is using an internal standard that differs per person. There is a question of objectivity. Many external standards like the OECD standards are not as objective as they appear.

It is important to stress in publishing the NanoEIS results that these are representative only for a part of the value chain. A user who wants to incorporate the nanomaterial in a product in textiles, space etc. may need different skills. Remke Klapwijk did a similar study for Saxion. The question is whether the same skills are needed by companies closer to consumers than for high tech companies.

1.3 Why are EHS skills needed?

Why does the need for EHS skills jump out in the findings of the NanoEIS survey? This could theoretically be because all respondents are toxicologists[2], or because all companies have to deal with those aspects because they are liable for the safety of their product. They may be interested to just fix this part in the story board. Therefore it is important to ask this question inside the company.

The point of the survey was to identify the different perspectives on skills needs of future employees between industry, universities and students at a more abstract level.

The risks are considered only relevant if you are producing nanomaterials, not for other nanotechnologies. However, risk perception of respondents may associate nanotechnology in general with risks. The survey did not predefine nanotechnology, nor were the respondents asked to state their definition.

2. Training needs for non-industrial employers (c.f. D2.2)

2.1 Industrial job market

Currently, there is no recruitment problem in industry. Graduates need work experience to get a job. It may therefore be better to teach students to start their own company. Most companies nowadays

[2] Comment from the coordinator: This is extremely unlikely. The study did not aim at EHS topics, so there is no reason why companies should select EHS experts to answer the survey. Furthermore, it is questionable whether the companies contacted all have toxicologists on the workforce. Within the NanoEIS project there are two partners with an EHS background (PLUS and NUID UCD). Neither of them was involved in the planning or execution of the industrial needs study.

prefer specialists in chemistry or physics with nanoskills, unless the candidates have a nanosafety specialisation. It could be that companies perceive that as the only area that is nanospecific. The NanoEIS survey suggests that students are currently not taught nanosafety skills, but it may turn out to be a very tiny job market.

In five years more nanoBScs and MScs will be needed. There is a discussion whether there will be plenty of jobs in industry if nanotechnology is in its infancy. Currently, maybe ten big companies in the Netherlands could be interested in hiring those students. Start-ups may be booming in five years. In general, companies don't hire graduates that know the most. Soft skills are equally important.

2.2 Natural versus social science background

The pros and cons of having a natural or social science background in industry were discussed. Do natural scientists lack soft skills in their education? Some participants believe that it is easier to teach a technologically educated person commercial skills than the other way around. This suggests that technological students should be allowed to acquire soft skills during their education. On the other hand, if enough students study STEM, the problem will solve itself.

3. Available nanoeducation

3.1 Best practice findings

In NanoEIS some best practices of interaction of students with industry were identified. NanoLabNL affiliated to NanoNextNL was selected, mainly because of the involvement of Philips, and Technical Universities that shared their lab facilities for student training. NanoLabNL is mainly investment in open access infrastructure, there is no formal cooperation between the university labs and Philips. Philips is involved to see what is going on, to avoid duplicating investment in infrastructure. It is also questioned whether there is an educational part in NanoLabNL, which facilitates companies doing first stage R&D. PhD students are also present and the students and companies staff lunch together and discuss issues like IPR etc. which may influence career perspectives. This may be called tertiary or quartary education.

The selection of best practice cases was questioned. It was based on cases where industry was involved in higher education. The cases were selected by NIA asking their members for good practices. E.g. BASF indicated that they had good experiences with the programme at MIT in the USA since 2007 recently incorporating Harvard. This was criticised as name-dropping. Counter-arguments are that BASF invested a billion dollar in the programme and many of its staff has graduated from these programmes. BASF taught students in the programmes.

The point of the NanoEIS study was that these types of programmes appear to be much more common in the USA than in Europe. Besides NanoNextNL and IMEC and the companies programme in Leuven, few European examples could be identified. This was criticised as comparing apples and pears. In the USA, if you want to use other companies' equipment, you have to pay for it. The university systems in the USA and Europe are very different. In the USA, there is a greater breadth of public and private universities that can work like companies and share their way of thinking.

One participant studied nanotechnology in the USA, in Albany, NY, that is supported by SEMATECH corp. Most classes were tailored, so after finishing the degree the student can work for the company. It is company funded training.

Another programme identified by NanoEIS was SHINE at the University of Washington and several schools in the area. The board of the programme is run by BOEING and HONEYWELL, Microsoft. The programme is offered to bachelor students from University of Washington in any subject that can get a one year certificate on nanotechnology. Part of it is going into schools as an honours student to do public engagement on nanotechnology with school students. Industry engagement was at the top, but it also involved experts from the companies teaching and after acquiring the certificate students could do their internship in the participating companies.

3.2 Overlooked programme: SAXION

The programme of SAXION fits in all the presented criteria, but was not selected as a best practice in the NanoEIS study. Arguments were given in favour of selecting this programme as well: They involve 16 company staff teaching in the courses. Students and companies sit together. More than 20 companies sit in the lab, interact with students, students come back to use equipment, etc. The province of Overijssel is investing a lot in it. 100% of the students have a job after they finish. All students have to spend 2x half a year in industry as an intern. Soft skills are also taught: E.g. the former head of the BASF Patent Office surface techniques is teaching patent law in the programme.

Overlooking SAXION may be due to the fact that the study focused on university level, not at the level of universities of applied science, and the cases selected were not meant to be an exhaustive list but merely a set of examples. The cases that NanoEIS found were probably well-documented with a lot of procedures. IMEC and KU Leuven was also not mentioned. The question was raised: How can the list of missing educations be drawn up?

4. Secondary school education in nano (c.f. D2.3)

It is important to teach nanotechnology at schools, because it is a pervasive technology. Is it the NanoEIS aim to reach all secondary school students? Should all young people have some knowledge about nanotechnology or only beta-students? Opinions differed about the relevance of learning about nanotechnology for economists, etc. On the one hand, it is important that the whole population is taught about safety-awareness, whatever job you are going to work in. The professional education needs are distinct from general public awareness needs. In general everyone could use tools to reflect on technology in general. Participants are reflecting on how to organise nanotechnology education. A problem is that embedding nanotechnology in secondary education is very time consuming.

5. Student interests

5.1 Motivation of students

There are cultural differences between European countries. (In the Netherlands) some students study for fun, and at the end they make their own company out of it. (In the UK), this is not the case, because studying is expensive and the student will end up with a debt he or she must pay back.

Employees follow the money: where can I get the biggest and best wins? This suggests that students may be interested in marketing and IP courses, not regulation.

From the perspective of (some) students (especially in the UK where university education is expensive), education is an investment. Choices are driven by the perspective of the student on a good chance of return on investment. Studying subjects you are good in (A-level) will help you find a job. This may be different in other countries like the Netherlands where education is less expensive. The UK system may be similar to the USA, which makes excluding nano from non-technical curricula understandable.

5.2 Alumni driven choice of university

According to one participant, in the USA, a student chooses the university that has the best alumni to improve opportunities to find a job after the study through networking with the alumni. The second best course in toxicology ranks so high because it has the best alumni that attracts the best professors and students.

6. Developing the nano-curriculum

6.1 The NanoEIS draft curriculum (c.f. D4.1)

Comments on the bachelor level curriculum: Not only marketing, also project management would be useful to include in the curriculum. The CAPSTONE project offers internships in industry. This trains management skills and focuses on something concrete. The advantage is that students get used to working in a project and using project management tools. According to some, students must first be introduced in industry and only in a second instance learn project management skills. The NanoEIS draft curriculum appears to be valuing the bachelors too highly. In many of the jobs for which the NanoEIS bachelor is supposed to train students, masters are currently dominating the labour market.

One has to realise that the study is only the beginning. Only during employment does the person gain experience. The BSc should allow the alumni to get into a laboratory and help to do experiments, as well as get into manufacturing. It offers a nice basis for a commercial job, without in-depth knowledge about nanotechnology. Most students will opt for continuing with a master after finishing their bachelor. In industry, the focus is on jobs in manufacturing and field services, equipment engineering jobs. Most laboratory equipment operators are currently master graduates. Companies don’t have plans to change that. They may decide to hire BScs after five years, but not yet. Currently there is no real need for bachelor nanoengineers. There could be opportunities in semiconductor fabs (there is one in the Netherlands), but they hire mainly masters graduates.

The graduates from the SAXION MSc will work in manufacturing. In five years, there will be more design rules in industry. Bachelor and Master graduates can continue to do an MSc in a related area. For instance a BSc in chemistry can do an MSc in nano and learn about services, marketing and regulatory aspects. There may not be a difference between marketing a nano-product and marketing another technical products, but marketing a technical product requires different skills from marketing a non-technical product. The marketing skills also depend on the value chain.

In the NanoEIS curriculum it is also important to learn to develop synthesis methods of new nanomaterials.

6.2 Different strands in the nanocurriculum

Overall, three directions in the curriculum may be distinguished: targeting R&D jobs in industry, setting up one's own company, or a sales job in industry. The third one is the most difficult to fulfil according to some. On the other hand, industry is always complaining that they don't get the right skilled employees.

6.3 EHS in the curriculum

In training it is better to teach awareness of EHS aspects, not to train a lot of nanosafety experts. On the other hand, one participant had the experience that most technological students do not like EHS as a minor in their studies. He expected that nobody will follow it. It could be better to have social students to follow nanoEHS courses. However, it is important to teach ethics. It is expected that EHS and RATA (Risk Analysis and Technology Assessment) courses are going to make money as an offer targeted to companies, not to students.

6.4 Disciplinary borders

Is there a course teaching nanotechnology regulation? There is a course teaching EU chemicals regulation. Leiden University currently offers a course on EU regulation. It would be possible to develop a targeted course on nanotechnology regulation, but this is not happening because social and natural science departments are not talking to each other. In the past, Dutch universities offered a course in commercial technology, but this is no longer there. Dutch industry associations lobbied to change this.

6.5 Comparing nanoscience with science for society

In the 1970s, Dutch universities offered multidisciplinary education on science for society. The proposals for the nanoscience curriculum look very similar to this according to some.

6.6 Lifelong learning

To fill the knowledge gap of employees with a non-technical background especially regarding EHS aspects of nanotechnology, professional training courses may be a good solution. MinacNed is organising a course on Nano for Dummies for the director, financial officer, secretary, receptionist etc. of companies handling nanotechnology to raise their awareness of the issues, especially safety aspects. It follows the example of an earlier course on Laboratory Technology for Dummies. This is to overcome panic because of misinformation on the potential risks of nanotechnology.

6.7 Successful commercial nano-courses

Is there an inventory of nanotechnology courses that are commercially successful? NanoEIS has not looked into that. It is suggested to check the offer of companies like REED Business that offer commercial courses, this may give an indication of the demand for post-academic training in nanotechnology. We may also look at the number of registered participants for the MinacNed course Nano4Dummies. This will be held in January 2015. For comparison, the existing course on introduction to semiconductors is very successful. Other successful courses are on manufacturing related technologies, process engineering, quality stuff, product introduction, (Failure Mode & Analysis (FMEAs), nanoelectronics, textiles etc.

7. SAXION-MESA+ joint master curriculum

At the beginning, it is a heterogeneous community of students from different disciplines. Therefore in the first semester it is important to homogenise the group. It includes refreshers in mathematics, physics, chemistry and biology, and the first course in nanotechnology defining the subject. This still needs to be filled with contents. This semester also includes a first practicum. The second semester it includes some practical cases of societal issues and of running a business, legal aspects, organisational aspects. Another practical course is included in this semester. The students have access to good labs at MESA+ and SAXION. Semester four focuses on a business case from nanotechnology to product. We focus on real world cases, learning from something that already exists to some extent. MSc students bring it to the next level to a product that can be used. “Nanotechnology for people problems.”

Remark: A lot of technicians nowadays know how to manage a business from a technical point of view, but they don’t know the business side. These aspects need to be blended in from an early stage. According to one participant, good technologists can learn about business, but not the other way around.

The students don’t only have to learn to write a paper but also a patent, with the aid of a patent expert. Another idea is a business angel idea for which SAXION asks MinacNed’s help. They need for each individual student a “godfather” who supports the students through his entire master and uses the system of old boys network. The godfather will bring in their share and can also influence the education. It is an important element of the proposed curriculum. Another participant criticised it, because he experienced a similar system in his education and it did not work because of incompatible personalities.

Societal aspects include risk aspects, societal discussions, and cases where a company is part of society. In NanoNEXTNL, the RATA course has been developed as a similar programme to raise awareness of risk and societal aspects in companies and researchers. They create three groups of students: future customers – scientists – policy makers. Then they discuss how to handle nanotechnology. They meet three times with a week in between. It starts as a game, but at the end the students identify with their role.

The SAXION course teaches nano-engineering, not nanoscience or nanotechnology. The time to market is tomorrow. The priority is on patenting so the scientist can make money from his research. This course has a different focus from the nanoscience focused master offered by the University of Twente. Most courses offered by universities focus on nanosciences and nanotechnologies. SAXION offers a course on nanoengineering. They are interested in learning from other similar courses in Europe.

8. Other issues

Several other issues were also discussed.

8.1 Difference nanomaterials – other chemicals

The question was raised what distinguishes nanomaterials from other chemicals and whether the materials have a specific nature. Opinions differed whether the distinction of nanomaterials with other chemicals was important. In response, the pervasive nature of nanotechnology (like ICT) was stressed: nanotechnology is entering all fields and products, it's not your choice anymore. Producing and handling it requires specific skills. It is existing in society as an important specific issue that needs to be discussed and understood by everyone.

8.2 User committee for steering technology

In the EU funded project NanoDIODE, a user committee confronts scientists with user needs and gives these users a voice in the steering of technologies. There is an enormous gap between science and technology. Professors teach students to be future professors. You need both types of education. You need engineers to make nanoproducts and technical solutions to human problems. Product development at universities is very different from the product sold on the market. The university does not sell products.

8.3 Pros and cons of patenting

There is a problem at the financial side. For a publication the scientist needs money to publish it and money for making it open access. A patent costs only US$500 in the USA and the scientist gets support for it from the side of the university. A problem in Europe is that the university owns the patent which runs the risk that it is not actually used. In the USA, universities allow professors to own their own patents. This is a more entrepreneurial approach than in Europe. The Dutch nanocommunity is high ranking in numbers of publications, but non-existing in numbers of patents. Other participants questioned whether patenting offers a competitive advantage in all cases. Especially for SMEs offering services, patenting is not in their interest. For investors it may be the most important question, but for Dutch SMEs is it not.

9. Conclusions and recommendations

9.1 Industry needs

Participants criticised the methodology used in the NanoEIS survey, comparing the questions with those in other surveys investigating the job market for nanotechnology graduates. There are different aspects to this issue that are highlighted in these studies, each calling for different study design.

Issues discussed include the differences in qualifications needed by employers in different stages of the distinct value chains from R&D via nanomaterials/nanotechnologies up to end product manufacturing in different sectors. It should be stressed that the NanoEIS survey covered companies in limited parts of these value chains.

The apparently high demand for employees with nano-EHS skills raised questions. The NanoEIS survey does not allow for an explanation. Different potential reasons were suggested, e.g. that all respondents could theoretically be toxicologists, or that there is a need for a limited number of nano-EHS specialists to fill gaps in the companies' expertise in the short term. Further study is recommended to clarify this.

Another issue that should be investigated further is to establish a realistic estimate of the job market for nanotechnology graduates, in particular for Bachelors. In the experience of some participants, most current jobs are fulfilled by Master graduates and physicists and chemists with nanoskills rather than nanospecialists, and there is no current recruitment problem in industry. In five years more demand for nano-BScs and MScs is expected, especially in start-ups that may then be booming.

9.2 Available nano-education and student interests

The selection of best practices by NanoEIS was criticised by some participants. It appears that this selection is biased towards the reality in some countries where students have to pay high fees for their education and where industry already has a lot of influence in higher education. In addition, education at universities of applied science may have been overlooked in the selection process. This should be stated clearly in publications of the NanoEIS results, e.g. by calling them “good” rather than “best” practices and by making the selection criteria explicit. Further study is needed to investigate what would be good practices in the context of other countries like the Netherlands, where the costs of education for students are lower.

9.3 Raising nano-awareness

While participants agreed that all citizens should have a basic awareness and knowledge about the pervasive nanotechnologies in society, opinions differed on how this should be taught: at secondary schools, through nanotechnology minors in other curricula, or in the form of lifelong learning courses (possibly offered by commercial training. It is recommended to study the attendance rates of commercial nanotechnology courses, e.g. those offered by MinacNed or REED business.

9.4 The nano-curriculum

Suggestions for improvement of the NanoEIS curriculum included:

- Adding project management (how and when this should be taught is a matter of discussion)
- Don’t value Bachelors too highly, most jobs foreseen in the NanoEIS curriculum currently require an MSc.
- Include teaching synthesis methods of new nanomaterials
- Divide the curriculum in three strands:
    - R&D jobs in industry
    - Setting up start-up company
    - Sales jobs in industry
- Teach awareness of EHS aspects to all nanotech students, rather than training many nanoEHS specialists
- Nanoregulation could be included, but requires more interdisciplinary cooperation between social and natural science faculties than is currently the case in (Dutch) universities.
- Experience with Science for Society curricula at Dutch universities since the 1970s may be relevant to developing the proposed nano-curriculum
- The NanoEIS curriculum and the SAXION-MESA+ curriculum (under development) may both benefit from exchanging ideas

9.5 Other issues

It is important to explicitly define nanotechnology as it is understood in the project, and also to clarify what distinguishes nanomaterials from other chemicals. EHS and social aspects of nanotechnology may also be handled by installing user committees for steering technology development. Opinions differed on the pros and cons of patenting, this appears to be depending on the national and sectorial context in which nanotechnology companies operate.

9.6 Recommended valorisation of NanoEIS results

The NanoEIS strategy foresees dissemination of results via different routes including Nanofutures association, the partners and direct contacts with universities. In the Netherlands, direct contact and teaming up with universities offering nanoeducation (SAXION, TU Delft, MESA+, UT) and the Topsectors are recommended routes. Look for integrating modules into the curricula of those universities. There is also a top-talent programme COAST (Comprehensive Analytical Science & Technology). This trains top students from applied sciences together with companies. It is copied by ISPT?

For secondary schools, ministries of education will be contacted by NanoEIS. There could also be opportunities for nanotechnology modules in the interdisciplinary course “Natuur, Leven en Technologie” (Nature, Life and Technology).

Annex 2: stakeholder webinar

Title: Responsive Tertiary Nano-Education

Location & date: internet, GoToWebinar, 24 February 2015

Registered participants (6 attended, 2 people arrived late due to a misunderstanding of the webinar schedule. All registered participants received the PowerPoint slides):

Dena Sherif, Victor Acha, Sachin Shinde, Raj Kumar, Ahmed Mourtada, Moshe Talesnik, Bartlomiej Szafran, Steve Meikle, Hernan Valenzuela, Joaquin Tutor, Albert Duschl (speaker), Ineke Malsch (organiser, speaker)

The webinar started with a presentation by Albert Duschl (Nanotechnology: Skills, training, education The NanoEIS experience). This was followed by a presentation by Ineke Malsch raising issues for discussion (Responsive Tertiary Nano-Education).

Comments by attendants:

The industry employees could change / disseminate the experience inside the university by giving presentations about real cases where all main topics could be involved like safety cares with logistic etc. It matches with the first presentation which detected that universities do not prepare people for the industry.

A question was raised about international cooperation in nanoeducation with Latin America. The NanoAndes network is developing a common curriculum on nanotechnology in Latin America: www.nanoandes.org. In the NMP-DeLA project we have organised summerschools on nanotechnology for health in Buenos Aires in May 2014 and on Nanotechnology for Water and Energy in November 2014 in Monterrey, Mexico: www.nmp-dela.eu.

Conclusion: a webinar for international participants is not a suitable format to table stakeholder discussion about project recommendations.

Annex 3: Education session EURONANOFORUM 2015

Euronanoforum - SESSION 13: EDUCATION AND PHYSICAL INFRASTRUCTURE NEEDS

Riga, Latvia, 10-12 June 2015 http://euronanoforum2015.eu/conference-proceedings/

Participants in the session: Around 100 industrialists, researchers, policy makers

Speakers:

Albert Duschl (Professor University of Salzburg, Department of Molecular Biology) Mind the education gap; University teaching in nanotechnology studies does not match job kill demands in the industry

Dorota Rutkowska-Żbik (Associate Professor Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences) The NanoEIS model curriculum

Paolo Matteazzi (Chair of NANOfutures European Technology Platform of Nanotechnology President of MBN Nanomaterialia spa): "Education and skills from an industrial point of view"

Emeric Fréjafon (Dr. HDR L'Institut National de l'Environnement Industriel et des Risques (INERIS)) and **Olivier Salvi** (Secretary General European Technology Platform on Industrial Safety (ETPIS)): "Risk Management Strategy for nanotechnologies"

Summary of discussions:

Questions to Albert Duschl: Did you include a question on the need for management and entrepreneurial skills? No, only on marketing. It was discussed whether the European Institute of Technology is relevant to industry. Another question touched on the feasibility of changing the university curriculum. The adoption of the model curriculum proposed by NanoEIS is expected to take 2-3 years and must be adapted to local requirements that are different in each (EU) country. The study gives evidence that professional EHS skills are needed by industry. Universities tend to be more conservative. The question is how to get technical faculties interested in this area. The safety and society programme of the Dutch programme NanoNextNL could offer an example. This programme is recently investing more money into a course on business development, including a module on safety and society. Their experience is that it is not easy to get PhD students to join the course, but after they have done it, their reactions are very enthusiastic.

Questions to Dorota Rutkowska: Is industry better off with nanospecialists or with disciplinary scientists who have followed some nanotechnology courses? If you have a nanotechnology degree, you know a bit of all aspects, but you are not a specialist in anything. In the UK, non-specialised nanogeneralists are preferred at BSc level, who must subsequently specialise at the MSc level.

Paulo Matteazzi: presented the education needs of the small company MBN. This company participates in a value chain for metal bond powders for diamond tools. These are eco-friendly because they are cobalt and nickel free. To bring a material in a product to the market, you need a value chain of companies. Employees need to be skilled in soft as well as technical aspects. This must be offered in education. They also need skills in modelling and processing. Skills and education needs are naturally correlated with regional and smart specialisation. The value chain includes design – materials – tools – assembly – products. MBN is situated in the phases of modelling – materials manufacturing – post-processing. Required skills include materials science, modelling, powder metallurgy, powder handling (solids handling) and new metrological approaches (nanostructures in 3D). Safety skills are not required because we follow the approach of safe by design. This is what we ask our local university to include in their education. It is important to integrate these company-specific skills with more general skills to understand the whole value chain and industrial ecosystem where we operate. The requirements are: design, multiscale modelling, LCA, materials science, tools, powder metallurgy, mechatronics, processing. The education roadmap should be linked to the product roadmap. Non-technological skills include safety of powder management, regulation on complex new materials, building a supply chain targeting product network engineering.

How to realise the links between education – industrial pilot lines – skills? Regional specialisation is important, focusing on local industrial needs. The demand for education and skills may come from industry. He apparently referred to the discussion on the "Implementation roadmap on value chains and related pilot lines" prepared by Nanofutures in the project Value4Nano, in consultation with stakeholders in industry and research.[3] This was discussed during a workshop on Friday 12 June.

[Oliver Salvi and Emeric Fréjafon : presented a risk management strategy for nanotechnology, allowing decision makers to use research results, developed in www.integrisk.eu-vri.eu. Their approach is based on the existing ISO standard 31000 (2009). This prescribes the integration of risk management in decision making procedures in the company. They also take into account the IRGC framework and EU and OSHA guidance. Tools developed in the project include risk ears: experts monitoring new risks, a risk atlas, new technology acceptance (monitoring stakeholder views). The standard framework is DIN CWAI6649:2013-10. They propose establishing a European Centre for Risk Management and Safe Innovation for Nanomaterials and Nanotechnology, networking the national risk management experts. The aim is to foster transfer of research results and to combine multidisciplinary expertise into operational tools and services: education, training, certification, monitoring feedback on research needs to upgrade expertise. It should also facilitate access to research infrastructures. The centre should be established in cooperation with trade unions, industry, ministries.

It is difficult to reach agreement on qualification skills for workers regarding worker safety. Currently, national governments ask their national expert centres for risk assessments. The quality will be better if all these national centres join their forces. Information on references to scientific literature should

[3] http://nanofutures.eu/sites/default/files/Draft%20Roadmap%20V4N%20Tresalia.pdf

be made available online via a website. We are producing guidance on best available techniques for risk management. This will be available in a few years for young researchers and SMEs. It is important to make available access to infrastructure for other organisations.

Regulation-based qualifications are needed. Education and training should be adapted to a diversity of stakeholders, taking into account the maturation of emerging risks.

Value4Nano has looked into risk management of nanotechnology, including the relations with existing centres, innovation, risk assessment, outside the EU. End of 2015, a concept for an EU proposal will be ready. In 2016-2018 we propose to create a demonstration. After 2018, we intend to achieve sustainable operation and an appropriate business model based on public and private funding.]

Remark from the audience: CEN can move quicker than ISO in standardisation. SUN www.sun-fp7.eu and other EU funded projects are developing specific tools for quantitative risk assessment. Skills training is stimulated by the bi-annual Nanosafety School in Venice, Italy. They are also cooperating with the USA.

Annex 4: Second Stakeholder workshop

Event: Interaction Between the Immune System and Nanomaterials: Safety and Medical Exploitation

Location and date: Polonia Castle, Pultusk near Warsaw, Poland, 4 - 9 October 2015

Presentation title: Responsive Tertiary Nano-education (by Ineke Malsch)

The focus of this talk is on improving the connection between tertiary education in nanotechnology and the needs of the labour market. We will present preliminary findings of and a draft model curriculum developed in the NanoEIS project www.nanoeis.eu. We will then invite your contributions on improving employer involvement in tertiary education in nanotechnology as input to the NanoEIS model curriculum, as well as on relevant modules for staff training in nanotechnology.

Discussion:

The session starts with a round of introductions highlighting how the education is relevant to the present job of the participants.

Ineke Malsch: I have a first degree in physics and a PhD in philosophy.

P1: I am a biochemist, I did a PhD in Biochemistry. I would like some additional project management skills and financial skills. You need to prepare for grants.

P2: PhD in gene technology. Our universities are not teaching nanotoxicology, so I missed most skills, but I learned most on the way. You learn technical skills, but you need additional skills like communicating, writing, accounting. These are perhaps more important than technical skills. I work in an independent research centre, an academic job, I am a research centre. It is an academic position, but because it is project based, I need management skills.

P3: I am an ecotoxicologist (PhD). I am a post-doc at FDA in the USA. We work on regulatory aspects of nanoparticles. I did a PhD at university of Arkansas. Industry people need lots of experience in practical conditions, that is lacking. People need to encourage young generations that have no experience in industry.

P4: I made a comment about the fact that we need to create people who are specifically working in one area. I had an MBA in the USA but it is so expensive that fewer people are getting an MBA. We did an experiment with a twelve week course. We need people to have these management and communication skills, but they can learn these in shorter courses. The field of education I was in was law. By teaching science students about business and teaching business students about science, you don't need a double education. By designing short courses, you don't need to send a student to get a 2-3 year course. A ten weeks course is enough.

P5. I was thinking about management and communication: then you miss responsible innovation. You need epistemology, history of mistakes of technology development. We are just trained to be rich, not to be responsible.

P6: My education is in pharmacy. Now I teach undergraduates. Undergraduates and early post-graduates are trained to get problem solving skills and be adaptable. I think I was trained quite well for that.

P7: Education does not prepare you 100% for a job, but it is the experience we get on the job. If you are a pharmacist, you have a degree in pharmacy. Even if you pass all the professional exams, you still don't have all the experiences you need, you will get those on the job. As a research scientist, you say you need skills to write grant applications. No degree prepares you for that. It depends where you are in your job. If it is very aggressive and you need grant writing skills, they will prepare you for that. It is the experience you get while writing the application, or how to manage the funds. If you look at the leading universities, they have a relatively high management to scientists ratio. The scientists are doing the actual work. In some universities they are doing the science and have to do the administration too.

Ineke: It is not the education, but how the work is organised.

P8: I am into regulation. The reason I am here is that regulation and policy is fundamental and it is not addressed enough. It is a monster everyone is afraid of, but does not learn in their education. It is about responsibility and negotiating problem solving skills. There is a trend towards transdisciplinary education. This should be a two-way process. The legal community should learn about science and the scientists should be teaching them. To be an effective scientist, you need to understand the legal context. I am very happy with my education, because I have a multidisciplinary education: public health and law and international relations, but not everyone has time for that.

Ineke: So time constraints are an issue. There are several solutions: one is to have concise courses to train additional skills. Are there different ways of addressing time constraints?

P9: Most jobs evolve and the issue of professional development is relevant throughout the career.

Ineke: In NanoEIS we included a series of case studies of academic education in nanotechnology at BSc, MSc and PhD level. At BSc level we studied 4 year courses (Ireland): Trinity College Dublin and

Dublin Institute of Technology. We also studied 3 year courses: University of Basel, Switzerland, iNANO Centre, University of Aarhus, Denmark, and Saarland University, Germany. Selected findings:

- The interdisciplinarity is a strong point
- The three year BSc is not sufficient to enter the industrial labour market,
- 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.
- Internships are mostly postponed to higher education levels
- Most graduates prefer to go for a higher degree

Good practices of industrial engagement:

- A compulsory seven months industrial internship in the fourth year, (Dublin Institute of Technology)
- An eight week industrial internship before the start of the course (University of Saarland)

I would like to take a step back from the findings in our study and ask you the following questions:

- What do you consider a good practice in employer involvement in BSc education?

P10: I did my bachelor at Dublin Institute of Technology. In my third year I had to do my internship, we could choose industry or another university. I went to University College Dublin, from January until July. This gave me an opportunity to experience what research is, that helped me to choose the topic of my PhD and I ended up doing my PhD in UCD because of the experience I received during my internship. I had 6 months experience in research, this helped me decide on doing a PhD.

Ineke: For University lecturers: what is feasible at your university? Is there some experience you would like to share with us?

P7: If you are doing a professional course, e.g. a pharmacy course, every pharmacy student gets a placement in his final year, either in a pharmacy or in industry. That was planned from the moment the course started. The same thing for a medical course: you get a placement in hospital, so you get that experience anyway. When you get to non-professional courses, you have to define what you consider a good practice in education. The aim of an academic scientific course is to prepare you for analytical thinking, to analyse problems. It does not matter what job you are preparing for. That is the basis of a university education. The best example is the city of London: how do they choose employees? You don't need to bring employers into university, as long as the university teaches the students properly and brings them to the stage that they can think independently. It is not: you do this and that and then we give you a degree. The problem is not the industry, it is the university. The universities are underfunded. They need more money and the only way they get this is by enrolling many students who can't reach the level. At the end of the day, you are not even allowed to fail the students.

P4: I have a related comment. I don't think we need degrees, especially at undergraduate level, that are specifically nano-focused. What we need is a better combination of Bachelor degrees with internships in industry.

P11: I am teaching mainly students of biology and molecular biology, but I have also been involved in setting up a bachelor programme for materials scientists. Industry involvement at bachelor level is not relevant to biologists. Materials scientists have to spend one semester in industry. The difference between the two is: for biology we have about 350 students per year. In materials science it is about 35. It is a question of numbers. If you need to accommodate a large number of people for hands on experience it becomes problematic. Secondly, for the materials sciences bachelor, through a legal loophole we managed to create a seven instead of six semester bachelor. The industrial semester is an additional seventh semester which is outside of the Bologna system.

Ineke: so you are going into the direction of the Irish system.

P4: I understand that the length of the curriculum and the materials you have to cover are an issue. I am talking about the American system, where I did most of my teaching. Comparing a group of students majoring in biology with a group of students majoring in biotechnology: this is my argument for changing the education system. What will those biology students do? Even if they end up in university, they will not go there immediately but first go for a master and PhD. All this time they will not know about industry and what they need from them. Why not train all the students all they need to know from the beginning?

P8: It seems that three years is not a lot of time. We had a four year degree, which I completed in five years. Students made posters about nanotechnology during a summer course when I visited them last summer. They are not exempted from their distribution requirements. They can read Shakespeare and learn a foreign language and do an internship, and that is because they have four years. We also had internships and distribution requirements and we did what we were special in. In my case my internship led directly to my graduate programme. It may be a function of the fact that even though the schools are excellent in Europe, you can't squeeze everything into three years.

Ineke: the length of the programme is a big issue. There should be enough time to involve industry or teach enough topics.

P7: There is another problem. Five years ago in Denmark we ran a programme where we invited people from industry, four big pharma companies and the head of the pharmaceutical industry association, to tell us what they need. The reason was that we thought the problem is the university, because it was reluctant to change. What they said was remarkable: many years ago we had pharmaceuticals based on small particles, then they became bigger and bigger and now we have biologics. We need students that can prepare us for this change. Can we change the university education to prepare for the required knowledge? What will be the regulatory requirements for these new drugs? Then we found that nobody in the university wanted to change the curriculum. They don't want to step outside their comfort zone. If you can change that, you have solved the problem?

Ineke: How can we change that?

P7: I don't know. We tried by inviting industry people, bringing them to say what they wanted us to change. They said it, but we did not want to change. This is the problem in academia. I have been giving this lecture every year, why should I change it? Why should I make life difficult for myself?

P12: this is a problem: Are you getting paid for changing the lecture? No, you are paid for getting a grant or PhD. I was wondering: I am coming from a university of applied sciences, and I am doing a five year course in applied pharmacy. We invited industry to talk to us and we designed the course after that.

P7: that is the difference. Most university teachers don't want to change.

P12: In a university of applied science they will change, they have to.

P11: I can tell you a trick how you can reform universities a bit. I have been vice rector for research at my university for 8 years. One of the first things we did when we entered in office in the administration was to change the rules of how money was divided. We gave more money if they brought in grants, for conference presentations, if PhD students finished rather than entered the course they got more money. The money is divided between the departments, so as some departments received more money, others received less. This increased the pain level considerably, so they come to you and have a big fight and shout at you. Eventually they ask what they should do to get more money as it is unfair. We said: it is simple, the rules are transparent: bring in more grants, more publications etc. Even though we were not talking about that much money it brings people out of their comfort zone rather quickly.

P13: It is exactly the point: if you can bring in more money for good education, this is an incentive.

Ineke: so it is a matter of the carrot and the stick.

P14: I realised that we have some courses that are very specialised, but the people who graduate from them have difficulties finding a job because nobody knows what it means. You need to have courses with a recognisable name like physics, chemistry or biology. Nanotechnology skills are important, but they should be incorporated in a more traditional course. It should be targeted: what do you need to know if you were working in chemistry, pharmacy etc. You need the traditional course and on top of that you need to learn about nanotechnology.

Ineke: Would that be a disciplinary bachelor and nano as a master, or nano as one topic among others?

P14: We have a basic education of two years, and we have a bachelor of 3.5 years. In the sixth semester we let the students choose: cell biology, or nanotechnology, or regulatory affairs or biotechnology, etc. Then they get a solid foundation in a topic and then specialise in a master.

P15: My experience with industry and university is: industry rarely gives unrestricted grants for education. They don't care. They like to train their own people when they are employed, mostly for intellectual property. Developing new products is a tricky business. If industry accepts to give lectures or short courses at universities, it is because they have funded some specific research of their interest. Then in addition, they can provide some of these lectures, saying what they need, how industry works and so on. They are good for a master degree. For a bachelor there is no time. In a bachelor there can be management, some economy, because it is important to get a job in industry.

Ineke: So from the industry perspective it is not so important to get involved in university education, but perhaps from the students' perspective it is? If they want to consider it for a job, they may have to get in touch with industry lecturers to get the idea that this might be something for them?

P15: A better link between academy and industry in new fields or high tech is mandatory, because there must be dialogue, not two separate tracks.

Ineke: in a more general sense it is not so much that students get a job in industry, but that the two parties work together more.

P7: When you come to more advanced topics like nanotechnology, industry is interested in one aspect of it, that is more being developed by small companies than by universities.

Ineke: Introduced the master examples studied. This was more or less the same as bachelor. There are no additional comments to what has been said before. Then the PhD examples were introduced.

P16: The involvement of industry in PhD education is much higher than in bachelor or master degrees. Albert and I have experience in EU funded training programmes where industrial partners have to be present and PhD students must have secondments to industry to see a different environment. We are involved in European Industrial Doctorals where they must spend half their time in industry. It is not good for the continuity of the PhD but from the training perspective, it gives them a much larger view on what the different approaches are.

Ineke: It is a success in the sense that the fellows get experience in industry and can choose an industrial career?

P16: the fellows that enter have not chosen one or the other career, they are still quite open.

P7: The industry ultimately wants a product, that is developed through research. The ultimate aim of the university is to have PhD level education. For that the result of the study needs to be a publication. Industry does not want a publication, because they want to patent the invention. And even after the patent they are reluctant to cooperate with a publication. After three years, if the PhD students have no publication, they are finished. This will eventually backfire, not only on the student, but also on the university.

Ineke: this is different from what your colleague said before in his plea for more university-industry cooperation. Now you say this may also backfire on universities. I am sure you want to comment on that.

P15: I don't believe in pure research, but only in research that is applied to finalise something. For the student, publications are important to measure progress. But industry involvement is important for two reasons: 1: there is a door that almost opened to be employed in the industry. And 2: the person does research on something that is important to the industry. I agree that it is also dangerous, because sometimes you have results you can't publish. PhD students have to publish at least a couple of papers in important journals, depending on the country. If this is the backfire you talk about, then I agree. If you work in something very useful for the development of a product I think that is more important. I don't know about nanotech, but in pharmaceuticals for diabetes, it is.

P5: there is a conflict between profit and knowledge. Companies will profit. Marketing departments of companies are driving research in the companies. If we are in this cooperation, we must also take resources from them. We would like to know what happens in academia. The problem is broader than that. It is a matter of technology and society. It is not just a matter of cooperating with industry. Industry is driven by profit. It does not care about life on the planet.

Ineke I think both sides of the controversy are clear, but I am sure we are not going to solve it today. I will present some results on training needs of non-industrial employers. … To the lecturers in nano: what could you offer to people who are working in non-industrial organisations who need to learn about nanotechnology? Are there special skills? You already mentioned short courses on management skills.

P17: You could get university lecturers to give online presentations on different topics and then you need an organisation or platform that puts it together and organises it.

P17: I was asked to explain nanotechnology to the medical society. They wanted to learn what was going. More professional societies may be interested. They don't need a complete curriculum, but specific targeted lectures. They have gaps in knowledge to do their job well, and need to fill these deficiencies.

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