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Executive Summary

NanoEIS has assessed nanotechnology teaching in secondary schools and has also evaluated how university study contents fit with the job skills required in the industrial and non-industrial (social) job market. It was also investigated which factors support the transition of students from the academic to the industrial sector. The individual studies have been published as deliverables and are available on the project website. Based on these data, the NanoEIS consortium makes suggestions to universities that already provide or plan to set up study programs directly relating to nanotechnology:

- For student recruitment, cooperation with secondary schools is essential. Nanotechnology teaching in secondary schools is sketchy or non-existent, but direct involvement of university experts can motivate young people to enter such study programs.
- University teaching contents are mostly focussing on traditional disciplines and on scientific topics investigated in university departments. Employers report strong needs on other subjects as well, including health, safety, regulation, standardization, environmental impact and sustainability. University studies on all levels should reflect that and address these subjects within obligatory courses.
- NanoEIS has published model curricula for bachelor, master, and doctoral studies. These model curricula are intended as a check-list to compare existing or planned curricula with generic study programs that do not reflect any local specializations, but are fully aligned with skill requirements of the job market.
- Direct involvement of industry in teaching was identified as a key factor that strongly facilitates transfer of students from university into industry. Project-oriented teaching with industry experts and training modules at industry sites break down barriers and enable students to enter the non-academic job market. Finding ways to engage employers in the educational curriculum development could be also a positive measure in this direction.
- Finally, communication with non-peer groups (media, the public, school classes, regulators and other stakeholders) is an essential skill that helps to address most of the topics mentioned above. In the non-industrial job market this skill is even

more essential then technical expertise. We suggest moving communication training beyond peer-to-peer communication as early as possible.

1. Introduction

Nanotechnology is a Key Enabling Technology that penetrates many different industrial sectors. Nanomaterials are thus increasingly present at the work place, in consumer products and post-consumption in the waste stream. The driving force of this new technology is that it enables products and functionalities that could not be reached with either bulk materials or chemicals, but become feasible with the specific properties of the nanoscale.

The success of nanotechnology is based on personal expertise: More and more people need to know about nanotechnology. This provides a growing job market in research and development, as well in the production of nanomaterials and in their use in different industries. Jobs also need to be filled outside of research departments and industries. Regulatory agencies, general and science-oriented media, recycling and waste management facilities, political bodies, NGOs, etc. all need to deal with nanotechnology on some level, which requires experts in this field.

In response to this developing job market, universities have set up nano-related studies (nanotechnology, nanoengineering, bio-nano technology, etc.). A study published in 2011 has identified 138 nanotechnology degree programs in 17 European countries (Kiparissidis, 2011). With respect to nanotechnology studies, universities face two problems. One is the recruitment of students, which is always more difficult if a subject is not directly represented in school, like chemistry or physics. The other problem is that the potential job market expands rapidly and involves different types of employers, so it is not trivial to assess what challenges the students will encounter after leaving the academic sector.

The NanoEIS project has analysed the job skill needs in the nanotechnology sector for industrial (D2.1) and non-industrial employers (D2.2, D5.4). It has also assessed the status of nanotechnology education in secondary schools (D2.3, D3.1) and has analysed representative university study programs (bachelor, master, PhD) regarding content (D3.2) and regarding transfer of students to the non-academic sector (D3.3). The individual reports are available on the NanoEIS project website, www.nanoeis.eu. Feedback on the results and on preliminary conclusions was received during two stakeholder meetings (24.11.2014 and 24.02.2015) and – mainly in connection with public presentations of NanoEIS findings – during discussions with audiences and interested individuals of different background. A final physical meeting with stakeholders is scheduled for 05.10.2015

The present report summarises our findings, addressing universities that either provide study programs within the field of nanotechnology or nano sciences, or plan to implement such programs. The recommendations made here are intended to be of practical use in setting up and improving study programs in the tertiary sector. It is appreciated that universities set up curricula within a specific context, including existing strengths in particular subjects, strategic developments of university profiles, existing or intended cooperation with local institutions and companies, and or course regional job markets. It will thus never be possible to establish a “best” curriculum. It was indeed not the purpose of NanoEIS to evaluate the quality of individual programs or to provide a complete overview of the European education landscape. A central goal was to provide data on the connections between secondary schools and universities on the one hand, and between universities and employers on the other hand. In this document we summarise key conclusions and, based on those, make recommendations for universities that are active in the field of nanotechnology education.

Terminology

Secondary schools: The EU and associated countries have significantly different secondary school systems. We refer to secondary school students as 9th grade and above only (*i.e.* 14-18 year old students).

NST refers to the general and interdisciplinary subject of **N**ano **S**ciences and Nano**t**echnology. Note that nano sciences include subjects that are not primarily focussed on engineering, for example bio/nano-technology.

STEM refers to **S**cience, **Te**chnology, Engineering and **M**athematics.

STI refers to **S**cience, **T**echnology and **I**nnovation.

Social employer is used interchangeably with non-industrial employer. The description refers to; *inter alia*, the media, government and transnational bodies, non-government organizations, advisory companies, funding agencies, and other employers that are not directly involved in researching, developing, producing or using nanomaterials or nano-enabled products.

Limitations

Note that the task of NanoEIS was not to overall analyse the NST education in the EU and associated countries. The data are thus based on information collected from representative rather than complete case samples. Also, since the university education in that area was at the centre of the study, other training providers were not included. Neither public Vocational Universities (Universities of Applied Science, Professional Universities) nor private training suppliers were included in the present study. The latter may be particularly relevant for lifelong learning activities, but analysing this sector was beyond the scope of the project.

2. Recruiting students to NST studies: Reaching out to secondary schools

STEM education is in a curious situation. It is widely accepted that a substantial number of students and graduates in this area is needed to meet challenges of modernization and globalization, but enrolment in many institutions is considered to be insufficient, a problem which the EU has already addressed in the Lisbon Process that started in 2000 (European Parliament, Presidential Conclusions Lisbon European Council). Efforts are under way on many levels, targeting in particular also females and educationally disadvantaged target groups (*e.g.* socially disadvantaged and migrants). For example, the European Schoolnet has reported on substantial activities in 31 member countries to promote STEM education (Kearney, 2011). Nanotechnology should be especially attractive for raising interest in STEM subjects, since it affects many products that the students use in daily life. Interest is thus usually quite high and where nanotechnology is part of teaching, the students respond very positive. Nevertheless, “nano” is usually not a specific topic to be covered, possibly because it could be integrated in many different subjects (biology, chemistry, physics, and mathematics), which may result in being left out of all of them.

NanoEIS has documented the state of NST teaching in secondary schools (D2.3, submitted July 2013). The main conclusion is that so far no “best practice” model has emerged. The inclusion of nanotechnology in secondary school teaching is reaching only a minority

of students, with Ireland (20%) being by far the European country with the highest exposure. Teaching programs are mostly young (less than 5 years old) and many are based on funded projects. National or international agencies fund such projects as pilots that should establish teaching methods, contents and evaluation methods, but are assumed to result in integration of nanotechnology teaching modules into normal curricula after the funding runs out. This assumption is not realistic since the projects are usually designed based on funding. In the majority of the cases, they cannot be permanently implemented without further financial support. Islands of good practice do exist, but there is no reason to believe that they can spread much beyond their present scope without changing contexts.
The various projects, including EU funded ones, have not been in vain. A large body of teaching materials has been developed that is designed to introduce NST to secondary school students at various levels. Examples are provided in EU-published compendia that are freely available (Bonazzi 2010, Filipponi and Sutherland 2012). NanoEIS has provided further modules to fill remaining gaps (D4.2). The problem is thus not how to teach NST in secondary schools, but how to implement it in practice.

Society and industry may have an interest that information about nanotechnology is reaching the general public via secondary schools, but obviously universities have an immediate interest that appropriate information is available for young people at an age where decisions about career and study options are taken. NanoEIS has found very different levels of university involvement in selected models of NST teaching (D3.1, submitted October 2014), but in general most secondary schools lack of an established connection with a university that would enable them to teach NST subjects.

Recommendation 1
Involvement with local and regional schools is an important way for universities to attract talented and interested students into nanotechnology studies.

This will be easier for closely located institutions, but it should be possible to reach out also to remote schools. Astonishingly, virtual platforms are rarely used in nanotechnology teaching (D3.1), but they would provide simple and cheap ways of reaching out to secondary school students. In a time where many universities have to deal with shrinking student numbers for some study programs, reaching out early and efficiently is an important task. As already mentioned, the tools are there, they just need to be employed to reach more secondary school students than they do now.

Virtual platforms would be particularly useful for secondary schools in remote areas, where no close spatial contacts with relevant academic and industrial institutions can be realized.

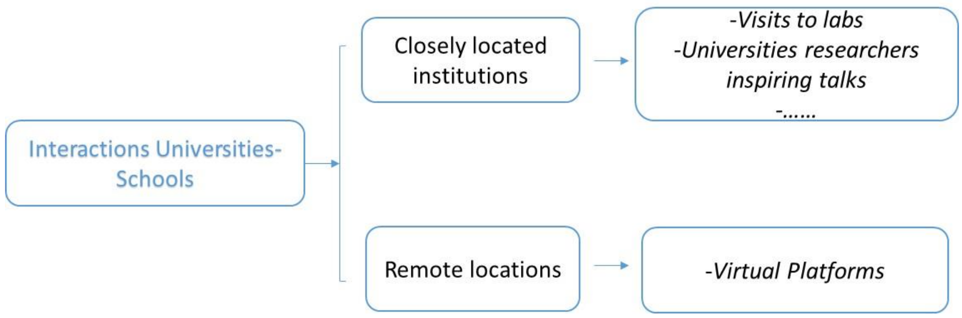

Figure 1. *Preferred ways and tools for interactions between universities and Schools*

3. Considering industrial job skill needs

NanoEIS has found substantial differences between university curricula contents (D3.2) and industrial job skill needs (D2.1). Universities provide research driven tertiary level education and their goal is to enable students to become "problem solvers". It is clear that the goal of university education is not a perfect and ready fit for an industrial job. On the other hand it cannot be ignored that most students choosing a study program in NST expect to enter industry. Main targets for students after graduation are indeed R&D and industry (D3.3), where both areas may be connected by an industry-driven project, or R&D as such is performed in industry.

Recommendation 2
The job skills required in industry have to be taken into account to ensure successful employment of the students after graduation

When comparing university study contents and job skill needs, some topics stand out where industry reports substantial interest but coverage by existing curricula is weak or even absent: **Health, safety, regulation, standardization, environment, disposal, recycling.** Subjects like health and environment are of course scientific disciplines, but they are usually not included as such in technical studies. The missing subjects thus all fall under the category of “additional”, “other” or “complementary” skills. None of these designations is satisfactory. It would be more accurate to call them “central” skills, since no scientific or technical work can be performed without taking these issues into account.
The problem in changing curricula to reflect this insight is that the number of ECTS per study is fixed, so if courses on these subjects are included in a study program as obligatory, other obligatory courses have to scaled back accordingly, which raises concerns that technical expertise may not be taught to a sufficient level.

Two considerations for universities to include the subjects of concern in curricula are proposed:
1) **Missing subjects can be integrated in existing courses**. The topics highlighted above are not only relevant to industry, but also to university based research. Health and safety in the workplace have to be ensured, regulations have to be followed, and environmental issues should be fully taken into account. Many universities have started to implement “green laboratory” or “green campus” practices. Integrating these efforts in existing courses as a teaching subject will make students knowledgeable and the specific situation of nanotechnology can be addressed. Including questions and challenges relating to these subjects in theoretical and practical examinations ensures that the topics are fully integrated. Additional specialization courses can train students that want more expertise in these matters. Polls taken from students showed that there is a high level of interest to learn about subjects where the students expect that they will be useful later on in industry

(D3.2). Interestingly, the most often mentioned subjects were environment/disposal/recycling and management/finance. Students thus would be ready to embrace curricula reforms that give them more information on job-related issues.

2) **Establish new courses to better reflect job skill needs.** NanoEIS has developed model curricula for the bachelor, master and PhD level (D4.1). These curricula are generic and are not intended to be realized as they stand. Nevertheless, they have been carefully designed to fully cover all scientific and non-scientific skills required in the job market. They provide a checklist for existing curricula and a model for new ones that can be adapted and changed to fit the needs and goals of an individual institution. In this respect it should be taken into account that universities are under pressure to be indeed not generic, but to develop and project a specific profile. The description of a university profile should address what distinguishes a specific university from others in terms of research and teaching. Curricula that are optimised to give their graduates skills that make them attractive in the job market could very well be part of a universities' self-description.

1. Involving industry in university teaching

Involvement of industry in technical studies can be expected, for example via direct contacts of university researchers with industry and also via integration of industry experts in curriculum design. Many studies also have an industrial advisory board. While these activities are useful, transfer of students from academia to industry remains a problem, since moving into a different environment is a challenge that many students prefer to delay, even if they are seriously aiming at a job in industry. The problem is mainly a mental barrier that needs to be broken down to facilitate a smooth transfer of students from university to industry. How can this transfer be supported? NanoEIS has identified a single factor that resulted in a much higher transfer of students out of academia into industry (3x higher) and into R&D (4x higher): **Students progress out of academia much quicker if they have taken part in internships at industrial companies or have realised projects commissioned by these companies** (D3.3).

Recommendation 3
Direct contact with industry in the context of an industrially driven activities to facilitate the transfer into the job market

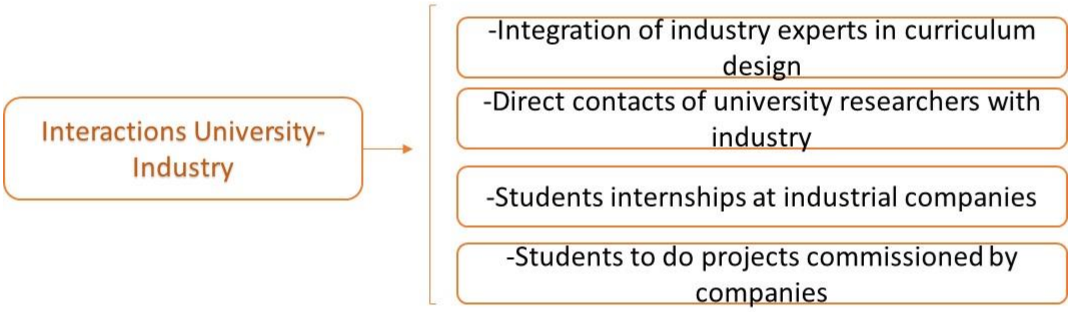

Figure 2. *Possible ways for interactions between universities and industry*

The direct contact with industry in the context of an industrially driven activity breaks down mental barriers and facilitates the transfer into the job market. Having substantial "face time" with industry representatives may play a role, but the experience of approaching problems from an industry point of view may also be rewarding and interesting in itself. It is not easy to get serious and sustained input from industry in teaching, but the success of such efforts shows that it is very rewarding. The already mentioned aspect of developing a specific university profile can also be taken into account for job-oriented teaching involving industry experts.

Recommendation 4
Direct contact with industrial expert focussing on teaching is also essential for lifelong-learning

Specific offers for training of people who are already in the workforce are in times of de-clining birth cohorts an important task for universities. They must be based on solid knowledge, which skills are in demand among employers. Existing research-based cooperations between universities and industries are not sufficient to ensure this, since they are based on technical issues. For non-technical aspects, like regulation or communication, the content of offers for lifelong-learning is ideally based on on-going teaching as well as on a detailed analysis of job market needs. Universities with curricula that already include the full spectrum of job market demands in their study programs will find it easier to respond to the challenges of the lifelong-learning environment, where universities play an important role, but compete with other training providers.

2. Other employers

For non-industrial employers, the job market is much more heterogeneous than for industry. NanoEIS has described three "ecosystems" in which nanotechnology students find jobs outside of industry: Dialogue/communication, regulation, and STI promotion (D2.2). These employers report a current interest in nanotechnology, but this interest is considered to be transitory and fleeting. With few exceptions, the non-industrial job market asks for people that have a solid background in their area of specialization, but are also good generalists and can approach other challenges as they turn up.

The education of NST experts that will enter neither academia nor industry is of crucial importance, since NST needs to be represented in the society as a whole. Many of the non-industrial employers play key roles in the development of technologies (*e.g.* regulatory agencies or bodies that distribute scientific grants), or they are multipliers that can reach large segments of the public (*e.g.* media or political interest groups).

The one factor that social employers have in common is a strong need for communication skills. Courses and exercises for training communication skills are mostly provided in study programs and they are already a best practice for PhD programs. However, most efforts focus on peer-to-peer communication, as exemplified by courses on how to give scientific conference presentations, how to write a scientific paper, or how to prepare a successful grant application. While all these aspects are important to scientists, social employers will be more interested in the communication skills aiming at other target groups, including first and foremost the media, but also lay persons in general, special interest groups, political bodies, children, etc.

Recommendation 5
Universities should ensure that graduates have strong communication skills outside of peer-to-peer communication

Some practical experience can be gained by students when they actively contribute to science-meets-public events, but special courses should be provided as well. With respect to nanotechnology, sceptical and critical voices need to be addressed. This requires skills in risk communication, a skill that is not coming easy to most scientists. Scientists are trained to strive for certainties and often feel uncomfortable to communicate about topics that include uncertainties. This is a key ability, in particular when addressing the media. Communication about risks is an acquired skill and for students that aim at social employers it is essential that they really have within their university studies the chance to acquire these skills.

3. Outlook

Nanotechnology will continue to be a challenge in terms of education. Specific aspects to be dealt with include the following aspects:

- The development of new materials and new methods takes place very quickly. Teaching contents need to be adapted accordingly.
- The technology penetrates more and more industries and applications, another factor that needs to be reflected in study contents.
- Regulation and safety procedures are still in development, as is full life cycle analysis of products beyond use. There are future challenges, but today's students need to be enabled to meet them.
- Nanotechnology studies need to be distinguished from those on materials sciences, physics or engineering. How different are the job markets for students passing through these studies?

These challenges can be overcome, but is they need to clearly defined and addressed. Cooperation between different stakeholders will be of great help to do so. For universities, this implies to forge and maintain close links with secondary schools and industrial as well as social employers with respect to NST study programs. Cooperation between different universities should also be further promoted, since they will be faced with similar problems. Joint development and sharing of teaching material would be one way in which nanotechnology teaching can be improved. The EU may play a role in supporting and fostering such activities that enable a successful cooperation between different stakeholders in the field.

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