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Executive Summary

NanoEIS is an EU funded research project dedicated to evaluate how nanotechnology education has been integrated into secondary schools and universities, how cooperation between different partner institutions were implemented, and in which ways industrial and non-industrial (social) employers have been and can be involved.

The individual studies have been published as deliverables and are available on the project website. Based on these data, the NanoEIS consortium makes the following suggestions to secondary schools systems, local, regional, national and European.

Recommendations were divided into 3 main categories, as written below:

A. Pedagogical/Academic

i. **Development/updating teaching materials –** We recommend developing 60 academic hours for secondary schools

ii. **Teachers Training –** We recommend developing and implementing 10-20 hours course of training.

iii. **High school accreditation in NST/STEM studies –** We recommend establishing a set of nanoscience and nanotechnology (NST) accreditation standards.

B. Infrastructure

i. **Accessibility to Regional Labs** –we recommend that all major cities in the EU and associated countries will appoint an NST research lab to host students learning NST for excursions and internships.

ii. **Teachers' training centres -** The centres (regional or national) must have the infrastructure and knowledge for the training of the teachers to teach NST.

iii. **European platform to collaboration -** A collaboration platform across these centres will serve for mutual learning and forming a community of educators in the NST subject.

C. Support plan

i. **Ministries of education -** could contribute by allocating teaching hours for the program; accreditation for NST in the baccalaureate; support the teachers training; and allocate resources for excursions, equipment and teaching and learning resources.

ii. **The EU -** could contribute by forming a set of standards for NST curriculum; by supporting the development of teaching and learning materials; and establishing NST education conferences across Europe.

iii. **Industry -** could contribute by providing grants for the development of NST teaching and learning materials; offer internship programs for secondary school students; and host teachers training courses etc.

iv. **Universities -** could contribute both knowledge and facilities in the form of hosting schools excursions; offering visiting lectures to schools and teachers' training centres; and offer students internships and advising in the development of teaching materials.

v. **Science centres -** could offer advice in developing teaching materials; and develop by themselves excursion programs in NST for secondary schools students.

Moreover, in this document, the estimated costs of the various components of these recommendations were also elaborated.

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, **E**ngineering, 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.
- **ELSA** refers to **E**thical, **L**egal, and **S**ocietal **A**spects of an issue (in this context NST). Nanotech teaching would benefit from including controversial arguments,

Students had to analyse a problem in-depth in order to gain an insight into its themes.

- **RRI** refers to **R**esponsible **R**esearch and **I**nnovation is an ethical concept promoting acceptability, sustainability and societal desirability of the innovation process and its marketable products.

Limitations

The task of NanoEIS was not to overall analyse the NST education in the EU and associated countries. Thus, the data is based on information collected from representative rather than complete case samples. In addition, since the secondary education in that area was at the centre of the study, other school systems such as vocational training systems were not included. Moreover, the field of NST education is dynamic and growing. For practical reasons, projects initiated after the survey for this report was completed were not included. Lastly it is important to note that this report contains general recommendation as deducted from an array of mostly local to national scale projects. The recommendations will apply mostly on national to regional scale and therefore the report does not contain specific recommendations for individual locations.

1.-Introduction

Nanotechnology is a Key Enabling Technology that penetrates various aspects of the modern life in the 21st century, including industry, academia, consumer products, health opportunities and risks, environmental issues and education. Due to its rapid development and growing societal role, these emerging fields should also grow in educational importance.

One of the 'grand challenges' for nanotechnology is education, which is looming as a bottleneck for the development of the field (Roco, 2003p. 1247). Roco's call pinpoints the very problem of NST: the fact that secondary schools lag behind industry and academia. This issue will, and perhaps already does, cause a shortage of skilled employees, researchers and lack of public awareness, all very much needed for the growing field of NST (Roco et al, 2010).

This report focuses on the potential contribution of secondary schools to enhance NST as a tool to achieve greater goals. These goals include increasing the number of students taking science & technology majors in secondary schools and later on in higher education; to provide better opportunities to combine the new discipline of NST with innovative pedagogy; to establish better preparation of graduates to meet job market requirements; and to raise awareness of the general population to approach NST opportunities and risks based on solid knowledge.

Achieving a solid knowledge on this subject is challenging because of its complexity and multidisciplinary. In this sense, the earlier it is included in the educational levels, the better for reaching the above-mentioned goals.

This document will introduce: The current situation of the collaboration of secondary schools (based on data gathered and analysed in previous reports) with universities; The expected outcome of integrating NST studies in the secondary schools; and recommendations regarding integration of NST to the secondary schools in the EU and associated countries .

This report will be sent to 30 members Ministries of Education in Europe to inform policymakers about the recommendations based on the findings of the project.

1.1 The current situation: teaching NST in secondary schools

The NanoEIS project began on 1st November 2012. During the project's life span, there were three reports (MS2, D2.3, and D3.1) as of product of a research conducted about the integration of NST in secondary schools, and the collaboration of schools with academia and industry in the EU and associated countries. The data was gathered through online questionnaires, key person interviews, survey of official documents, and visits to schools.

The main findings of the reports were:

- The teaching of NST is in its infancy. As a whole, the total exposure of NST is minor: from a few thousand students to 20% of all students at best (Ireland).
- Where the total number of hours is small, introducing NST might encounter resistance due to trade-off with other subjects.
- Several NST programs were implemented over the last 5 years, yet most included no more than a few schools and the projects typically ended within a year or two.
- Regarding the contribution of NST curricula to the transition of students to university, we found some very optimistic reviews from involved teachers. Only one national program (Spain) actually introduces students to universities. Other schools and teachers do it (or not) voluntarily.
- Since the academic curriculum is mostly theoretical, when cooperating with schools that seek relevance to their students in the form of career choices, schools are often left empty-handed.
- The main characteristics of the 12 best practices programs that were researched:
    A. The main strength of a best practice project is being taught as a theoretical and compulsory subject
    B. Virtual platforms were not found to have been used very much
    C. Community involvement was generally scarce.
    D. The projects greatly vary in terms of the independence of the subject and cooperation with industry and academia. This variance suggests that mutual

learning could greatly contribute to promoting good practices

2.-Expected outcomes of implementation of NST in secondary schools

One of the main historical functions of the secondary schools in Europe was, and continues to be, preparing young citizens to higher education. This role must be reshaped continuously to follow ever changing trends in academic demands as well as job market trends. Below some expected outcomes of implementation of NST (as a good STEM program) in the secondary schools are listed:

1. Facilitate transition to universities (science studies)

, NST can be offer, as a leading example of interdisciplinary STEM education, due to its innovative character and potentials in order to fulfil this role. The long decline, or at least stagnation, in the number and ratio of secondary school's graduates choosing science and technology tracks in higher education has its source in the often poor science and technology education at secondary schools. Therefore the change must take place in the same realm.

The evaluation data that was gathered after implementation of a NST program for secondary school in Australia showed that, after taking the course, there was an increase in the number of students who chose to continue studying science (Alford *et al*., 2009). Similar results have been reported for other nanoeducation courses (Blonder & Dinur, 2011).

NST is a model for interdisciplinary STEM education, as it combines various disciplines underlying the cutting edge field of nanotechnology. This model could be replicated for other interdisciplinary STEM curriculum such as biotechnology, neuroscience, aerospace engineering, etc.

The key elements to make NST such a leading candidate, besides the combination of various disciplines, are its hands-on approach, broad relevance to everyday life, appeal to greater population of students and the potential future in the job market.

Another important characteristic is the correspondence of NST studies in secondary schools to the current trend in science and technology in higher education (a trend recommended to be broader embraced in higher education in the EU in NanoEIS D6.2).

To conclude, **the modus of NST, as a pioneer example of interdisciplinary STEM edu-**

cation in secondary schools, it is recommended for its better appeal and preparation towards entering university programs (see below). In particular, including NST teaching of secondary school graduates would facilitating them to consider and eventually chose science & technology studies in university.

2. **Preparation to university**

Science and technology students in universities face ever-growing offers of curricula. Novel curricula require from them broader preparation in STEM subjects and consequently may discourage students with narrower preparation. NST, as an example of interdisciplinary STEM education, holds potential for a better preparation of secondary school graduates to the current developments in both threshold requirements and the mind-set required from science graduates in the 21st century.

NST meets this outline in its core and sets an example to be replicated for other STEM curriculum.

3. **Preparation to the job market**

The job market has starting to have communication with academia and therefore influences new trends in higher education. On the other hand, there is little if any communication between the employers and secondary schools in most EU countries. This lack of communication causes general disregard, lack of cooperation and perpetuates wrong stereotypes about the job market.

Cooperation between secondary schools and the industry holds great potential for both sides in the form of offering a direct glance at the cutting edge of technology, internships, and generally greater appeal to the subject matter, as for the industry it seeds the future potential employees with the will and interest in NST.

4. **Awareness among civil society**

NST has generated broad public interest and media attention. New science and technology, and in particular the introduction of new consumer products are often received with concerns about the safety and other social implication it may hold. A healthy public discussion weighting the benefits and potential good vs. the risks and potential harms requires some basic public understanding, to the very least, of the science and technology behind it, as well as better discussion and critical thinking skills. Misconceptions and poor understanding amplify concerns and disregard benefits. This amounts to unhealthy discussions and wrong decisions at consumer, regulatory and social levels. The introduction of NST offers an opportunity not only to inform the public about science and technology, but also to better the critical thinking and discussion skills on the **e**thical, **l**egal and **s**ocial **a**spects (ELSA) in the early stages of introduction.

This attitude meets the concept of the RRI (Responsible Research and Innovation). As Von Schomberg (2011) defined it, RRI: "is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products."

Equipped with knowledge and better skills of critical thinking, secondary school graduates are best candidates to serve as agents of a more productive discussion on the matter.

Hence, following the RRI principals, we recommend that the curriculum in NST will include the practice of discussion in the ELSA of NST in class and outreaching to the community with such discussions.

5. Gender issues

Across Europe, and worldwide as well, science and technology classes in secondary schools, are gender biased. For most students secondary school is the first time in their life facing the option to learn science and technology. Over the years, female students in secondary schools had opted out or where not encouraged to take science and technology, and consequently did not continue this path in higher education. This trend had continued even when blocks where lifted, often due to an unappealing image of science and technology presented to girls. NST programs in secondary schools have proven to overcome this last inhibition and therefore offer a unique by-product benefit in the decades-long effort to level the gender formation of the science and technology classes in secondary schools (Jackson, 2009).

3.-Recommendations

NANOEIS recommendations about what is required for the best integration of NST in the secondary school in EU and associated countries is presented in this section. These recommendations are based on the schools needs and the insights from the best practices surveyed and analysed. They are categorized into 3 main topics: Pedagogical/academic; Infrastructure; and support plan. The estimated cost of the components is detailed in the next section of the report.

3.1 Pedagogical/Academic

i. **Development/updating teaching materials** – As found here, in best practice programs, NST had been taught as an independent subject. In the last years dozens of teaching and learning materials were developed in most EU languages (in EU funded projects, the materials are translated to various languages). What is required is to gather the materials to a full school year program, and to culturally adapt and contextualize them locally.

   We recommend developing 60 academic hours for secondary schools that can be based on existing materials. In this manner, the students will learn the basic concepts of NST (Sakhnini and Blonder, 2015), conduct experiments, visit research centers, and prepare and participate in a debate about ELSA issues. This, of course, requires national curricula recognition and support.

ii. **Teachers' Training** – most science teachers in EU countries do not have the expertise to teach NST. They may have the appropriate background, but they need to go through a teacher training, in which they will learn the main concepts. (Jones *et al*., 2013). In the best practices that we have surveyed, in which the teachers conducted the teaching (and not visiting lecturers), the training varied between no training at all to 60 hours of face-to-face and virtual lessons.

   We recommend developing and implementing 10-20 hours (1 hour of training for 3 hours of teaching) of training that will include expert lectures, hands-on experiments, virtual learning and experience preparation and participation in ELSA debate. A teachers' guide and background materials must accompany the course.

iii. **High school accreditation in NST/STEM studies** – in order to better prepare young students for careers or further training in NST (*e.g*. at a university), this kind of accreditation is needed to be part of the baccalaureate. This accreditation could be realized with the support from policy-makers and the different stakeholders (university and industry).

We recommend establishing a set of NST accreditation standards (A levels, vocational, etc.). This will increase the appeal of the program to the students and enable the validation by stakeholders to make NST a sustainable component of the curriculum.

3.2 Infrastructure

i. **Accessibility to Regional Labs** - In order to improving the core understanding of NST for the next generation, we recommend that all major cities in the EU and associated countries will appoint an NST research lab, whether academic or industrial R&D, to host students learning NST for excursions and internships. Another possibility is to have remote access to NST labs. Since it is unfeasible to demand that the education systems establish such labs just for this purpose, collaboration with industry and academia is required.

ii. **Teachers' training centres** - The teachers training centres (regional or national) must have the infrastructure and knowledge for the training of the teachers to teach NST. This will require collaboration with industry and academia to acquire and constantly update the knowledge and equipment needed, as well as access to virtual remote labs.

iii. **European platform to collaboration –** A collaboration platform established across these centres will serve for mutual learning and forming a community of educators in the NST subject. The European School Net could serve as a basis for this network.

3.3 Support plan

i. **Ministries of education –** The ministries of education could contribute by allocating teaching hours for the program, accreditation for NST in the baccalaureate, support the teachers training and allocate finances for excursions, equipment and teaching and learning resources.

ii. **The EU -** The EU could contribute by forming a set of standards for NST curricula, by supporting the development of teaching and learning materials for schools (as done in projects like NanoYou and Nanopinion), and by initiating NST education conferences across Europe.

iii. **Industry -** As mentioned above, the collaboration between industry and secondary schools could benefit both. The industry could contribute by providing grants for the development of NST teaching and learning materials, offer internship programs for students, host teachers training courses, etc.

iv. **Universities** - The universities could contribute both knowledge and facilities in the form of hosting schools excursions, offering visiting lectures to schools and teachers' training centres, offer students internships and advising in the development of teaching materials.

v. **Science centres** - Science centres could offer advice in developing teaching materials and develop by themselves excursion programs in NST for secondary schools students.

Costs

This table reports an estimate of costs of the actions recommended. As required, the costs are detailed respectively to the components relevant to ministries of education and the EU. Note that the cost may vary depending on local situations.

Component	Description	Cost	Comments
Development of teaching materials	30-60 hour course, 3-6 months of payment	16,500-33,000€	EU standard monthly payment (PM=5,500 Euro)
Teachers' training	10-20 hours of training, 2-4 months of payment + facilities and costs	15,000-30,000€	Per training course of 15-20 teachers
High-school accreditation	Inspection, coordination, 1-2 months	5,500-11,000€	Consulting and coordination
Teachers	0.25 to 2 year payment added per school (depending on the size of the school).	1,375-11,000€	Reallocation of hours from other subjects could lower the costs even further
Excursions to labs, science centres & industry	Costs may vary according to distance, entrance fees, traveling etc.	50-200€	Costs per student.
Regional to national teachers training centres	Costs vary bases on local costs and existing infrastructure.	5,000-50,000€	Costs per use of training courses
Use of NST lab	Cost per hour of machine use[1]. Lab assistant not included.	30-150€	Current scarcity of labs offering this service may change if demand will rise.
European platform to collaboration	Coordination Conference	11,000€ 10,000-20,000€	Year-long Per conference

[1] https://www.scienceexchange.com/services/sem

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- **Reports carried out as part of NanoEIS project:**
  - Selection of secondary school programs for in depth study (2013)
  - Report on secondary schools education (2013)
  - Report on best practices in nanotechnology education at the secondary school level (2014)