NANOYOU Teachers Training Kit in Nanoscience and Nanotechnologies

Chapter 1 – Introduction to Nanoscience and Nanotechnologies

Module 1- Fundamental concepts in nanoscience and nanotechnologies

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Chapter 1: Introduction to Nanoscience and Nanotechnologies

This is an introductory chapter to define nanoscience, nanotechnologies and nanomaterials. It illustrates in general terms what is "special" about the nano-world, and why this area of science is exciting and worth bringing into the classroom.

Definition of Nanoscience and Nanotechnologies

The most common working definition of nanoscience is the following:

"Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale"[1].

Bulk materials (the "big" pieces of materials we see around us) possess continuous (macroscopic) physical properties. The same applies to micron-sized material (e.g., a grain of sand). But when particles assume nano-scale dimension, the principles of classical physics are no longer capable of describing their behaviour (movement, energy, etc). At these dimensions, quantum mechanics principles apply. **The same material (e.g., gold) at the nanoscale can have properties (e.g., optical, mechanical, electrical, etc.) which are very different from (even opposite to!) the properties the material has at the macro scale (bulk).** Nanotechnologies are defined thus:

"Nanotechnologies are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale."

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[1] *Nanoscience and nanotechnologies: opportunities and uncertainties, report by The Royal Society and The Royal Academy of Engineering 2004,* http://www.nanotec.org.uk/

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In the next sections of this chapter we will discuss these definitions and their meaning, starting with what is meant by the "nanometre scale".

The nanometre scale

The nanometre scale is conventionally defined as 1 to 100 nm. One nanometre is one billionth of a metre (10^{-9} m). The size range is set normally to be minimum 1nm to avoid single atoms or very small groups of atoms being designated as nano-objects. **Therefore nanoscience and nanotechnologies deal with at least clusters of atoms of 1nm size**.

The upper limit is normally 100 nm, but this is a "fluid" limit; often objects with greater dimensions (even 200nm) are defined as nanomaterials. A valid question a student might ask is "why 100nm, and not 150nm?", or even "why not 1 to 1000nm?" The reason why the "1 to 100nm range" is approximate is that the **definition itself focuses on the effect that the dimension has on a certain material – e.g., the insurgence of a quantum phenomenon – rather than at what exact dimension this effect arises**. Nanoscience is not just the science of the small, but the **science in which materials with small dimension show new physical phenomena**, collectively called quantum effects, which are size-dependent and dramatically different from the properties of macro-scale materials.

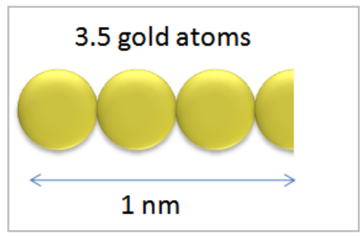

Figure 1. Three and a half gold atoms placed in a row equal to 1nm (assuming a covalent radius of 0.144 nm each). (Image credit: L. Filipponi, iNANO, Aarhus University. Creative Commons ShareAlike 3.0)

Nanoscience is the study of materials that exhibit remarkable properties, functionality and phenomena due to the influence of small dimensions.

What is a nanomaterial?

A nanomaterial is an object that has at least one dimension in the nanometre scale (approximately 1-100nm). Nanomaterials are categorised according to their dimensions as shown in **Table 1**:

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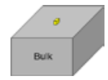
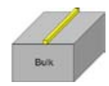
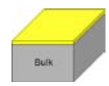
Nanomaterial Dimension	Nanomaterial Type	Example
All three dimensions < 100 nm	Nanoparticles, Quantum dots, nanoshells, nanorings, microcapsules	
Two dimensions < 100 nm	Nanotubes, fibres, nanowires	
One dimension < 100 nm	Thin films, layers and coatings	

Nanomaterials can be of two types:

• "**non-intentionally made nanomaterials**", which refers to nano-sized particles or materials that belong naturally to the environment (e.g., proteins, viruses, nanoparticles produced during volcanic eruptions, etc.) or that are produced by human activity without intention (such as nanoparticles produced from diesel combustion).

• "**intentionally made**" nanomaterials, which means nanomaterials produced deliberately through a defined fabrication process.

The definition of nanotechnologies does not generally include "non-intentionally made nanomaterials", and is therefore limited to "intentionally made nanomaterials".

A very important concept to bring into the classroom is "**the smallness of nano**". Nanomaterials are larger than single atoms but smaller than bacteria and cells. It is useful to use a scale like the one shown in **Figure 2** where students can visualise the relationship between bulk materials, like a tennis ball, and nanomaterials.

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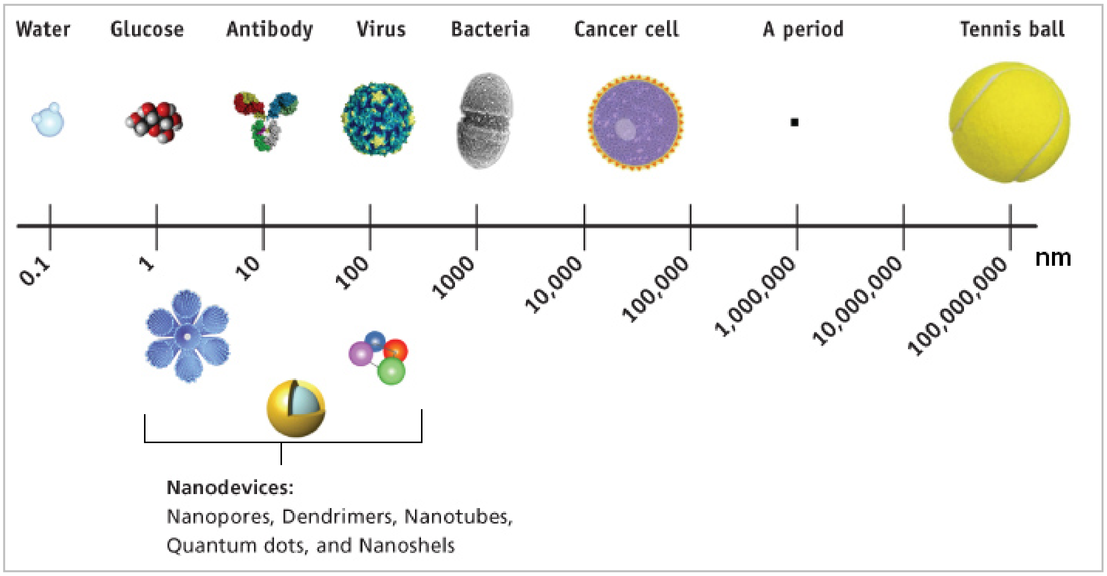

Figure 2. From macro-materials to atoms. Nanomaterials and nanodevices that are of interest in nanotechnologies are in the lower end of the scale (1-100 nm). (Image credit: adapted from: "A snapshot of nanotechnology", National Cancer Institute).

Some **good examples** to bring into the classroom:

- Our **fingernails grow** at the rate of 1 nm per second.

- The **head of a pin** is about 1 million nanometres across.

- A **human hair** is about 80,000 nm in diameter.

- A **DNA molecule** is about 1-2 nm wide.

- The **transistor** of a latest-generation Pentium Core Duo processor is 45 nm.

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What makes "nano" special

"Nano" means small, very small; but why is this special? There are various reasons why nanoscience and nanotechnologies are so promising in materials, engineering and related sciences. First, at the nanometre scale, the properties of matter, such as energy, change. This is a direct consequence of the small size of nanomaterials, physically explained as quantum effects. The consequence is that a material (e.g., a metal) when in a nano-sized form can assumes properties which are very different from those when the same material is in a bulk form. For instance, bulk silver is non-toxic, whereas silver nanoparticles are capable of killing viruses upon contact. **Properties like electrical conductivity, colour, strength and weight change when the nanoscale level is reached. The same metal can become a semiconductor or an insulator at the nanoscale level.** The second exceptional property of nanomaterials is that they can be fabricated atom-by-atom, with a process called **bottom-up**. The information for this fabrication process is embedded in the material building blocks, so that these can self-assemble in the final product. These two fabrication methods are reviewed in **Chapter 7 of Module 1 ("Fabrication methods").** Finally, nanomaterials have an **increased surface-to-volume ratio** compared to bulk materials. This has important consequences for all those processes that occur at a material surface, such as catalysis and detection. The properties that make nanomaterials "special" are further discussed in **Chapter 4 of Module 1 ("Fundamental 'nano-effects'")**.

Nanoscience and nanotechnologies depend on the exceptional properties of matter at the nanoscale level. In this context, "nano" doesn't only mean "1000 times smaller than micro", and nanotechnologies are not just an extension of microtechnologies to a smaller scale. It is an entirely new paradigm that opens entirely new scientific opportunities.

The exceptional properties of matter at the nanoscale are the subject of **Chapter 4 "Fundamental 'nano-effects'"**.

From Nanoscience to Nanotechnologies

Nanoscience is an "interdisciplinary science", which means that it involves concepts of more than one discipline, such as chemistry, physics, etc. There are other disciplines that are inherently interdisciplinary, like materials science (and engineering), which cover at the same time concepts of chemistry and physics. Nanoscience further expands the borders of material science by adding to the

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mix biology and biochemistry. Nanoscience is thus a "horizontal-integrating interdisciplinary science that cuts across all vertical sciences and engineering disciplines"[2] (**Figure 3**).

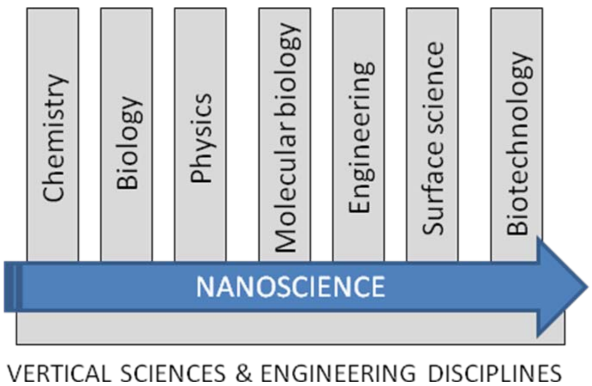

Figure 3. Nanoscience is a horizontal-integrating interdisciplinary science that cuts across all vertical sciences and engineering disciplines. (Image credit: L. Filipponi, iNANO, Aarhus University. Creative Commons ShareAlike 3.0)

Nanoscience offers educators the possibility to bring into the classroom the concept of "interdisciplinary". As it will be discussed in the next chapters (**Chapter 2 and Chapter 3**), we have numerous examples of nanoscience in Nature, as well as in historic artefacts. The educator has therefore an opportunity to truly show how nanoscience integrates not only scientific disciplines (chemistry, physics, biology etc.), but also humanistic ones. Some practical ideas on how to exploit this opportunity are given at the end of this Module in end of this teachers training package in a document titled **"Nanoscience and nanotechnology in the classroom".**

The application of nanoscience to "practical" devices is called nanotechnologies. Nanotechnologies are based on the manipulation, control and integration of atoms and molecules to form materials, structures, components, devices and systems at the nanoscale. Nanotechnologies are the application of nanoscience especially to industrial and commercial objectives. All industrial sectors rely on materials and devices made of atoms and molecules, thus in principle all materials can be improved with nanomaterials, and all industries can benefit from nanotechnologies. In reality, as with any new technology, the "cost vs. added benefit" relationship will determine the industrial sectors that will mostly benefit from nanotechnologies.

[2] From: G. L. Hornyak et al., *Introduction to Nanoscience*, CRC Press, 2008.

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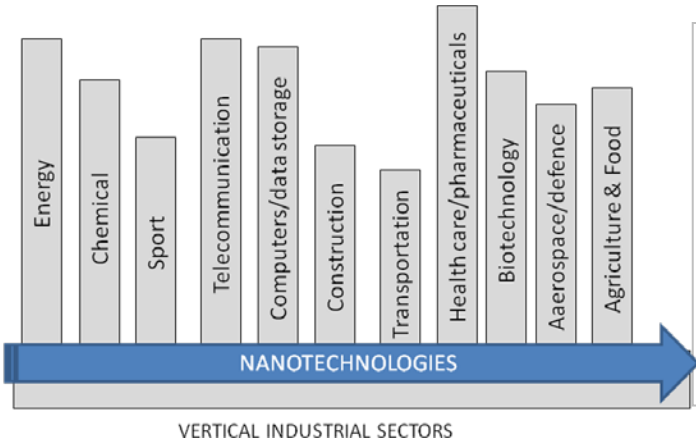

Figure 4. Nanotechnologies are horizontal-enabling convergent technologies which cross all vertical industrial sectors. The different heights of the industrial sectors in the graph are only indicative and are intended to emphasise the fact that the level of impact of nanotechnologies will be different in each industrial sector. (Image credit: L. Filipponi, iNANO, Aarhus University. Creative Commons ShareAlike 3.0)

Thus, **nanotechnologies are horizontal-enabling convergent technologies**. They are "horizontal" because they cut across numerous industrial sectors; they are "enabling" since they provide the platform, the tools to realise certain products; and are "convergent" because they bring together sectors of science that were previously separated.

One example is **DNA silicon chips**, which are an example of convergence between semiconductor science (inorganic chemistry) and biology, with applications in the medical industry.

Is it Nanotechnology or Nanotechnologies?

When the term was first used in 1959, it was used in the singular, "nanotechnology". In the last few years the field has evolved steadily in terms of science and technology development. Scientists have also started to address the safety, ethical and societal impact of "nanotechnology". In doing so it has become clear that this is not one technology, but that different nanotechnologies exist (which all share the common concept of using the properties of matter at the nanoscale). There has even been a call from a prominent scientist and expert in nanotechnologies to stop using the singular, and to use the plural, precisely to communicate the variety of materials and methods involved in nanotechnologies. Nowadays the plural form is most used, and it is the form that will be used in this Teachers Training Kit.

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Bringing "nano" into the classroom: why and how?

There are numerous reports that emphasise the need to "revitalise" science teaching in school, particularly at the high-school (14+) level. It is also often recommended in those reports to encourage inquiry-based science education (or problem-based learning), where teaching is conducted through an inductive (rather than deductive) method. This should be combined with numerous "hands-on" activities to allow students to see science for themselves, and then learn and understand the theoretical explanation of what they see. Nanoscience and nanotechnologies offer such opportunities!

A cutting-edge science and technology

Nanoscience and nanotechnologies offer teachers a new instrument to **bring exciting science and technology into the classroom**. Nanotechnologies are now used in numerous devices young students are very familiar with, such as computers, mobile phones and iPods. Nanoscience offers the possibility to improve numerous material properties and create new ones; in the future we will have more and more products that incorporate some form of "nano"-either a nanomaterial, or a nano-enabled technology. Bringing "nano" into the classroom means bringing in the latest cutting-edge science and technology and talking about very exciting future scientific developments.

Hands-on nano!

One of the peculiarities of nanoscience is that numerous "nano-effects" can be seen in our "macro world". The best example is a gold colloid (made of gold nanoparticles about 15 nm dispersed in water) which is red in colour. When some salt solution is added to the gold colloid, it turns blue! There are many "hands-on" activities and demonstrations that can be used to show the properties of nanomaterials – effects that are visible! So even though the "nano-world" is invisible, we can appreciate its effects in materials that youngsters are very familiar with, like gold. In this teachers training kit these activities are described in an "**Experiment Module**" and throughout the main text as simple demonstrations that a teacher can perform in the classroom.

"Nano" in the context of "conventional" scientific disciplines

One of the challenges a science teacher might face is to think how to insert nanoscience in the conventional science curricula. Where does this "new" science fit into the "conventional" scientific

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disciplines, like chemistry, physics or biology? The aim of this training kit is also to provide teachers with practical ideas on how to integrate nanoscience and nanotechnologies in their science curriculum.

Nanoscience is not new per se, it is a name we now give to a number of fields of research that share a common principle: the investigation of matter at a scale which is intermediate between "bulk" matter, described by Newtonian physics, and atomic matter (meaning atoms, electrons, etc.), described by quantum physics. Nanoscience works in this "size window" which is approx. 1-100 nm in scale where matter shows some remarkable properties. In this "window" are included a number of scientific fields that have very old origins, like colloidal science (see also Chapter 3 of Module 1 "History of Nanotechnologies"). In a sense **the study of atoms and molecules is the basis of most natural-science disciplines**, such as chemistry, biochemistry and physics. Nanomaterials are not all new either: nanocrystals, nano-sized catalysts and magnetic nanoparticles have been studied for many years now, for a variety of applications. Some "nano-tools" are not that recent either: for instance, the Atomic Force Microscope (AFM) and the Scanning Tunnelling Microscope (STM) techniques were first introduced to the scientific community in the mid 1980s.

So the question is: if it's not all new, why is it so special? In recent years researchers have been able to uncover enormous potentials of nanoscience and nanotechnologies thanks to a **new set of analytical and fabrication tools**. At the same time, in recent years new nanomaterials have been intentionally fabricated or discovered, novel nano-tools have been developed and old ones implemented, and novel properties of matter at the nano-scale level have been discovered.

All of this has allowed the **systematic investigation of nanomaterials and the realisation that the exceptional properties of matter at the nano-scale level can be used to build new materials, systems and devices with properties, capabilities and functions that could not be achieved if bulk materials were used**. This is where the novelty is, and the reason for being excited about it! The exceptional properties of matter at the nanoscale have prompted scientists to "reinvent" the way materials are engineered and produced, and is opening up exciting new opportunities in many different fields.

Nanoscience is thus a "work-in-progress science". A "work" that finds its roots in disciplines, such as chemistry and physics, where a lot of fundamental knowledge is well established, and that is progressing towards fields where new knowledge is currently being created and collected.

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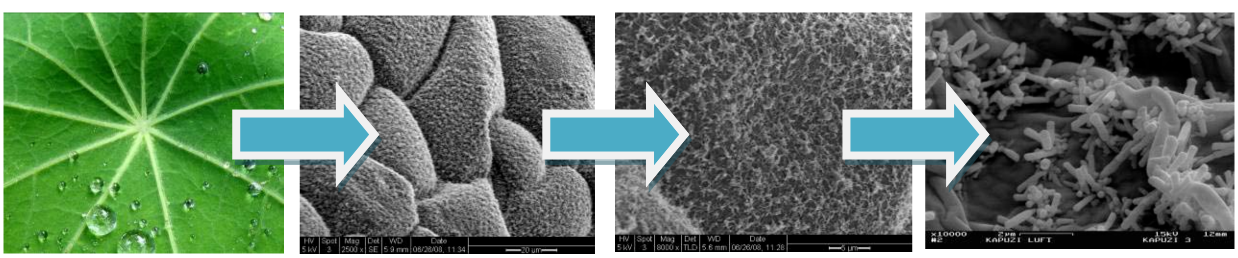
For these reasons we prefer to describe **nanoscience as an evolution** of more traditional scientific disciplines. “Nano” is not a revolution per se, but nanotechnologies might have some revolutionary implications for our society, in terms of applications or tools that they will enable.

Nanoscience in Nature: a great starting point

Even though nanoscience is often perceived as a science of the future, it is actually the basis for all systems in our living and mineral world. We have hundreds of examples of nanoscience under our eyes daily, from geckos that can walk upside down on a ceiling, apparently against gravity, to butterflies with iridescent colours, to fireflies that glow at night. **In Nature we encounter some outstanding solutions to complex problems in the form of fine nanostructures with which precise functions are associated**. In recent years, researchers have had access to new analytical tools to see and study those structures and related functions in depth. This has further stimulated research in the nanoscience area, and has catalysed nanotechnologies. So, in a sense, natural nanoscience is the basis and inspiration for nanotechnologies.

Natural nanomaterials offer a great starting point to bring nanoscience into the classroom. Images from microscopes are a great resource, especially if used consistently in a “zoom-in” fashion, starting from a macro object (such as a plant leaf) and showing how **zooming in** with subsequent magnifications reveals finer and finer structures. This becomes extremely effective if we start with familiar, natural objects, like plants and animals. **Students will be fascinated to discover how many natural nanomaterials are around us**



MACRO **MICRO** **NANO**

Figure 5. Close-up views at progressive magnification of a nasturtium leaf revealing the presence of surface nanocrystals (image on the far right). (Image credit (A): A.Snyder, Exploratorium; (B, C): A.Marshall, Stanford University, (D): A. Otten and S. Herminghaus, Göttingen, Germany, all images are material of the NISE Network, reprinted under NISE network terms and conditions).

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Teaching challenges

The definition of nanoscience naturally brings along the definition of a nanometre, which is a billionth of a meter. Although the are many examples that one can present of objects that have dimensions in this regime, such as the width of DNA (2nm), **mental visualization of these objects is impossible**, and many studies have reported how young people, especially children, lack the mental capacity to actually imagine something this small because of lack of experience. Even for adults, *mental visualization of objects with sub-micron dimensions is extremely difficult (which is a result of the inherent resolution of our visual ability, which is 2 µm)*. So as much we can ask students to imagine something that is a thousand times smaller than their hair, we need to ask if they really understand the sense of the dimensionality we are talking about. And more importantly, if they understand the difference between objects that are in the nanoscale regime and objects that are even smaller, like atoms. For some people knowing that a rock is a million of years old or a thousand of millions of years old makes no difference, both dimensions are just "huge" and are confused in a "time blur". Similarly, the nanoscale and the atomic scale can be perceived as a "scale blur", just too small to think of. Therefore the challenge here is to introduce the nanoscale and the concept of nanoscience in a meaningful way, one that grasps the attention of the students but that also means something to them. In this sense, an enquiry based approach (based on student questions) together with hands-on activities can help. For instance starting from a cube of a soft material, and cutting it progressively until it can no longer be handled (which will not lead to a nanometre sized cube, but will give a sense of smallness); or using **ratio examples**, such as how tall would a tower of single papers sheets be, assuming each sheet to be 1nm. **Images from microscopes** are probably one of the best resources we have, especially if used consequently in a "zoom-in" fashion, like described in the section before. But what is also important is showing the peculiarity of the nanometre scale, why objects in this regime are "special" and behave differently from their bulk counterparts. Examples should be given so instead of trying to imagine a nanometre, the students perceive what it means for example for a certain material to be 2 nanometres rather than 2 millimetres. Gold is a primer case, and the classic example is a gold wedding ring compared with multicoloured gold quantum dots (colloidal gold). Whatever the example or the methodology chosen to communicate it, it is important to remember the young people will have strong difficulty in conceiving nanoscale objects; so it is important not to ask them to they visualize how small a nanometre is, but that they appreciate what it means to be so small. NANOYOU has developed numerous tools (memory game, puzzles, lab exercises) precisely to overcome those difficulties.

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One aspect that is often overlooked (or assumed) when introducing nanoscience and nanotechnology is the actual nature of a "nano-object" or "nanomaterial". It is possible to mistakenly give the impression to the audience that these are free-standing objects or that these are aerosol-like particles that can float in a medium. Although some nanoparticles are airborne, most of the nanomaterials under research or used in commercial products are **integrated or attached to another substrate**. Also, nanoscience does not just deal with nano-objects but also nanostructures within larger objects. For instance, a wire having the dimension of a hair (say, 2 µm) can be formed of molecules which are orderly arranged in nanowires.

Talking about the "bigger picture"

Nanotechnologies have progressed at a fast pace in the last few years, both in laboratories and in the commercialisation of numerous products. The promise of nanotechnologies is great, in many applications, and this has resulted in conspicuous investments both at the research level and in industry. Other emerging technologies in the past were presented to the scientific community (and industry) as revolutionary, with enormous potential for commercialisation, most notably the genetic engineering of foodstuffs. Genetically modified organisms were expected to bring profit and advancement in the food and medical industries. Due to a number of issues (one of the most important being very poor communication between the scientific community and the popular media), GMOs were not received favourably by the consumer community, and the result has actually been the opposite. In many countries these products have been banned or strongly regulated. Numerous ethical questions were also raised on "who" would benefit from these products, and what implications they might have for people's long-term health, as well as the life-cycle of animal and plants. The GMO case is a clear example of an emerging technology that did not go through a careful **Ethical, Legal and Social Aspects (ELSA) analysis**. It is also a clear example of an innovative technology that suffered a backlash from the consumers to the point where research was stopped and entire research centres were closed. Consumers had a power that scientists (and even the media) did not realise until it was too late.

With nanotechnologies there is a general determination to "do it differently" at all levels. **Probably for the first time in the history of scientific innovation, researchers, regulators, non-governmental organisations (NGOs), consumer organisations, trade unions and industry are all involved in setting guidelines, action plans, protocols, codes of conduct, regulations, etc., to make sure that**

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nanotechnologies realise their potentials while protecting the safety of consumers, the environment (in terms of pollution and impact on its life-cycles), and are ethically-sound. Clearly this is a massive effort and the work is complex and has only started. Throughout this teachers training material we will indicate areas of nanotechnology applications that are raising ELSA issues, and the actions that are currently being taken to address them.

For the teacher, bringing ELSA issues into the classroom is an opportunity to talk about of science, technology and innovation in a more complex, “three-dimensional” fashion. It gives educators an opportunity to stimulate discussions in class about which innovations students think are valuable (and which not), who will benefit from these, at what cost. **It is a chance to think and talk about the “bigger picture” of science and innovation and think about its implications not just for the single individual, but for society**.

Talking about ELSA and safety in the classroom

Questions of ethics, social impact, safety, etc. are rarely part of a secondary science curriculum. Depending on age and school curricula, some students might have undertaken some philosophy courses, others probably not, therefore ELSA issues are probably a new concept for most. The question is then **how to introduce those concepts** without overloading pupils with information, and how to respond adequately to questions raised in class. Otherwise the result might be a feeling that ELSA and safety questions are just too big to be even analysed.

The aim of NANOYOU is also to provide teachers with resources to encourage class discussion about ELSA topics related to nanotechnologies. To focus the discussion, the teacher has access to a number of tools, indicated in **Table 2** in next page:

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NANOYOU Tool	**Description**
NANOYOU Nano Role Play (Card game) – download at www.nanoyou.eu	This is a role-play card game with various dilemma scenarios. For each dilemma, several "roles" have been created; each student (or a group of students) gets one specific role and a class debate is held on the dilemma. The dilemmas relate to specific applications of nanotechnologies; these dilemmas are discussed in the **Module 2 of this Teachers Training Kit** within the various application areas (**"*NANOYOU dilemma*" blue boxes**).
NANOYOU NT Virtual Dilemmas (Computerised animations) – download at www.nanoyou.eu	These are computerised animations where students enter a virtual world and are confronted by various dilemmas relating to nanotechnology applications.
ELSA Topics in the NANOYOU Teachers Training Kit	In this kit teachers will find ELSA boxes throughout the text of the chapters of Module 2 (**"*ELSA Topic*" red boxes**).

In the next section we provide an **overview of ELSA topics which relate to nanotechnologies** and an overview of **safety of nanomaterials**. We highlight in each section the **relevant NANOYOU tools** that have been developed to promote dialogue in class.

When discussing ELSA and safety topics it is useful to encourage students to reflect on **other innovative technologies** that they are familiar with and that have had important ELSA and safety implications. In **Appendix A** some examples are provided.

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Overview of ELSA issues in nanotechnology

What follows is a short overview of crucial ELSA questions that are relevant to nanotechnologies. The list is not exhaustive and aims at giving teachers an idea of the vastness and complexity of these issues. Most are open questions for which we don't provide answers-they are meant to be spikes to initiate debates in class with the students.

Privacy

We live in a world where our movement is often controlled by hidden cameras. Miniaturization has allowed integrating these devices in many objects, and nanotechnologies will most likely lead to even more small devices and allow integrating them inside textiles and other composite materials. Consumer choices are nowadays tracked by internet purchases and other indirect means, but "smart" labels are under development with an in-built tracking system called Radio Frequency Identification (RFID). These labels already exist, but are fairly large, for instance in the e-passports (see **Module 2- Chapter 4 "Nanotechnology in ICT"** for more information). The vision in the future is to miniaturize them to a point that every commercial object will contain one, and be able to communicate its position. This would ensure in the case of food packages the product integrity, transport conditions, etc. RFID technology could be the ultimate solution to theft and fraud. Opponents warn that such devices could be used as "spychips", even integrated on humans, and which could be used by governments, leading to an increased loss of civil liberties. If private employers were to use this type of chips on the products they consume would have access to an incredible amount of private information.

Another vision in the ICT industry is the concept of **ambient intelligence**: computation and communication always available and ready to serve the user is an intelligent way, meaning satisfying certain requirements. The vision is to have electronic devices that work as a gateway between the user and the environment. This will require **ubiquitous sensing and computing**: devices must be highly miniaturized, integrated in the environment, in soft materials like textiles, autonomous, robust, and require low power consumption. Nanotechnology has the *conceptual* capacity to realize this vision. The time frame from "vision" to reality could be decades, but if this was to come true, we would live in a world where we are even more interconnected, never "alone", scrutinized. Clearly this would add numerous benefits to our current life but would also threat our personal privacy even more.

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NANOYOU ROLE PLAY GAME and VIRTUAL DIALOGUE TOPIC	DILEMMA	MORE INFO…
GPS Jacket	Should we buy a jacket with an in-built GPS?	Module 2- Chapter 4 “Nanotechnology and ICT”, page 29
Internet for Everything	Do we want to live in a world where everything is connected, monitored observed and open to scrutiny?	Module 2- Chapter 4 “Nanotechnology and ICT”, page 27-29

Justice

Who should benefit from nanotechnologies? Are nanotechnologies going to further increase the economical and social divide between “north” and “south” in the world? This is refereed to as the **“nanodivide”.** Will medical diagnostic devices, or therapies, developed with nanotechnologies, be available for anyone, and distributed through the public health system, or will they be so expensive that only a limited sector of the population will have access to them?

*NANOYOU PPT: Teachers can find a Power Point Presentation which covers aspects of justice, “nanodivide”, and responsible development of nanotechnologies. The presentation is called **“Benefits and risks for developed and developing countries”** and can be downloaded from www.nanoyou.eu under the “About” section.*

The questions of justice that are related to nanotechnologies are not unique, but rather relevant to may technological advancements. The history of drug development, and the associate generation of patents behind commercialized drugs, is definitely filled with questions of justice. Nanotechnologies are enabling technologies with application in many sectors, which promise to improve the life quality of individuals in numerous ways. For this reason the question of justice are even more important and vast.

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Early diagnostics

Diagnostic nanosensors will allow for the early detection of various diseases, like cancer, at the very onset of the symptoms, before the disease is perceived by the patient (see **Module 2- Chapter 1 "Nanotechnology in Medicine & Healthcare"**). Early detection means a higher chance of successfully treating and overcoming the disease. On the other hand, some worry that this will give doctors access to a large amount of personal information. The question is: where is this information going to be stored, and who will have access to it? Also, what if those devices are used not as a diagnostic tool but as a mean to assess a person's medical condition by other entities, such as insurance companies or job agencies? Clearly these devices open questions of **privacy data use and possible misuse**.

Some early diagnostic devices already exist, like genetic screening devices. Nanotechnology is directly involved in the development of more powerful and precise genetic screening devices, which nowadays are available only for a small range of common diseases and are fairly imprecise. In genetic screening the doctor gathers information on the genetic predisposition of a patient to have a certain disease. Scientists know well that the evolution of a disease does not only depend on genetic predisposition but also on the diet followed by the patient, the lifestyle and the environment he/she lives in. So the question is: does having **a predisposition to a disease make a person "ill"**? When does "illness" start? And even more: do we want to know this kind of information?

NANOYOU ROLE PLAY GAME and VIRTUAL DIALOGUE TOPIC	DILEMMA	MORE INFO…
Nanosensors in medical diagnostics	Should nanosensors be used to diagnose medical conditions in the early stages when there are still no definite restrictions in place to protect patients' privacy?	Module 2- Chapter 1 "Nanotechnology in Medicine & Healthcare", pp. 5-11.

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More than "human"?

Humans have always tried to improve their health condition and lifestyle. Nowadays there are numerous drugs and medical technologies that can treat conditions that only few decades ago where deadly. But medical advancements have not just been limited to treatment of disease. Reconstruction of injured body parts is now possible though innovative biomaterials and implants, and tissue engineering is opening the possibility to recreate organs from cultures of stem cells. Nanotechnologies are already playing an important part in modern medical diagnosis and treatment technologies, and are opening new venues for future developments.

Many technologies we have today allow doctors to restore a loss sustained as a consequence of an injury or a congenital condition (e.g. vision or hearing impairment). Some would argue that this is already "unnatural", in the sense that it gives humans a capacity that they would not otherwise have. If you think about it, even glasses provide people that have poor vision a capacity they would not have naturally. Today, we also have access to treatments that alter our natural appearance through plastic surgery. In the future, researchers think it might be possible to create implants that allow humans to have additional skills, like being able to see in the dark, or have implants that can improve human brain capacities. Neuroprosthetics are another example. Bioengineers and medical engineers say that their role should be to compensate for a body's deficit (as result of an accident or a disease), not to replacing any existing function. It should not lead to enhancement of human capabilities. Nevertheless nanotechnologies are making these developments more feasible and affordable, obliging researchers in the field, as well as regulators, ethicists and sociologists to reflect on the social, medical and ethical consequences of these devices (see **Module 2- Chapter 1 "Nanotechnologies in Medicine and Healthcare"**).

Nanotechnologies are involved in those medical advancements, as also genetic engineering, and biotechnology. So the question becomes: are these developments leading to treatments that surpass being "human"?

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NANOYOU ROLE PLAY GAME and VIRTUAL DIALOGUE TOPIC	DILEMMA	MORE INFO…
Want to be superhuman	Is it acceptable to use processes developed for medical treatment to enhance the human body?	Module 2- Chapter 1 "Nanotechnology in Medicine & Healthcare", pp. 23-26.
Improve human brain capacities	Is it ethically acceptable to use technologies developed for specific medical treatments for other purposes like improving human capabilities?	Module 2- Chapter 1 "Nanotechnology in Medicine & Healthcare", pp. 28-31.

Nanotechnologies in consumer products

Since 2006, the Project on Emerging Nanotechnology (Woodrow Wilson International Center for Scholars) has created a Nanotechnology Consumer Products Inventory with the intention of collecting, archiving and sharing information regarding consumer products which producers claim to be nano. About 200 products were identified in March 2006; after little more then one year, this number had more then doubled. At the time of writing (August 2010) the inventory has more than 1100 listed.

Products in this inventory are categorized based on their (explicit) application, specifically Appliances, Automotive, Goods for Children, Electronics and Computers, Food and Beverage, Health and Fitness, Home and Garden. Although the project aims at identifying true nano-products, the inventory curators clearly state *"we have made no attempt to verify manufacturer claims about the use of nanotechnology in these products, nor have we conducted any independent testing of the products".* Therefore the inventory contains products that claim to be enabled by nanotechnologies, but this is not checked nor demonstrated. For this reason one should be cautious when looking at this list, and should also remember

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(1) There are a large number of nano-characteristic that could be included in a consumer product, such as a coating (thin coatings and layers in the nanometer range, either applied to the material or formed upon use) or a nanomaterial (e.g., nanotubes, nanoparticles). Also, nanotechnology could be used to produce the consumable without being responsible for its final characteristics: in this case, nanotechnology is only the enabling technology for production.

(2) Technical, detailed information regarding those consumer products is often limited due to corporate secret.

To date, the majority of products listed belong to the ´Health and Fitness´ group, among which cosmetics and textiles represent the majority of products.

Among the materials that are claimed to be responsible for the nano-label, silver is the most common material mentioned in the product descriptions, followed by carbon (which includes fullerenes), zinc (including zinc oxide), silica, titanium (including titanium dioxide) and gold.

Safety of nanomaterials

The safety of nanomaterials has become a crucial question in the last few years, particularly as the number of consumer products containing them has been raising every year.

The fact that nanomaterials, by definition, are materials that have size comparable to biomolecules (e.g., proteins, DNA etc.) raises the question of their safety. Could nanomaterials interact with biomolecules in an adverse manner, triggering a toxic effect? Could nanomaterials pass protection barriers in cells? In nanomedicine, as we will see in **Chapter 1 of Module 2 "Applications of Nanotechnologies: medicine and healthcare"**, nanomaterials are used precisely to target infected cells and deliver drug agents locally. They are designed to pass though cell membranes, for instance. The question of toxicity extends also to eco-toxicity: what happens when materials containing nanoparticles reach landfills and degrade? Will nanomaterials be dispersed in the environment? In what dose? Could this harm eco-systems?

It would be incorrect to say that we know nothing about the toxicological properties of nanomaterials. In the last years, a wealth of information has been collected and reported by authoritative research groups. What it is not clear is how relevant these results are for humans, since tests have so far been conducted in animal models or *in vitro*. Another problem is that different testing methods are used in

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different laboratories, which makes it difficult to compare the results. Research so far has focused mainly on two group of materials: carbon-based nanomaterials (carbon nanotubes and fullerenes), and metal or metal-oxide nanoparticles (like ultrafine titanium dioxide (TiO_2)). Several studies seem to indicate that some forms of carbon nanotubes show pulmonary toxicity and that this depends on production method, length and surface properties of the carbon tubes. Similarly, TiO_2 has been reported to cause inflammation in the lungs when inhaled in high dose.

Scientists recognise that before a full assessment of nanomaterial toxicity can proceed some fundamental issues need to be resolved:

- The need for a **definition of nanomaterial** is crucial: it is not just a matter of nomenclature; it is more importantly a matter of defining what "cut size" should be considered in nanotoxicology. It is a common belief among toxicologists that the conventional scale 1-100nm now used to define a nanomaterial in nanotoxicology is not exhaustive, as nanomaterials often aggregate or agglomerate in larger particles that have dimensions ranging from hundreds of nanometres to microns.

- Defining the **reference materials**: scientist report how the same nanomaterial (e.g., nano-sized TiO_2) purchased from two different manufacturers gave striking different toxicological results when tested. In order to define some reference materials, these need to be fully **characterised**, which means deciding what standard **measuring methods** to use (or possibly developing new ones, if the existing ones prove inadequate);

- Importance of testing **materials pure and free from contaminations**: for instance, carbon nanotubes are commonly contaminated with iron due to their manufacturing process. Scientists report that removal of the iron from the carbon nanotubes moiety dramatically reduces the oxidant generation and the cytotoxicity (i.e., toxicity to cells) of the material. The hypothesis is that it is the nano metal oxide – rather than the carbon nanotube – that generates reactive oxygen species 8, responsible for the toxic effect.

- The **medium** used to disperse the nanomaterial during the toxicological testing is crucial. It has been reported how fullerenes are best dispersed in calf serum, whereas they cannot be dispersed at all in water. Lack of dispersion can lead to false results or confused toxicological results; therefore it is essential that dispersion media are defined for each nanomaterial to be tested.

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Overall, the scientific community agrees that progress has been made in the toxicological evaluation of nanomaterials. There is still a lot of research to be done, but some key matrices have been identified, for instance that surface area is a more important parameter than mass when dealing with engineered nanoparticles, and some targets and common behaviours have been also identified. The question is now how to make a risk assessment framework from these data, how to convert scattered numbers collected in numerous laboratories around the world into a risk management strategy for the safe handling of nanomaterials.

Before a **risk management for nanotechnologies** can be developed and implemented, a fundamental question needs to be answered: **what is the real risk of nanotechnologies?** Presently nanotechnology is an umbrella term that covers a very large number of materials, applications and instrumentations. There is a need to classify nanotechnology applications and nanomaterials. This applies also to the risk debate: the starting point for this debate is to identify what are the real safety concerns of nanomaterials. Presently, while there is at times hype in describing the benefits of nanotechnology, there is also hype in the risk debate connected to it. The starting point should be to identify **what are the safety concerns that are peculiar to nanotechnologies and to identify the key safety needs in specific areas of applications**. This will allow us to move from a rather uncoordinated and scattered toxicological assessment of nanomaterials to coordinated research and cooperation between different institutions. Precisely for this reason it is now preferred to use the plural (nanotechnologies) rather than the singular (nanotechnology) in discussing these matters.

The second question to be answered is: **how are engineered nanoparticles (ENPs) different from non-intentionally made nanoparticles** (also called “nanopollution” or ultrafine particles)? Nanopollution is already a reality in many workplaces, from the welding industries to paint shops and bakeries. Nanoparticles are produced by airplane and motor vehicle exhaust emissions, erosion of man-made materials (e.g., tires), as well as by natural erosion and volcanic activity. **Humans are already exposed to nanopollution** in many ways and to different degrees. At the workplace, there are already some effective protective measures for workers exposed to ultrafine particles (filters, textiles, gloves). There is some evidence that established protective measures against ultrafine particles would also be effective against ENPs, should these be classified as hazardous. So the question becomes: **are ENPs new hazardous materials and if so, do these pose a risk for humans and/or the environment**? Is this risk different from “nanopollution”, and if so, how, and what should be done to deal with it? This is a

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complex question, one that will need time to be fully answered. Basically at the moment there is not enough data to provide an exhaustive answer and more research is needed and being undertaken. But the risk associated with any material depends on the **exposure route and dose** of it, so research is also focusing on developing some measuring tools capable of detecting and distinguishing the presence of nanoparticles in the environment, regardless of their source.

Research into the potential toxic effects of nanomaterials is now a priority in most funding institutions and agencies, as it is clear that the success of nanotechnologies will also depend on how the issue of safety is handled.

Among all, particular attention is given to silver, titanium dioxide, silica nanoparticles and carbon nanotubes, since it appears that these are the nanomaterials mostly used in consumer products. For more information on these nanomaterials, their properties and their uses, see **Chapter 5 "Overview of Nanomaterials" in Module 1**.

NANOYOU ROLE PLAY GAME and VIRTUAL DIALOGUE TOPIC	DILEMMA	MORE INFO...
Antibacterial socks	Is it right to sell antibacterial socks containing silver nanoparticles while it is not known yet if these are entirely safe for the environment?	Module 2- Chapter 2 "Applications of Nanotechnology: Environment, pp. 13-14.
Nano tooth brush	The question we ask is if the prolonged use of the tooth brush can cause the degradation of its material and the accidental release of nanoparticles in the saliva and if this could have some negative health effects.	Module 2- Chapter 2 "Applications of Nanotechnology: Environment, pp. 14-16.

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Nanotechnology in food packaging	Should nanoparticles be used in our food or pharmaceutical packages to detect freshness, when we still do not know the full ramifications of the using them?	Module 2- Chapter 2 "Applications of Nanotechnology: Environment, pp. 23-25.
Boat coating	Nanoparticles in the coating could break down and pollute the ocean waters	Module 2- Chapter 2 "Applications of nanotechnologies- Environment", pp.14-16
Pioneer cancer therapy with nanoparticles	Should gold-coated nano particles be used to treat patients' bodies before possible health risks have been explored?	Module 2- Chapter 1 "Applications of nanotechnologies- Medicine & Healthcare", pp. 16-23
Sun screen with nanoparticles	Nanoparticles of TiO_2 contained in the sunscreen could penetrate through the skin and have some health effects	Module 1- Chapter 4 "Fundamental Nano-Effects" p. 21; Module 1-Chapter 5 "Overview of Nanomaterials" pp. 22-24.
Revolution for the light bulb	Quantum dots (QD) integrated in light-emitting devices (QD-LEDs) could be toxic or eco-toxic once these devices are disposed.	Module 2- Chapter 2 "Applications of nanotechnologies- Energy", pg. 11
Nano-based solar cell	Nanomaterials inside photovoltaic cells could be toxic or eco-toxic once these devices are disposed.	Module 2- Chapter 2 "Applications of nanotechnologies- Energy", pg. 29

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APPENDIX A

In this Appendix we provide some ideas that teachers can use to encourage students to reflect on **other innovative technologies** that they are familiar with and that have had important ELSA and safety implications.

- *Automotive transportation*: cars and motor vehicles have certainly improved our lives in giving us the opportunity to move freely, save time in travel, and explore new places. However, pollution produced by fuel combustion is in part responsible for global environmental issues that we have to face now. In addition, transportation has mostly benefited industrialised nations; poor countries lack the infrastructure (metalled roads) in most cases and people cannot afford these commodities. In our societies we have become extremely dependent on cars especially for short trips, when alternative transport solutions exist but are not so convenient and easy (public transport, bicycle). In recent years there has been general call from health advisors and environmental organisations to reconsider the way we use cars, and to favour other means of transportation that pollute less and render us physically more active.

- *Synthetic plastic*. About 100 years ago synthetic plastics like Nylon® where created. Plastics have revolutionised fabrication processes and enabled a massive production of affordable consumable goods. Nowadays nearly all tools we use and have around us are made of plastic: laptops, iPods, packages, shoes, cars, etc. Being artificial, these polymers don't degrade naturally (as opposed to biopolymers, used in biodegradable plastics). The consequence is that they pose a tremendous challenge when it comes to disposal. Indeed, plastics are one of the most important pollution agents in water and land. The problem of plastic toxicity is widespread and involves also humans: research is now showing that numerous chemicals used in plastics are toxic to humans and possibly carcinogenic. Nevertheless the world as we know it would not exist without plastics.

- *Internet*. Our society has been enormously changed with the advent of the internet. This tool was invented to allow research centres around the world to communicate and exchange information easily. Today the internet is an unlimited source of information for everyone, and more recently it has become a new form of social communication and networking. Imagine what would happen if the internet were to shut down. This tool is also having an important role politically: bloggers in war areas are able to communicate what is *really* happening. Socially, the internet is re-shaping the way people communicate,

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some say even too much. Experts are concerned that youngsters use the web as their primary communication channel, and that personal, face-to-face communication is progressively being lost. There are concerns that an abuse of this form of communication could deprive youngsters of personal encounters, which are considered essential for personality development.

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