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1 Introduction

The present document constitutes Deliverable D3.5, prepared in the framework of the project entitled “*Report on best practices at all levels of education*” (Project Acronym: NanoEIS; Contract No.: NMP4-SA-2012-319054).

This report has been prepared by PLUS, project beneficiary number 1, based on the activities performed within Work Package 3 “Assessment of EU education in nanotechnology”, and the data gathered along the tasks of the Work Package. It describes general observations and conclusions deriving from an analysis of existing practices in teaching nanotechnology at the secondary school and university level.

This deliverable will be made available to the general public due to its nature as a general report aiming at all stakeholders.

2. Secondary schools: the best practices established by Task 3.1 of the project

Teaching materials for nanoscience and nanotechnology that are already available for secondary schools are in general useful and up-to-date. It is suitable for motivating the students to continue their education in science and technology directions, and enhancing their interest in the topics taught on the regular basis, by presenting the cutting edge of scientific research. Now and/or missing examples could be easily added, so teaching materials as such are not a limiting factor. The project task 3.1. has analysed a number of programmes, including local, regional and national ones. Two EU funded projects were also included. The programmes are overall remarkable for good quality and high motivation of the teachers involved. However, the education in EU calls for introduction of the nanoscience and nanotechnology programmes into the national secondary school programmes as a whole. The present situation, in contrast, offers “islands of good practice”, but there is no clear perspective for extending them to the national level. As already remarked, this can be neither ascribed to lack of teaching materials nor to the absence of relevant models that might be copied. Two exemplary programs are mentioned below, but more are available as described in other deliverables.

An interesting model is implemented in Spain, in the form the nation-wide subject *Sciences para el Mundo Comtemporaneo.* The course is a mandatory subject, 2 hours per week, including 8 hours for nanoscience and nanotechnology per year. A similar program (Sparkling Science) exists in Austria. The program is taught as part of school lessons within school hours. The material for the Spanish program was originally developed by the University of Valencia, while the role of educators was passed on to the teachers. The Austrian strategy involved matching local universities with the high schools and included direct contacts of the students with researchers, which is a recommended strategy for secondary schools, but benefits universities as well, since it helps to raise interest in technical subjects and can influence study choices.

The recommended best practice is the introduction of nanoscience and nanotechnology as an obligatory course or as part of an obligatory course into the high school curricula. The integration of nano-topics is possible within many classical school subjects (mathematics, physics, chemistry, biology – essentially all STEM subjects), by taking examples from the real world that involve nanotechnology and that are relevant in the students' daily life. Smartphones, pregnancy assays and modern bicycles are nanoenabled products, so they would be good subjects for project-oriented learning involving nanotechnology. Suitable teaching materials are, as already mentioned, largely available and in particular increased use of remote learning could help to bring knowledge of nanotechnology to all secondary school students.

A substantial weakness of many existing programs it that they are structured as projects. After the end of the project, when extra financing is no longer available, many good initiatives will be discontinued. For this reason a national (or regional) curriculum reform, rather than stimulation of best practices by special programs, is deemed to be the best practice.

2. Universities: the best practices established by Task 3.2 of the project

A good practice – in setting up the curricula in nanoscience and nanotechnology is starting with a general background in mathematics, computer science and natural sciences (chemistry, physics, biology), and next to proceed to more specialized elective courses. The starting semesters of BSc courses – generally the first 12 or 24 months of the studies that were analysed by the NanoEIS project – include a compulsory intensive course in the elementary foundations of traditional disciplines: physics and chemistry (always) as well as biology and material science (for most of the programmes) supported by a strong training in mathematics and computer science. Trainings in the specific elements of nanoscience and nanotechnology are intensified in later years, which introduce partly elective courses. The student gets an opportunity to specialise in one of the many possible directions, in particular in the BSc thesis. This common profile of the education seems adequate and can naturally be indicated as a good practice. The role of the electives naturally depends on the overall orientation of the specific degree programme. The profile of the individual university is thus alrady involved in bachelor study design.

Again, two examples will be given among those analysed and reported in other deliverables.

The University of Basel, which perfroms a degree program in general Nanoscience, allows a quite wide choice of elective courses, which constitute the majority of the credits at later semesters, inlcuding industry involvement. Another Nanoscience degree programme is offered by the iNANO centre wihtin the University of Aarhus. The mandatory general courses in the first semesters are split in the final year into two specialisations (Nanocharacterisation and Current Nanoscience), and the elective courses for the particular interest of individual students constitute half of the programme.

The interdisciplinary character of the BSc courses is generally perceived as a strong point of the curricula. The interdisciplinary character of the education within the first year of the studies is one of the possible factors to motivate the students to enlist for the BScs. Students with a broad interest in natural sciences have an opportunity to study more than one discipline, and decide at a later point on their specialisation at the Master stage.

The degree of specialisation at the Master level within the general field of nanotechnology is considered a necessity. Some programmes that were analyzed by the NanoEIS project assume a fully elective programme. In particular in the iNANO centre of Aarhus, the Board of Studies approves an individual plan for each of the students who can choose from all the courses taught by Aarhus University. The Technical University of Denmark (Master in Physics and Nanotechnology), which introduces electiveness at the level of both the separate modules and study lines, implements a more structured choice. This master programme offers a number of elite courses in MSc honours option with a limited number of participants that need to fulfil high quality criteria to enlist.

A prominent example of ellectiveness and openess of the programme is represented by the Swiss Master of Advanced Studies in Nano and Micro Technology. The program has an elective modular character with selection of courses left as a free choice for the students. Each of the modules has an intensive character and a limited duration. The students needs to complete the required number of ECTS and prepare the Master thesis in order to complete the course. However, the time that it takes for the student to complete the Master is not strictly limited: The requested number of ECTS points is to be gathered within 6 years[1]. Moreover, the separate modules are open also for industry employees that are not interested to enlist on the full Master course. This seems a highly recommendable practice in the context of the lifelong learning, which is considered of increasing importance for the mobile job market. As an additional benefit, the stu-

[1] It should be noted in passing that the option of acquiring credits over a long time is especially useful for students that need more individual freedom, e.g. for professional reasons (they may already have a job) or for family reasons. With good supervision there is no reason to assume that the quality of a Master study completed in 6 years is not on the same level as one completed in 2 years.

dents with no previous professional experience cooperate within the courses with peers who are active in their profession, which gives the students an additional training opportunity, and provides him / her with a network of professional relations (1/3 of the students are former or present employees of the industry). Moreover, the program offers half time jobs, mostly in R & D departments of SMEs. Representatives of ‘Bioelectronics & Nanotechnology' specialisation in the Hasselt University in Biomedical Sciences also reported that the separate modules are open for interested people from outside of the Master course, which again refers to lifelong leraning being integrated with formal university studies. However, those programs are in this respect unusual and this integrative approach is rather a rare practice in university study programmes.

Training in nanotechnology requires a broad set of competences that need to be transferred to the students and it also requires the availability of substantial equipment for practical teaching. A good practice is therefore teaching by larger consortia, including several departments of the same university or of several universities. Note that the analysis of the NonoEIS project covered three nation-wide programmes in nanoscience and nanotechnology (Technical University of Denmark, Swiss Master in Nano and Micro Technology, Spanish National School on Molecular Materials), as well as several European projects (Nanomat European Master programme, Erasmus Mundus Monabiphot Master in Nanoscience, Erasmus Mundus Nanofar PhD Programme).

In addition to the university consortia, a good practice is placing the educational programmes within a wider environment involving science, research & development centers, industrial companies and other stakeholders. The iNANO center at Aarhus is the most promiment example.

Introduction of courses on marketing and commercial applications to the scientific & technology curricula appears as a good practice inparticular considering studnets aiming for start-up enterprises. A prominent example is the Master of Philosophy in Micro- and Nanotechnology Enterprise by the University of Cambridge, which adopts a part of the existing courses of business management and covers problems involved in the processes of discovery and exploitation. The curriculum contains modules on Science Communication in Media, Business and Research, as well as Management of Technology and Innovation, which are taught by experts from industry. Training in business related modules is present in Bachelor courses at Saarland University, nanotechnology BsC degree offerd by the Technical Institute of Dublin and within NanoFar Erasmus Mundus. In the last case, industrial experts teach Entrepreneurship / commercialisation. Similar training relevant for industrial property rights are taught at Saarland University. The Dublin Institute of Technology provides modules in Entrepreneurial skills, Invention, Innovation and Commersialisation.

The survey of Task 3.2. indicated that transition of the graduates to the job market within the competences they acquired during the education is strongly influenced by interactions with industrial partners. The best practices with this respect were pointed out in Deliverable D3.4. that is submitted in parallel to this document. Here we highlight just the main conclusions: The transfer of graduates in nanoscience and nanotechnology programmes to industry and R&D companies is largely facilitated when the students participate in cooperation with industry or when they undergo industrial internship training. This single factor was established by the present study as the most effective one for a successful start of industrial careers of graduates. Programmes that include courses taught by industrial experts produce graduates which are three times more likely to find employment in R&D companies. Courses introduced by industrial demand to curricula increase three times the flux of graduates to industry, but reduce somewhat the one for the R&D companies. Cooperation with industry in setting up the curricula has a positive, but quite limited effect on the transfer of graduates to industry and R&D companies.

In conclusion, there is no substitute for direct and substantial contact of students with industry to break down for them the (probably mainly mental) barriers between academia and industry and to facilitate their smooth transfer into the non-academic job market.