# ETHICAL REFLECTION ON NANOTECHNOLOGY; BUT WHAT DOES «BEING NANOTECHNOLOGICAL» MEAN? A CONTRIBUTION FROM AN EPISTEMICALLY REALIST POINT OF VIEW

Pere RUIZ TRUJILLO
Salvador BORRÓS GÓMEZ
Albert FLORENSA GIMÉNEZ

## Abstract

Nanotechnologies are considered to be one of the spearheads of emerging technologies. They are qualified by some as a new technological revolution, in the sense that they can change the way humans perceive ourselves and relate to our natural and social environments. If a human activity is thought to cause such revolutionary changes, it should be accompanied by a reflection. In order to give such a reflection an ethical dimension we need to fix a framework, a set of commonly accepted definitions of concepts and terminology. Questions like: «what does being nanotechnological mean?» do not seem satisfactorily answered, or the answers given to date do not seem to satisfy all stakeholders. We analyze the lacks in some of the definitions found in available literature. From this analysis, and taking as a basis the philosophical paradigm of epistemic realism, which we claim it could be adequate for ethics purposes, we go on to propose an approach which, we argue, could motivate further thinking on definitions that could serve ethics reflection on nanotechnologies.

**Key Words:** Nanotechnology, Ethics, Epistemology, Definition

## Resum

Les nanotecnologies són considerades una de les puntes de llança de les tecnologies emergents. Alguns fins i tot les qualifiquen com una nova revolució tecnològica, en el sentit que poden canviar la manera en que els humans ens percebem a nosaltres mateixos i com ens relacionem amb el nostre entorn social i natural. Si una determinada activitat humana pot comportar canvis tan revolucionaris, hauria d'anar acompanyada d'una reflexió. Per tal de donar a aquesta reflexió una dimensió ètica, és convenient

fixar un marc, un conjunt de definicions de conceptes i terminologia acceptada. Preguntes com ara: què significa «ser nanotecnològic»? no semblen estar respostes de manera totalment satisfactòria, o al menys les respostes donades fins ara no semblen satisfer a tots els afectats. Analitzem les mancances en algunes de les definicions trobades a la literatura disponible. A partir d'aquesta anàlisi, i prenent com a base el paradigma filosòfic del realisme epistèmic, del qual afirmem que pot ser adequat per propòsits ètics, proposem un enfocament que entenem que pot motivar el pensament sobre noves definicions que puguin ajudar en la reflexió ètica sobre les nanotecnologies.

**Paraules clau:** Nanotecnologia, Ètica, Epistemologia, Definició.

## 1. Introduction

Nanoscience and nanotechnology are considered part of what some authors call emerging and converging technologies, the spearheads of scientific research and technological development in all kind of fields. Thus, whenever a research line receives the «nano» label, in no matter what field, it automatically conveys the idea of techno-scientific novelty. Nanotechnological applications can be very different in biology, medicine, chemistry, physics, materials science, engineering, electronics, or security. Consequently, terms like «nanomedicine», «nanochemistry», «nanobiology», «nanoelectronics», etc. are commonly used to refer to the applications on «nanotechniques» to different fields of science and technology. In order to point out this kind of transversality, some authors prefer to refer to «nanotechnologies» instead of «nanotechnology» (Gordijn, 2005).

Some sources, including the National Nanotechnology Initiative, affirm that progress in nanosciences and nanotechnologies, and the world of possibilities that this progress entails, could imply a new technological revolution (National Nanotechnology Initiative, 2000). If that is so, then a reflection is needed; and not only a general philosophical reflection, but also a reflection centered in the ethical and social issues which originate from these stunning novelties.

Before trying to give an answer to many other relevant questions, or as an early step in the reflection process, there is a primary concern to be addressed: we need to fix, as much as possible, the reflection framework. We need to agree on the reference and the scope of our reflection. If our aim were to perform an ethical reflection on weaponry we would first have to define what a weapon is, even if we agree that the border between being and not being a weapon can be very vague. The same way, if it is our intention to reflect on something called «nanotechnology», first we have to try to find out, if vaguely, where the border between being «nano» and not being «nano» is. We could

consider this to be the problem of meaning, which will determine the reference framework of nanoscience and nanotechnologies (ObservatoryNano 2009). An ethical reflection on a given entity and on its implications can be hindered if we do not have a fairly clear idea of what we are referring to when we use the linguistic repertory associated to that given entity.

The 2010 ANEC/BEUC inventory lists examples of 475 products available on the EU market claiming to contain nanoparticles (ANEC/BEUC, 2010). According to the Woodrow Wilson International Center for Scholars (2011), over 1300 *nano*-based products are commercialized worldwide, and these include commodities, cosmetics, pharmaceuticals, materials or electronic devices. And this figure continues to increase. Nevertheless, the only criterion for being included in this inventory is not an epistemic one but merely the manufacturers' declaration (Woodrow Wilson International Center for Scholars, 2011). Actually, there are still no fully agreed standards of what «being nano» means for a product. The European Commission feels committed to solve this need, and has published a new definition of «nanomaterial» (Official Journal of the European Union, 2011), but this definition does not seem to fully satisfy everyone, and criticism has immediately aroused (Clark, 2011), (NanoWerk News, 2011), (MD avec l'équipe Avicenn, 2011).

Therefore, one of the first problems that we must face when beginning a reflection on a new field of knowledge or an emerging technology, as is the case of nanoscience and nanotechnology, is the meaning of words and concepts. Only by doing so can we reasonably fix the scope of reflection. The questions that we should be able to answer are one way or another summarized in the generic «what do "nanoscience" and "nanotechnology" mean?». And this question includes others which range from «How do we recognize a single entity as "nanotechnological"?» –assuming that «being nanotechnological» is something that may be predicated of some entities– to «Is the intention of a manufacturer or researcher reason enough to give the «nano» label to the object of their work?». Moreover, is nanotechnology always something really new, or is it sometimes only a new terminology for already existing knowledge or applications? Is there an ontological basis or a good epistemological reason for us to believe that there is a differentiated scope of knowledge deserving a specific new terminology?

There is still no agreement within the scientific community on these questions. But the significant number of marketed products labeled as «nanotechnology», and the fact that the «nanotechnology» tag is already a widely used tool, by both public and private funding institutions, demands such an agreement.

This paper analyzes different kinds of definitions used in the area of nanoscience and nanotechnology. After examining the problems that these definitions show, the paper proposes an epistemically realist reflection as an adequate approach to the kind of definition that could be appropriate when the final purpose is moral reflection.

## 2. Definitions

The defining of things may differ depending on the function or purpose of the definition. The defining (and the definition) of «gold» will not be the same if it is made by a jeweler, a chemist, a poet or someone who is writing a dictionary. Even if the four of them, *prima facie*, are referring to the same entity –the substance known as «gold»– the approaches will be different. In this sense, a definition with positive regulatory functions may be different from a definition whose intention is to indicate the object of philosophical reflection, even if both have the same entity as reference. According to the Stanford Encyclopedia of Philosophy, «The different definitions can perhaps be subsumed under the Aristotelian formula that a definition gives the essence of a thing».[1] If this is accepted, then a realist approach –including notions like *concept*, *substance* or *essence* as existing things– could be adequate in order to find a definition that responds to the function of interest for an ethical reflection on nanotechnologies. Then, the relevant question is «what are the actual facts that make a particular entity nanotechnological as compared to others that are not?», or «which real fact or set of existing circumstances make that particular «nanotechnological entity» interesting?». These questions drive us to the fundamental one: what is *to be* nanotechnological? What is the *essence* of nanotechnology?

### 2.1 Current definitions

There is a general recognition that there is a lack of consensus definitions in «nanoterminology» (Mantovani, Porcari, Morrison, & Geertsma, 2010), (Maynard, 2011), (Stamm, 2011), (Euractiv.com, 2011). Besides that, there are particular demands on certain terms like «nanomaterial» (AmCham, EU, 2010), (SCENIHR, 2010) or «nanoparticle» (Schmid & Fenske, 2010).

In response to a petition of the European Commission, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) gave its opinion on what they consider the essential elements, from a scientific point of view, to elaborate a working definition with regulatory purposes of the term «nanomaterial». This opinion gives also an analysis of the criteria used in the different definitions that can be found in specialized literature. According to the SCENIHR, size is the main defining element in every definition of nano-scale and nanomaterial. They also recommend taking into account the size distribution and the standard deviation, as well as the specific surface (in relation to volume, not to mass). Despite admitting that there is no scientific evidence as to whether a given size determines the «nano» characteristic of a product, they consider it important to use measurable criteria as their main aim is regulatory. It is in

[1] http://plato.stanford.edu/entries/definitions/. Accessed 8 April 2011

this sense that the SCENIHR accepts size as the main definition criterion and propose accepting the conventional agreement of the 1 to 100 nanometers range for size and of 60 $m^2/cm^3$ as the lower limit for the surface/volume ratio (SCENIHR, 2010).

But the fact is that it is not yet fully clear whether the use of the prefix «nano» in terms like «nanomaterial», «nanoparticle», «nanoscience», «nanotechnology» or «nanostructured» in both the specialized literature and in generalist publications is always epistemologically justified if their intention is to refer to things different than «material», «particle», «science», «technology» or «structured» respectively. Thus, it seems necessary to deepen the reflection about the uses of this terminology (Nanowerk, 2010), (International Alliance for NanoEHS Harmonization).

A first step could be approaching to a conceptual definition of «nanotechnology», and we could start with an analysis of what can be found in the scientific literature. The classification proposed by Schummer (2007) is clarifying in order to summarize these definitions. The entry «Definitions» of the *Stanford Encyclopedia of Philosophy* (Gupta, 2009) can also be helpful in this sense, and we will use it eventually as a complement.

### *2.1.1 Nominal definitions*

Nominal definitions seek to define a term with a set of necessary and sufficient conditions. In order to simplify, we could say that nominal definitions are the definitions that we usually find in a dictionary. This would be the case for the most commonly used «nano-» definitions. There are other definitions, compatible with this kind, that define «nanoscience» as the study of matter and its properties, and nanotechnology as the manipulation, design and/or creation of materials, devices, products or functions at the nanometric scale, a scale commonly defined as the range between 1 and 100 nanometers (1 nm = $10^{-9}$m) (Hunt & Mehta, 2006).

Thus, according to this set of definitions, all those entities in which at least one of its dimensions is within the 1-100 nm range are considered objects of nanoscience or nanotechnology. Therefore, if we follow the nominal definitions scheme, size is the necessary and sufficient condition for being «nanotechnological». This definitions focus almost exclusively on size. This is an interesting option from the regulatory point of view, because the stipulation of a specific range of size, a measurable property, greatly facilitates the task of identification/classification of entities.

According to the SCENIHR (2010) «there is no scientific evidence in favour of a single upper limit. However, there is by general consensus an upper limit of 100 nm which is commonly used. There is no scientific evidence to qualify the appropriateness of this value»[2] Thus, the sizes given as benchmarks in this type of definitions are in fact

[2] SCENHIR, *op.cit.*

arbitrary or stipulated. Such definitions could thus also be included in the so-called «stipulated definitions» appearing in the entry «Definitions» of the Stanford Encyclopedia of Philosophy (Gupta 2009). These solutions can be considered reasonable when the goal is of a pragmatic nature, such as legislation, but of little epistemic value –fundamental, in our opinion– when the purpose is related to ethical reflection. The different size scales are themselves conventional means that we use to measure space, instruments used to characterize objects in a relative way (in relation to a given scale) and/or to compare/classify things according to their sizes. But from a realist point of view, when predicating something substantial of a given entity, there should be a good reason for it, i.e. there should be a causal relationship between what is predicated and a real fact or set of real facts. For instance: if we classify a given object as «microscopic», as belonging to what we define as «the microscopic world», it is not because this object is in the micrometric range, but because it cannot be seen by the naked human eye. The truth is that there is a number of tiny entities that a normal human being is unable to see without the help of an external device (a microscope), due to their smallness. Within the naturally limited microscopic world, being micrometric is instead arbitrary, accidental. For the microscopic world the essential real fact includes the participation of human beings, not as conscious creators of an arbitrary criterion based in the metric scale, but as holders of a capacity –eyesight or the perception through the eyes of a specific range of light spectra– that is naturally limited. This natural human limit is thus part of the essence of «being microscopic». In a similar way, from a realistic point of view, if it were true that being «nanotechnological» was something real the fact of being «nanotechnological» would have to be causally related to a real fact, even if this real fact was in one way or another connected to the interaction that humans have with the objects in question.

On the other hand we now know that nanometric particles exist, either naturally produced or as byproducts of given human activities, and that they have always been present in our lives or were even produced back in Ancients Rome and Egypt with technical purposes and used as cosmetics, pigments or weapons, long time before we were aware of their nanometric condition (Walter, *et al.*, 2006), (Mitin, Sementsov, Vagidov, 2010), (Reibold; Paufler; Levin; & Kochm, 2006). Is it correct to say that Romans or Egyptians were working on «nanotechnology» thousands of years ago?

Besides, taken literally, nominal definitions could embrace almost every field of science and technology dealing with material objects, because most materials can in one way or another be considered «nanostructured» since their molecular structure, at the nanometric level, is always responsible for some of the properties in which their technological uses are based.

Strictly following this definition nanotechnology does not seem to entail anything new, other than the name itself. In fact, a nominal definition of nanotechnology can be used by some companies and researchers to label their products and researches as «nano», only as a launch pad.

### 2.1.2 Teleological definitions

Other approaches define the nanotechnological nature of objects taking their future uses or goals as a reference. This is what Schummer (2007) calls the teleological approach. These goals can be general values such as health, security or wellbeing, or relative values like «smaller», «stronger» or «cheaper». In any case, teleological definitions of nanotechnology are expressed as visions of a future technology that will radically change every dimension of human life. Following this definition, a research could be qualified as «nanotechnological» if it helps to carry out these visions of nanotechnology, i.e., if it helps to achieve the expected or predicted goals. These objectives range from «shape the world, atom by atom», to trans-humanist ideas which raise even an hypothetical «immortality» of human beings. These forecasts could be directly qualified as science-fiction and seem more intended for shaking emotions than for producing knowledge.

The main objection to definitions of this kind is that these visions are generally scientifically impossible or unfeasible, at least in a foreseeable future. As a matter of fact, it is difficult to relate them to current research activities.

In this case, the corresponding definition in the *Stanford Encyclopedia of Philosophy* could be a combination of the «explicative definition» and a peculiar form of «stipulative definition» that could be better qualified of «speculative».[3]

### 2.1.3 Real definitions

A third kind of definition is what we could call, along with Schummer (2007), «real definitions». These refer to a list of specific research topics included regularly under the denomination of «nanotechnology» in national research programs, research centers, scientific publications and conferences. This kind of definition is based on a historical use of the word, and it considers the concept as a set of elements that make up its extension.

But a definition based on a list like this presents some problems when used for ethical reflection. The first problem is that the research areas included in the list belong to very different disciplines, and it is almost impossible to find a common point between them. If this was not enough, they encompass the most advanced research in their respective fields. This problem could be partially solved if we spoke of «nanotechnologies» instead of using «nanotechnology», as Gordijn (2005) suggests. Another problem of this type of definition is that it is very unspecific, and it can differ substantially in time and in different countries. Anyhow, this definition does not tell us anything about the nature of «nano», and this does not help us in our task of forming a concept of «nanotechnology» that would enable us to identify possible ethical aspects.

[3] http://plato.stanford.edu/entries/definitions/. Accessed 8 April 2011

## 2.2 Realist reflection

We accept the utility of all the different kinds of definitions mentioned above for their different purposes, like regulation. However, in our opinion, a more adequate definition for the purpose of ethical reflection could be found.

Our objective is to reflect philosophically on the moral issues that can arise from an eventual «*nano*-scope», that is to reflect on the existence of certain «moral facts» linked to nanotechnological entities. The existence of «moral facts» related to nanotechnological entities seems connected to the existence of «epistemic facts» in these same entities, as both moral and epistemic facts are normative facts (Cuneo, 2007). Then, an epistemic realist approach could be seen as a good path to explore the elaboration of a definition of «nanotechnology». But even if moral realism (the acceptance of the existence of moral facts) is only a philosophical posture, an epistemic realist position (the acceptance of the existence of epistemic facts and therefore of objective epistemic truths) continues to be, in our opinion, an adequate option to think about the existence of a «nano-scope», to determine whether it is real (facts-based) or it is conventionally stipulated, and to formulate a suitable definition with the purpose of ethical reflection. Reaching a definition that captures the essence of the concept that we generically call «nanotechnology» appears then to be a task that will have to be done as we increase our scientific knowledge about it.

In this sense we could ask about our ability to recognize things in the world in successive encounters, through time and in different conditions; we could ask about how we develop and use concepts –in this case the concept of «nanotechnology»– to identify a certain entity and to make, if necessary, an eventual task of classification. In this regard, Ruth Millikan's proposals on what she calls «"*substance" concepts*» (Millikan 2000) as a central factor in her explanation on the mission of human cognitive mechanisms could be of some help, at least as a starting point. Millikan's ideas about *substances* show indeed an Aristotelian inspiration.[4] We must ask, in short, what makes something «nanotechnological» or what does being «nanotechnological» mean.

First we must ask about the nature of whatever we refer to through the use of the concept «nanotechnology». Which is its referent in the world? Is it a *substance* or a *real kind*?[5] If nanotechnology is a *substance* or a *real kind*, then we should be able to make projections (forecasts) about the entity «nanotechnology». A sort of invariable «organizing principle», with a real existence, which somehow gives us the ability to identify «nanotechnology» every time we come across it; the ability to recognize it, to learn

[4] *Metaphysics, III, IV, IX.*

[5] We refer here to «substance» and to «real kind» as understood by Ruth Millikan in Chapter 2 of *On clear and confused ideas* [7]: things we can learn things about that can be applied in successive encounters with them, for making projections and for which this possibility is not accidental but based on what we could call an «ontological ground of induction», or even «essence», in an extended sense.

things during an encounter that could be applied to future encounters, to make well-founded inductions, as with other substances that we get to know: «chair», «dog», «gold» or «chemistry». A «principle» that makes the substance be what it is and that, despite having a real existence and therefore an ontological character, is defined in epistemological terms because it helps us to recognize this substance, acting as a basis for making inductions about it. It is important to point out that our ability to identify substances is submitted to error, and that vagueness is an attribute of some concepts as could be the case for «nanotechnology».

In what could this «organizing principle» consist in the case of «nanotechnology»? It seems that the most intuitive answer is directly related to size (nanometric scale or nanoscale). But this solution is problematic for the reasons mentioned in the «Nominal definition» section. Thus, it seems appropriate to explore ways to complement it.

Let's have a look at what the extension of the concept of the substance «nanotechnology» would be. It would be defined by the substance itself; a substance that must be found in the world in the form of certain entities (activities, applications, objects, materials) considered to be «nanotechnological». In this sense, when we say that a certain entity «is "nanotechnology"», we are actually saying that this entity *is a part of* «nanotechnology» or maybe that *it is* «nanotechnological». This leads us to define «nanotechnology» as the set of entities considered to be nanotechnology, and we would then be talking of something very similar to the aforementioned «real definition». In this case we would still have to establish who has the right competence or authority to determine that an entity is «nanotechnology».

When we refer to an entity as *a part of* «nanotechnology», we must be aware that knowing that it is *a part of* nanotechnology leads us to some questions about this entity which need to be answered in order to truly indentify it: What kind of entity are we talking about? To which field of science or technology does it belong? What new properties does it present? What are its dimensions? How can we use it? and so on.

At this point, and bearing in mind everything said above, we might also consider the possibility of thinking of «nanotechnology» as a kind of property (or set of properties) that certain entities (activities, applications, objects, materials) have, instead of considering it a substance. We would then be talking about the «nanotechnological» entities to refer to those activities, applications, objects and materials that have the property of «nanotechnology». We would then have to think about the property «being nanotechnological» and about the concept of the property «being nanotechnological». In this case the question is: What is for an entity «to be nanotechnological»?

### *2.2.1 An approach to a realist definition*

In order to answer these questions, and whether we consider «nanotechnology» a property or a substance, we must first elucidate which are the real facts related with an

entity that cause certain properties to show up and that lead us to considering it *nano* (be it an activity, an application, an object or a material) and that are instead not present in an analogous non-*nano* entity. What makes the difference between substance[6] «X» and substance «*nano*-X»? As we have already seen, «nanotechnology» is commonly used to refer to those things that meet certain size criteria; specifically, at least one of the physical dimensions of the entity has to be in the nanoscale, defined as the 1-100 nm range. But these physical limits are not supported by scientific evidence, as we have already mentioned (SCENIHR, 2010).

According to researcher Amarnath Maitra there is no semantic parallelism between nanotechnology and nanomedicine. In other words, the same set of characteristics that make a certain technology «nanotechnology» are not always met when literature refers to «nanomedicine» (Maitra, 2010), as happens for instance with applications based on cellular uptake of nanosized materials such as drugs or other chemicals. He therefore believes that at least a part of what is known as «nanomedicine» should not be considered «nanotechnology». We can find a definition of nanotechnology in Maitra's work that is quite interesting from the realist standpoint that we are proposing:

> The study of physical properties such as electrical, optical, magnetic, mechanical and thermal characteristics of an entity in which the surface atoms dominate over the bulk atoms is called nanotechnology» Moreover: «Incidentally, an entity dominated by surface atoms and depleted by bulk atoms automatically assumes nano-size in one, two or all the three dimensions of the material. Therefore nanotechnology is the science and technology of surface atoms. Because of the size restriction of these surface atom-dominated entities, the mobile electrons are confined either in quantum wells, quantum wires or in quantum dots.[7]

According to this definition, even if size is a property that must be taken into account when pointing to the essence of «nano», it does not seem fully appropriate to make size the only parameter when defining the «nano-terminology».

What make us think that a differentiated entity is worth the name of «nanotechnology» are the properties that are epistemically interesting to us in the entities that we call «nano». In other words, we are interested, epistemically speaking, in the discontinuities in the trends of some physical size-related properties (electrical, optical, magnetic, mechanical or thermal), and there is evidence that these discontinuities are a direct consequence of an increase of the surface/volume ratio, which in turn is a direct consequence of the fact that surface atoms of those material objects dominate over the rest of bulk atoms (SCENIHR, 2010). It is true that an object accomplishing these conditions

[6] Substance from the chemistry point of view.

[7] A. Maitra, 2010, Op. Cit.

must necessarily have some or all its dimensions in a scale considered to be «nanometric» (1-100 nm), but this truth is in reality an accidental consequence of another fact. It seems that the ontological priority should be assigned rather to the fact that surface atoms predominate over bulk atoms than to the fact that the object has a certain size, because it is the first and not the latter (which actually is an effect of the first) that causes certain interesting properties to be relevant in that object. These properties can be associated to the scope of quantum phenomena, and cannot be observed when bulk atoms prevail over surface ones.

When surface atoms prevail, many of the properties of materials can vary in relation to the properties of these same materials at bigger scales; and it is precisely on these properties at the *nano*-scale that most of the applications of nanotechnologies base themselves, not exclusively on size as such. We are talking about properties such as electrical, optical, magnetic, mechanical or thermal. These «new» properties basically develop when, under certain restricted conditions, some quantum physics effects become relevant. Thus, if we considered a nominal definition based on a size range, how should we qualify an application where quantum effects were fundamental but with 200 nm objects, and so outside the stipulated «nano-metric range»? Could we consider it to be a «nano» application? And the other way round, should we consider «nano» an application based on objects within the stipulated size range, say 50 nm, even if no essential property of that application deviates from the trends shown in the macro scale? What if size was not even a fundamental feature for this application?

Given that the prevalence of surface atoms over bulk ones in certain entities gives origin to substantial differences when compared to entities with the opposite prevalence (perceptible through a number of physical properties over which we may perform based –not accidental– inductions), should we consider those entities to be different substances?[8] Only a real scientific and technological novelty would eventually justify epistemically the use of a new terminology such as «nano». This novelty would have to be proved through the study of these entities and the practical use of their «new properties», or by determining that we are talking about different substances. This is what could be qualified as «revolutionary». The fact that an object is undetectable to the naked human eye –or even to certain devices– because of its smallness is a condition already assigned to the «microscopic world». And the fact of a smaller object fitting in a smaller space is not exactly a new property either. This obviously does not mean that we can obviate the importance of the possibility of miniaturization down to the nanoscale as a facilitator for certain applications in which nanometric size certainly

[8] We understand here «substance» in the same sense as Millikan. So, a macrometric material shows physical properties (optical, electrical, thermic, mechanical or magnetical) very different to those of the «same» material in nanometric form (for example, gold vs. nanometric gold).

makes a difference. This is the case in certain nano-objects with a size in the «detection threshold» of some «physiological sensors».

Thus, if we follow this reasoning, we could split somehow the universe of techno-scientific entities in two: the ones with predominance of bulk atoms over surface atoms and the ones with predominance of surface atoms over bulk atoms. The existence of observable differences in properties between the entities with predominance of bulk atoms over surface atoms and the ones with predominance of surface atoms over bulk atoms is what a realistic definition of «nanotechnology» should keep in mind. The realistic definition should take into consideration the historic-causal linking relation between the features that make nanotechnological *substances* epistemically interesting, and thus meaningful to us –the new observable properties–, and the facts that cause these features.

As such, the observable properties in a particular *substance* are nothing but the *expression* of certain structural features in this *substance.* When surface (atoms) overcomes (in number) bulk (atoms), quantum effects take relevance in some observable properties. These relevant quantum effects are in fact changing the trends in which we base our projections about observable properties of what we considered –maybe wrongly, and that is the key– the *same particular substance* (for example gold as compared to nanometric gold). The direct cause for this phenomenon is that, in the «nanotechnological» entities, there is predominance of surface atoms over bulk atoms and not the fact of being «nano-metric» *per se,* which would actually be a measurable consequence of the positive surface/bulk atoms balance itself. Surface atoms behave, at a quantum level, differently from bulk ones because they have different surrounding influences, and this is the reason for certain properties to show discontinuity at the point when predominance begins to be of surface over volume.

The possibility of submitting a specific property to a conventional measuring scale, as is the case of size in the metric scale, makes this property especially attractive at a practical level. But the ontological principle that provides us with an epistemic foundation on which to build a concept and a realistic definition should be of a more solid nature. In the case of «nanotechnology» it seems reasonable to link this principle to the surface atoms versus bulk atoms ratio, which is the real fact that primarily causes the effects that will finally be of importance to us: the discontinuity of the trend in certain observable properties.

Changes in the relevance of certain quantum effects may constitute an intermediate cause of the final observable outcomes, but are indeed a consequence of a previous cause: the reversal of the surface/bulk atoms ratio. Similarly, the size of one or more dimensions of the entities should also be considered a measurable and observable effect of the initial fact (ontologically speaking) already mentioned. It is a task for nanoscientific inquiry and for philosophical reflection to answer whether «being nanotechnological» is in itself a *property* of some *substances* or whether it is a characteristic that would

allow us, based on a principle with ontological character, to consider new *substances* or *natural kinds* that would have to be represented and recognized through a differentiated concept.

In summary, we consider that a feasible realist definition for *nanoterminology* that would allow us to fix the reflection framework for the ethical and social aspects that may arise from it could be based on the real facts mentioned: the existence of a discontinuity in certain observable physical properties (such as electrical, optical, magnetic, mechanical or thermal) (Maitra, 2010) that confer to the object in question certain characteristics, and the fact that this discontinuity has a causal relationship with the predominance of surface atoms over bulk ones. Of course, this necessarily implies that at least one of the external physical dimensions must be within the margins of what we call «the nanoscale». Whether or not this discontinuity is relevant for a specific application will determine the suitability of certain means as a way to achieve certain ends, but will not be pertinent as to determine whether the use of particular vocabulary to refer to certain reality is epistemically relevant. What we are proposing is a realistic definition strategy, an attempt to substantiate the combination of ontological and epistemic factors which are the heart of what «nanotechnology» actually is. Of course, a certain degree of vagueness must be accepted in a concept defined in such terms.

For nanotechnology to be the reference in the real world of a specific terminology in the language, it has to be identifiable as an ontologically differentiable entity (material or abstract), and thus based on the existence of an «ontological principle», an *essence.* It seems as well that something like the «ethical implications of nanotechnology» should be founded on the eventual moral implications of the use of «nanotechnological» entities related with the «ontological principle» that makes the entities being «nanotechnological», and not of any use of them. Otherwise we will not be talking about «ethical implications *of nanotechnology*».

## 3. A realist reflection on the ethical implications of nanotechnologies

It is not new that technology, as a human activity, raises some aspects that may affect different spheres of societies' and individuals' lives. Consequently, a reflection from the ethical perspective is relevant. Certainly, throughout the history of civilizations there have been specific technological advances that brought with them new paradigms, the implications of which meant a qualitative leap, further than the ongoing quantitative accumulation that technological development always implies. These technological advances have sometimes deserved, generally *a posteriori*, the creation of new tools for ethical thinking. Genetics and biotechnology in general, or the so-called ICTs (Information and Communication Technologies) and specially the Internet, are some examples of current technologies that have led to qualitative leaps and worth a special reflection.

It has been said that nanotechnologies represent a new technological revolution; if this is true, nanotechnologies could be bringing another of these «qualitative leaps». As seen, it is convenient to determine first the object of reflection and then find out in which aspects it could represent a genuine revolution and in which ones it is just another step forward in the continuous quantitative accumulation of scientific knowledge and technological development. For this purpose it is therefore necessary to define nanotechnology in the proper terms. An adequate choice on which to base the definitions of the «nano-scope» could be to consider that reality is something that exists independently of subjects, and that «nanotechnology» –a part of reality we should care about– is something founded on real facts whose existence is independent of us.

As modern techno-science has an operational character, in its paradigm, an entity will be considered as part of reality if it has power to act, i.e. it is true if it allows us to operate on nature. For instance, particle size is considered a real criterion as it allows us to measure physical dimensions of particles (which is an action on actual particles). In this context, our epistemically realistic approach could be dismissed by someone as useless, if compared to approaches such as those that enable us to classify entities by measuring them by technological means. However, power to act, as a criterion, does not fully fit in our approach, which is meant to be helpful for reflection, and not just for operational, purposes.

Nevertheless, size should not be totally discarded as one of the main properties that helps us to recognize nano-entities when considering their interaction with human beings. If «being too small to be seen by the naked human eye» is the fact already assigned, as a vague borderline, to recognize the «microscopic» scope, other size-based borderlines related to «bio-detectability» –linked to immunologic system or to the blood brain barrier, for example– could be assignable to species of the «nano» gender.

Another problem directly derived from this need of definitions is the possibility of an unfounded use of the «nano-» terminology, as a mere marketing tool by publications, manufacturers, researchers or thinkers. If *nanoterminology* were to respond to a realistic definition of nanotechnology, this would help to properly identify its ethical and social implications. Obviously, a proper identification of ethical and social implications of nanotechnologies is an essential early step of the ethical reflection. We need to know what we are reflecting about and we need to know if it is new to us or, conversely, is something we already knew.

As a recent contribution, the European Commission, within its 7th Framework Programme's NanoCode[9] project, is currently in the process of a multi-stakeholder dialogue collecting inputs to implement the European Code of Conduct for Nanosciences &

[9] http://www.nanocode.eu/. Accessed on 11/10/2011.

Nanotechnologies Research. NanoCode Project is elaborating the CodeMeter,[10] a tool to measure the degree of implantation of the Code, and has recently released the second draft of its MasterPlan,[11] a compilation of «issues and options on the path forward with the EC Code of Conduct on Responsible N&N Research». One of the conclusions of the «Promoting responsible innovation: The future of the European Code of Conduct for Nanotechnologies» [12] international conference, held in Brussels in September 2011, was that it would be perhaps a good idea for the future of the «EU Code of Conduct for Nanosciences & Nanotechnologies Research» to be extended beyond «nano» to all emerging technologies, and beyond research to all the value chain, in part due to the difficulties found in the tasks of standardization and elaboration of definitions and to the complexity of determining the degree of novelty of nanotechnologies[13] as such. This seems a solution that somehow would direct efforts of ethical reflection towards the new properties of nano-entities because of being new (the novelty factor) rather than because of their size.

## 4. Conclusions

Nanoscience and nanotechnology represent, according to several sources, a techno-scientific revolution as they open a whole world of possibilities by acceding to certain levels of matter, and promise substantial changes for individuals, societies, humankind and the environment. These changes demand a philosophical reflection to tackle the aspects of an ethical, social and legal order that this revolution may lead to.

For a reflection about the ethical, social and legal aspects, a first step is to fix the scope of reflection and this requires a reflection upon the meaning of the terminology used within the framework of nanoscience and nanotechnology, a task addressed in different forums but that seems not to be solved yet as some authors admit.

The specialized literature gives us different types of definitions of «nanotechnology». The most common are *nominal* definitions, but *teleological* and *real* definitions are also to be found. Generally, the different kinds of definitions respond to the functions for which the definition is elaborated.

We think that a definition from a *realist* point of view, based in notions like «*substance*» or «*essence*» as existing things, could be feasible for the purpose of ethical reflec-

[10] http://www.nanocode.eu/files/codemeter-draft.xls. Accessed on 11/10/2011.

[11] http://www.nanocode.eu/files/masterplan-second-draft.pdf. Accessed on 11/10/2011.

[12] http://www.nanocode.eu/content/view/225/40/.

[13] NanoCode International Conference: «Promoting responsible innovation: The future of the European Code of Conduct for Nanotechnologies». «Extending the boundaries of the Code?» Round table with representatives of different Countries to illustrate the respective position about responsible innovation and discuss the possibility of extending the Code's principles and approach on a global scale and beyond research.

tion. A *realist* definition has to be founded on real entities, and on what (the *essence*) makes something (the *substance*) be what it is. The *essence* can be seen as an «organizational principle» of ontological character but defined in epistemological terms, because it enables us to learn things of the substance that will be useful for making inductive projections.

Under the realist point of view, if nanotechnology is a novelty, a revolution or something *substantially* different from other technologies (i.e. if it is a different *substance* or a different *real kind*) and deserves a specific terminology, it must have an *essence*, even if we are unable to define it.

In line with an extended and popular interpretation, what makes nanotechnology be what it is, it is the fact that at least one dimension of the objects involved in the applications is within a stipulated range (1-100 nm). Under a realist point of view, though, it seems more reasonable to consider that it is the fact of the existence of a discontinuity in certain observable properties of the objects, and that this discontinuity has a direct causal link with the real fact of the number of surface atoms of these objects outweighing the number of bulk atoms and the resulting emerging new properties, mainly quantum-related. The fact that one or more dimensions of these objects are within the nanometric range is a necessary consequence of its high surface area/volume ratio, but not the primary cause of the observed discontinuity in certain properties.

We may consider that the ethical, social and legal implications of nanotechnologies are those issues that could, in some ways, affect individuals' lives, humankind development and/or social progress, and are derived from a use of «nanotechnological» entities based in what it really makes them be nanotechnological, i.e. the «new» properties due to the predominance of surface atoms over bulk atoms. The implications of a use based upon already known properties of the matter, such as «a smaller object fits in a smaller space» or invisibility due to miniaturization, are very important and should be taken into account, but it is not clear whether they represent real novelties –with the possible exception of those related with detection limits of certain biological sensor systems unreached until now.

Some European thinkers are envisioning extending the ethical reflection scope, and in consequence the EU Code of Conduct, from nano- to emerging technologies as a possible solution to vagueness and/or to problems derived from the lack of definition of nanotechnologies.

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Pere RUIZ TRUJILLO
Bioengineering Dep., Institut Químic de Sarrià (URL)
*pere.ruiz@iqs.url.edu*

Salvador BORRÓS GÓMEZ
Bioengineering Dep., Institut Químic de Sarrià (URL)
*salvador.borros@iqs.url.edu*

Albert FLORENSA GIMÉNEZ
Càtedra d'Ètica, Institut Químic de Sarrià (URL).
*albert.florensa@iqs.url.edu*

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