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From nanoscience to nanoethics: the viewpoint of a scientist

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ABSTRACT
Nanotechnologies are an emerging and multidisciplinary field of research, which is recently knowing a growing interest because of the basic and applied scientific breakthrough. Despite a deep understanding of the nanoscience is far to be achieved, the debate about the impact of nano-objects in everyday life is gradually involving both the scientific community and civil society. Here we provide some arguments to reflect upon the so-called "nanoethics". We will start with a brief introduction about the definition of nanotechnology and then the circularity that links the characterization techniques in comparison with the discovery of nanotechnology will be discussed. Conclusion remarks about the presence of nanotechnology in everyday life will be finally presented.

KEYWORDS
Nanoscience, Nanotechnologies, Nano-objects, Self-assembly, Nanoethics, Characterization Techniques

1. *From the discovery of nanotechnologies to present days*

The birth of *Nano*-technologies as a multidisciplinary field of research can be dated up to 1959, when the Noble Laureate physicist Richard Feynman delivered the famous speech "There's Plenty of Room at the Bottom" at the annual meeting of the American Physical Society at the California Institute of Technology (Feynman 1959). Feynman was the first scientist who recognized the possibility offered by the manipulation of matter at an unprecedented length scale, that is the nanometer scale. Nanometer is not simply a billionth of a meter; in fact the nanometer scale is commonly recognized as the boundary between *atoms* and *materials,* as reported in an interesting dissertation about the definition of "material" by Steven Moss (Moss 2012). Across this boundary, intriguing and unexpected phenomena occur, enabling a number of futuristic spin-off. When the most effective achievements were still far to be discovered, one of the first speculations about the so-called "nanoworld" were referred to the possibility of self-replications of the nano-machines, creating *de facto* the first sort of "alien virus" that the human being could experience outside the science fiction. Following the *grey goo* theory, never ending self-replication of nano-structures should lead to the formation of an undefined mass of nanometric machines disaggregating our world and the whole universe (Drexler 2013; Smalley 2001; Whitesides 2005)[1]. The first debate about the impact of the nanotechnology to the every day world sounded hence like a millenarian discussion about the future of the earth and, as a matter of fact, did not involve a massive participation of the civil society. However, the following development of the field led to face less generic and imaginative issues of the nanotechnology; a nanomaterial is invisible as a virus or bacteria and cannot be "killed" or "sterilized" because is not a living organism (in fact, viruses cannot be considered as living organisms themselves since they can replicate only inside living cells; however sterilization protocols can protect against virus diffusion). Compared to larger and bio-derived structures, nanomaterials, especially nanoparticles, cannot be observed neither by optical microscope nor by scanning electron microscopes. Powerful and high magnification equipment, such as the transmission electron or the atomic force microscopes, is usually necessary to clearly detect objects of nanometric size.

A nanomaterial typically shows an incredible surface compared to its weight. Since most of the chemical and bio-chemical reactions occur at the interface (or surface) between the two systems, this means that nanomaterials have a strong tendency to react with their environment.

To resume, after the very first discovery, the nanomaterials appeared as invisible, unknown and potentially very reactive materials. This scenario obviously aroused serious concerns... The European community is actually trying to tackle the "nanotechnologies issue" by applying a number of recommendations to be adopted by all the nations members. Since the implications are manifold, especially those related to industrial and mass production, to some extent, they are still under debate.

2. *What is a nanomaterial?*

A first matter of discussion is a clear definition of a nanomaterial and therefore, in order to have a better understanding of what are the most critical points, we should introduce some basics.

First of all, up to now we have talked about nanomaterials trying to figure them out on the nanoscale in all the three spatial dimensions, however it does exist a variety of nanomaterials that have to be taken into account. In particular, there are four classes of nano-objects, which can be envisaged considering the dimensional morphology of the object: 0, 1, 2 and 3-dimensional structures. The 0-dimension structures are commonly referred to as *quantum dots*; these are nanoparticles with extremely small size typically in the range between 2 and 10 nanometres (fullerene is not a quantum dot, but is usually assigned to this class). The 1-dimension objects are nanotubes or crystalline rods with a diameter of few nanometres and a length up to a few microns. Nanosheets, such as graphene or caolinite-based platelets, are commonly referred to as 2-dimensional nano objects: layers with nanometric thickness and larger planar size.

Moreover, there are also 3 dimensional nanostructures; this definition could appear slightly odd because, by following the rationale used for the three previous classes, it would involve materials with three dimensions bigger than nano-scale (in particular,

[1] An exhaustive report about the theory of self-replication and grey goo is not the focus of this brief article.

larger than 100 nm). This issue raises a question: why does a 3D nanostructured material is considered *nano*? The answer lies in the properties that nanostructured materials show, although they can be manipulated by hands and observed by naked eyes. A gram of this material, for example, can be so porous that, if one measured the area of all the pores, he would easily obtain a value comparable with several football fields. Despite their promising applications as carbon dioxide collectors or hydrogen carriers, these types of materials are very puzzling to define. In fact, if we admit that a macroscopic material can be considered *nano*- because of the organization of its structure at the nanometric level, this definition should also include cells, virus and bacteria. In other words, there is no sharp limit between nano-world and the human-scale world, because *nano* does not mean inorganic or living, but simply indicates the scale on which the phenomena occur.

Being aware of the complexity beneath this topic, The European Community has therefore decided to set a range of properties to define nanomaterials for legislative and policy purposes, with several exception and inclusions (European Commission, 2011):

"'*Nanomaterial means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm.* "

"*…fullerenes, graphene flakes and single wall carbon nanotubes with one or more external dimensions below 1 nm should be considered as nanomaterials.*"

Finally, facing the impossibility to find a more comprehensive definition for 3 dimensional nanomaterials, the recommendation states:

"*compliance with the definition in point 2* [i.e. definition of a nanomaterial] *may be determined on the basis of the specific surface area by volume. A material should be considered as falling under the definition in point 2 where the specific surface area by volume of the material is greater than 60* m^2/cm^3*. However, a material which, based on its number size distribution, is a nanomaterial should be considered as complying with the definition in point 2 even if the material has a specific surface area lower than 60* m^2/cm^3*.*"

3. *Nanomaterial or characterization technique: who came first?*

Since the very first achievements, nanotechnologies and their characterization techniques grew up side by side. One example is the transmission electron microscopy; although the visibility of a single atom with this technique has been reported on 1970 (Crewe et al. 1970), the first examples of imaging of molecules on graphene nanomaterials have been only recently shown (Meyer et al. 2008).

An even more interesting example is represented by the scanning tunnel microscopy, or STM. The prototype of this instrument can be dated back to 1981 from the work of Binning and Roher (Binnig and Rohrer 1986) while the development of scanning probe microscopy techniques, such as the atomic force microscopy, was developed in the following years. These techniques allow identifying and studying the surface and the morphological properties of very tiny materials, such as nanomaterials, by using a tip with atomic size. They also allowed for the first time to manipulate the matter at atomic level by providing fascinating examples of nanostructures with quantum properties, such as the quantum corrals (Crommie et al. 1993). Fabrication and development of the tips for scanning probe instrument is of crucial importance for a large variety of specimens, in particulars, high-resolution images can be obtained by using *nanomaterials* as tips, such as carbon nanotubes or nanowhiskers (Wilson et al. 2009), since it is of extreme difficulty to manufacture highly reproducible standard materials with atomic termination. Moreover, sometimes the best materials used to calibrate analytical equipments are nanomaterials themselves, since they can be characterized by precise shape and size that are difficult to obtain on bulk materials. If we would like to resume and simplify the message, we could state that sometimes the best way to study nanomaterials is by exploiting their interactions with other nanomaterials.

This introduces a circularity in the ethical issues related to nanotechnology: "Is it possible to study nanomaterials without developing advanced analytical techniques based on nanomaterials?" Interestingly the method adopted to evaluate the materials size and properties are also argument of the recommendation of the European community since it is not already well established what analytical technique offers the more reliable and consistent results on nanoparticles (SCENIHR 2010; European Commission, 2011).

"*Measuring size and size distributions in nanomaterials is challenging in many cases and different measurement methods may not provide comparable results. Harmonized measurement methods must be developed with a view to ensuring that the application of the definition leads to consistent results across materials and over time. Until harmonized measurement methods will be made available, best accessible alternative methods should be applied.*"

The question about the birth of nanomaterials, in relation to our ability in detecting them, makes even more sense if we look at the latter studies about the impact of nanotechnology onto the environment. Several works are trying to unquestionably assess the presence of "nanocontamination" of soldiers in modern battlefields, sometimes correlating this contamination with serious diseases affecting some of them after their return from war zones (Gatti et al. 2009). Moreover, several other works deal with the possibility of nanoparticles formed as a consequence of explosions or burning coal waste (Ribeiro et al. 2010). These eventualities pose obviously a question: "are we sure that nanomaterials did not exist before their *official* discovery?" The question is not so unreasonable; it is well known that particles of small dimensions are produced by natural events, such as volcano eruptions or erosions of particular minerals; it is not unlikely that such events lead to the formation of particles with sub-micrometric dimensions (Danihelka et al. 2011). Other sources of nanoparticles formation have been found as a result of anthropogenic activities; under particular, but not rare, conditions, fire combustion or ceramics friction with metals can produce ultrafine particulate. For this reason, it should not be too much of a surprise if the latest characterization techniques will reveal that barbeques or car brakes are nanoparticles factories.

To summarize, all the facts that have been reported until now provide a more detailed scenario for a proper evaluation of the nanotechnologies. Rather than being an "alien technology", that is a completely new synthetic way to shape the matter, the nanoscience represents a tool capable of providing a deeper understanding of various natural phenomena occurring in the universe. Under this perspective the concept of nanotechnology does not envisage a catastrophic or radical change in the reality, as we know it, but rather an increased awareness of the events occurring on the Earth. This awareness is not obtained through uncontrolled manipulations of the matter, but more likely by a slow and fatiguing discovery of our environment. The fact that nanomaterials could pre-exist to the human perception of *nano* does not mean that they are human-friendly, as in the case of many other natural-based materials, such as asbestos, radioactive minerals or radon gas. However the possibility that nanostructures existed since the beginning of the planet Earth should change the perception of the nanoscience as completely artificial and out of our pristine surrounding. In this context, to assess the risk of nanotechnology without a careful use of nanotechnology appears an impossible task.

4. *Advance of nanomaterials in everyday life*

Nowadays nanomaterials are progressively entering in the everyday life, conquering an increased importance in many fields of technology; nano-based ingredients can be found in many products on the market such as paints, building materials, cosmetics and also food (SCENIHR 2010)[2].

In the first two applications the risk involved in the use of nanomaterials is sufficiently low because the nano-objects are usually embedded into polymers (paint) or inorganic pastes (mortar, concrete) to produce functional thick layers[3]; on the other hand, the second two applications require a careful study and test to avoid unexpected effects (EFSA 2011[4]).

Nevertheless, the concept of nanoscience assume different shades depending on the context; it is, for instance, explanatory to observe how the marketing specialists attribute good or bad qualities to nanomaterials or even try to hide the presence of nanomaterials into the products. It is not unusual to read "powered with *nano-something (nanosomes, nano-charges, nano-spheres etc)*" on the packaging of detergents and anti-wrinkle-creams, but, in most of the cases, it is hard to verify whether the products really contain a nano-ingredient or if it is, instead, just a way of improperly advertise them. On the contrary, although some alimentary additives are considered nanomaterials, it is extremely rare to find an explicit indication on the food packaging. A third scenario involves products and goods with innovative and nano-based formulations, which really work better than the traditional ones. In this occasion, depending on the cases, the improvement provided by the nanotechnologies is highlighted through advertisement or kept secret in order to maintain the leadership upon a specific market.

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[2] A complete review of the nanomaterial-based products available on the market is outside of the scope of this article. More information about the industrial application of nanotechnology is available on the SCENHIR website.

[3] The low risk in the use of a particular material does not exclude the possibility of a high risk in the manufacturing of the same material. Before production, in fact, an extensive risk assessment should be performed to avoid health risk of the labour and prevent accident in the production line.

[4] The European Food Safety Authority (EFSA) has recently published guidance about the risk of the application of nanoscience and nanotechnologies in the food and feed chain. In this article, it is illustrated a practical approach for assessing potential risks arising from applications of nanoscience and nanotechnologies in the food on the basis of analytical test.

Therefore, the ambiguous management of the public perception of nanoscience and nanotechnologies has produced a grey area where disinformation and worries were free to grow up, feeding unjustified oppositions towards the nanotechnologies.

In order to increase the awareness about the possible risk related to an uncontrolled supply of nanoproducts on the market, the European Community charged the Scientific Committee on Emerging and Newly Identified Health Risks (SCENHIR) to investigate and provide a state of the art of the nanotechnologies. Although the aforementioned complexity of the problems that have to be faced, the SCENHIR is trying to indentify some critical fields where the use or abuse of nanotechnology could lead to uncontrolled risk for the public health. At the same time, the committee plays an active role in understanding the nanomaterial properties and examining the development of improved testing methods. In fact, a quantitative evaluation of the percentage of nanomaterials contained on the goods is crucial for a clear legislation on this topic. A well-defined laws apparatus should contribute to provide clear data regarding the situation of the market and applications of nanomaterials, making all the information about nanotechnologies more accessible to the final customers.

5. *Conclusions*

The nanotechnologies have played a leading role in the scientific and technological innovation of the last decades. Since the first developments, nanomaterials gave rise to worries into the civil society because of their unknown properties and completely artificial nature. However, further improvements in the study and risk assessment of the nanotechnologies have revealed that nanomaterials are produced both in many anthropogenic and natural events. The debate about the impacts of nanotechnology on the society is largely due to a lack of awareness because of the controversial definition of nanomaterials and the intrinsic complexity of the multidisciplinary field of nanoscience. A further development of reproducible and scientifically validated protocols for the quantification and measurements of nanomaterials is at the basis of a precise control on the diffusion of nano-based products and better information for citizens and consumers.

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