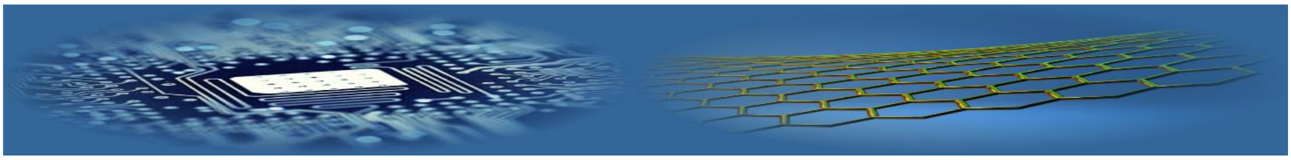

Nanotechnology application challenges: nanomanagement, nanorisks, nanoeducation and consumer behaviour. Review paper

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Abstract

New emerging technologies are entering the society, which makes civil society the location for moral authority. Society is about the quality of human relationships, it is where people have to accept responsibility for the consequences of their actions; it is where the *nano* meets the *micro* and the *micro* meets the *macro* issues. Society belongs to all of us and everyone has his role to play. A new way of systems thinking - nanothinking demonstrates technology trends from perfectness to non-regularity. The removal of current contradictions between regular and non-regular systems and the corresponding nanophenomena is the way to novel processes in the development of nanosciences and nanotechnologies, education and industry, consumer society and policy making. This review is intended for nanomaterial consumers, managers, education practitioners, students-researchers, manufacturers, work health and safety practitioners, and other interested people who do not have a background in technical sciences but who need to understand the benefits and hazards of engineered nanomaterials and require guidance on managing risks associated with these.

'While technology shapes the future, it is people who shape technology and decide what it can and should be used for'
Kofi Annan

1 Consumer insights into nanotechnology: Introduction to rational consumerism and consumer behaviour

The map of the globe does not show a place called Techno Union, yet in many ways we are already its citizens and consumers. And, as consumers, our lives and behaviours are strongly influenced and shaped by an ever increasing system of modern technology, transcending national boundaries to create a vast technological synergy grounded in complex applications in industrial production, logistics, electronic communications, agribusiness, medicine, and science. We begin to realise, whether we like it or not, that we have become a part of techno culture.

The term 'consumption' is usually defined as 'the using up of goods and services' to satisfy man's needs. In Neoclassical Economics, an individual tends to gain more than he or she can personally consume. The economic theory deals with the behaviour of the 'economic human' and his relationships with the environment.

The Rational Choice Theory [1] presents individuals as rational beings acting to realize their interests, having all available information, taking account of probabilities of events, and potential costs and benefits in determining preferences, acting consistently in choosing the self-determined best choice of action and the reasoning required to make objective decisions in order to maximize their personal gain. The concept of rationality used in the rational choice theory is different from the colloquial and most philosophical use of the word.

Colloquially, 'rational' behaviour typically means 'well-thought', 'sensible', 'predictable', or in a 'clear-headed manner.' Rational choice theory uses a narrower definition of rationality, when behaviour is considered rational if it is goal-oriented, evaluative/reflective, well informed, and consistent (across time and different choice situations), which is in contrast with impulsive, uninformed, non-evaluative, and random behaviour. In reality, the latest studies in behavioural economics demonstrate that man does *not* behave rationally.

Professor Dan Ariely, an international expert in behavioural economics, describes in his book, *Predictably Irrational: The Hidden Forces That Shape Our Decisions*, many incidents of such irrational behaviour. One example deals with a person who was willing to make a 15-minute drive to save seven dollars on a pen that cost $25, but would not drive 15 minutes to save the same seven dollars for a $455 suit [2].

Our ambitions have grown alongside with technological and industrial achievements. Over time, people have adopted the 'culture of consumption,' otherwise known as 'consumerism.' This implies acquisition of goods and services *not* for satisfying fundamental needs, but for obtaining social status. Thus, the product has become a symbol of one's social status, and the product itself and its worthiness have very little value. Buying the product may well bring more pleasure to the buyer than its actual use.

In the modern, technologically saturated consumer society, happiness has become a function of an individual's level of consumption, while consumption itself has become the essence of our lives. Barbara Kruger, an American conceptual artist, memorialized the consumer society with her piece in the Museum of Modern Art - a paper shopping bag with the words: 'I shop, therefore I am' - paraphrasing Descartes' famous words describing the essence of man: 'I think, therefore I am.' Man has become an avid consumer with a new pastime - shopping. With the advent of new technologies constantly penetrating all spheres of our life, excessive consumption has become a culture in the modern society - as a 'vending machine' - and its primary characteristic.

In our high-tech time, even the human body is sometimes metaphorically referred to as a machine. We 'fill our tanks' while eating to 'oil our bearings' and to 'keep our motors running.' Our hearts beat like 'clockwork.' A complex problem sets our 'gears turning.' Can we view ourselves as a machine with replaceable 'parts'? Today the answer will sooner be 'not'. However, the future might be promising. Human is not a simple machine, but an amazingly complex system that is perfectly ordered. Looking at ourselves from the Systemic point of view, we can classify our human system as open, developing, non-regular, and dissipative. It means that the system can exist physically, mentally, and spiritually only provided there is a continuous exchange of substance, energy, and information with the external environment (nutrition, breathing, heat exchange, excretion, reproduction, cognition, production of utilitarian and spiritual values, communication, etc.). However, according to the conventional medical wisdom, too much external loads result in illnesses and ageing of the human system. In other words, loads reduce the degree of ordering, causing unstable reactions or disrupting the normal periodic rhythms of the processes in the body. Hence, there is a need of awareness in everything that we consume – what we eat, what we dress, what we breathe, and what we do for the environment we live in.

The industrialized world has developed into a production and consumption global community with a highly advanced level of technologies. Technological advancements have led to markedly increased demands for a standard of living and consumption. However, the current economic crisis has provoked a growing consensus that the 21st century consumer society is on a path that cannot promise its citizens a hope for sustainable future. The prevailing forms of political economy are failing to guarantee the consumers economic stability, preserve ecological resources and services, reduce social inequality, maintain cultural diversity, and protect physical and mental health of citizens. We face related crises of political, social, cultural, educational, and personal sustainability.

Moreover, current developments in scientific and technological research raise a number of ethical questions comprising responsibility. Areas of research as nanotechnology and biotechnology, regarding food, healthcare and environmental issues, elicit complex and undeniable debates within society today. Sometimes, scientific-technological research and investments in different areas do not advocate a common good as their overall aim but serve the interests of those who finance the research itself, whilst forcing those who use these products into commercial traps, often without enough research and information regarding the effects they may have on consumers' health.

Striking developments of new technologies, particularly nanotechnologies, are finding applications in all spheres of life and producing rapid, systemic, and far-reaching effects in business, government, society and the environment, alongside with the challenges they pose to the society. Furthermore, rapid technological changes are forcing organizations to embrace new technologies and change the way they work and interface with suppliers and consumers, thus, leading to changes in many behaviour patterns based on the great expectations for nanotechnologies promising tremendous benefits in the future.

Unfortunately, there is no one-way-fit-all strategy to guarantee a brighter tomorrow for everyone. Nor can the separate efforts of businesses, governments, organizations and individuals cope with the tasks imposed by advanced technologies without complementary contributions of others. Yet everyone can benefit from the insights of reasonable research into the nature of change in rational consumption stipulated by the advent of nanotechnologies and innovations.

2 Nanoscience and Nanotechnology: What is special about 'nano' and why should consumers be informed?

Consciously or unconsciously, the term 'nanotechnology' is firmly entering the life of every consumer-citizen of the global community. It designates both relatively simple nanomaterials and goods such as plastic bags and containers, and very complex technologies that are supposed to change radically the future of humanity such as prosthetic implants that look, feel, move, have a sense of touch like real ones, and are controlled by the brain. However, the general public often lacks awareness and understanding of the basic properties, and sometimes even the existence of nanotechnologies and their implications linked to the consumption of nanoproducts. Moreover, a generally sceptical attitude within the society prevails towards new technologies.

The general lack of public knowledge about nanoproducts that are already on the market in full swing is likely to bring irrational and erroneous, potentially harmful results. Therefore, modern technology requires educated workforce and responsible consumers and hence imperative for educated population. Education should begin with a clear understanding of what nanotechnology is.

Nanotechnology is not really anything absolutely new. In one sense, it is the natural continuation of the miniaturization revolution that we have witnessed over the last decades, where millionth of a meter (10^{-6} m) admittance in engineered products have become commonplace. A good example of the application of nanotechnology is a mobile phone, which has changed dramatically in a few years – becoming smaller and smaller, while paradoxically growing cleverer and faster – and cheaper! The same is true about the computer industry, and many clever gadgets we use today that have *nano* features – such as cameras, flash memory, computer processor chips, car airbag pressure sensors, inkjet printers, and many others, simplifying many things in our life.

What is new about nanotechnologies, though, is the multidisciplinary approach, the convergence of various sciences and technologies making it possible not just to 'see' these tiny entities – atoms and molecules – but also to manage them. Although scientists have manipulated matter at the nanoscale for centuries, calling it physics or chemistry, it was not until a new generation of microscopes were invented in IBM, Switzerland, in the late 1980s that the world of atoms and molecules could be visualized and managed. Now biologists can discuss steric effects of cell membranes with chemists, while physicists provide the tools to watch the interaction *in vivo* - infra-red microscopes to study molecules and X-ray microscopes to study atomic structures and even to handle single atoms. What is really breath taking - is the unprecedented degree of control over materials at the molecular and atomic levels. This may not capture the imagination as much as a tiny machine that precisely assembles materials atom by atom, but it is an extraordinarily interesting and useful phenomenon and is, ultimately, why nanotechnology is kicking up such a fuss.

Nanotechnology is an advanced and exciting area of scientific research and development that is truly multidisciplinary, bringing to the agenda the convergence of technical sciences (technosciences) and even humanitarian sciences (humanosciences). None of separate disciplines would be able to study all aspects of this tiny world.

It is noteworthy that the prefix 'nano' originates from the Greek word meaning 'dwarf' and in modern science means 'a one-billionth part' (10^{-9}) of a metre. It seems next to impossible to draw a picture of one-billionth of a metre in our imagination. To imagine it more vividly, let us take a 'meter' – the unit of length. Now let us imagine a person of medium height – about 1 meter 70 centimetres. Reducing this size by 100 times – we will get the diameter of the iris (a round coloured part of the eye). Further reduced by 10 times – it will make the diameter of the pupil (a black movable opening in the middle of the eye through which light passes). But if once again we decrease it by 1000 times, it will turn out a micron – an extremely small unit, our red blood cell is five times bigger. And if we divide it by 1000 times more, we will get a nanoparticle – the size of molecules and atoms. Consequently, the talk is about researches of the world at the scale of atoms and molecules, which is one-billionth of a meter in size - the nanometre, (or one millionth of a millimetre), which is tiny and unseen. A sheet of paper is about 100,000 nanometres thick, a single human hair is about 80,000 nm wide, a red blood cell is approximately 7,000 nm wide, a DNA molecule is 2 to 2.5 nm, a single gold atom is about a third of a nanometre in diameter, and a water molecule is almost 0.3 nm. The important thing is that size matters!

On a nanoscale (dimensions between approximately 1 and 100 nm), the properties of materials can be very different from those in bulk matter. **Nanoscience** can be defined as 'the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, in order to understand and exploit properties that differ significantly from those on a larger scale' [3]. The question arises, – why do the properties of materials become different on a nanoscale? There are two main reasons for it.

First, nanomaterials have, relatively, a larger surface area than the same materials in bulk matter (for example, sugar powder and sugar cubes). And, consequently, they become more chemically reactive, showing very useful physical and chemical properties (for example, copper which is opaque at a macroscale and becomes transparent at a nanoscale). They become many times stronger than steel and, at the same time, hundreds of times lighter. They demonstrate exceptional electric conductivity and resistivity, a high capacity for storing and transmitting heat. This is confirmed by the fine-grained materials that we use in our daily lives, such as flour, which can become explosive in some circumstances. Nanomaterials can even modify their biological properties (with silver, for example, that becomes bactericide at a nanoscale, nanogold kills cancer cells, nanotitanium kills influenza viruses – nanoparticles of these metals are very active).

Second, below 50 nm, the laws of classical physics give way to quantum effects, causing different optical, magnetic and electrical behaviours of nanomaterials like gold, for instance, which has different optical absorption properties [7] and demonstrates a wide range of colours depending on the size of nanogold particles (see Figure 1).

FIGURE 1 Picture of solution containing gold nanoparticles

These properties, however, can be difficult to control. For example, when nanoparticles touch each other, they can fuse, losing both their shape and those unusual properties, as magnetism – that scientists hope to exploit for a new generation of nano (bio) sensors and devices. Therefore, **Nanotechnology** can be defined as the 'understanding, modeling, design, engineering, production and application of structures, devices and systems by controlling shape and size on a nanometer scale' [3]. Specific functionalities, therefore, can be achieved by reducing the size of the particles to 1-100 nm.

A concise definition is given by the US National Nanotechnology Initiative: '**Nanotechnology** is concerned with materials and systems whose structures and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes due to their nanoscale size. The goal is to exploit these properties by gaining control of structures and devices at atomic, molecular and supramolecular levels and to learn to efficiently manufacture and use these devices' [4]. This term can be applied to many areas of research and development – from medicine to manufacturing, to renewable energy, transport, computing, and even to textiles and cosmetics.

Using nanotechnology, materials can effectively be made to be stronger, lighter, more durable, biocompatible, more reactive, more sieve-like, or better electrical conductors, among many other characteristics due to the fact that it is possible to set the required essential structures of materials at the nanoscale to achieve the desired specific properties.

Most commonly discussed nanomaterials – basic building blocks – are *nanoparticles* which are below the wavelength of visible light and therefore cannot be seen; *carbon nanotubes* (single-walled and multi-walled) which are thin cylinders of atomic layers of graphite; and *quantum dots* – fluorescent nanoparticles like 'artificial atoms' made of silicon, for example, and are invisible until lit up with ultraviolet light.

Nanoparticles are not new. Nanoparticulate carbon black has been used in vehicle tyres for decades, currently at a rate of six million tons per year. Nanoparticles can be found in nature, ranging from milk products (containing nanoparticulate casein) to the burning candles, or almost anything that burns, creates nanoparticulate material. We live surrounded by nanoparticles: a normal room can contain from 10,000 to 20,000 nanoparticles per cm^3, in a forest – 50,000 nanoparticles per cm^3 and 100,000 nanoparticles per cm^3 in city streets. The bright colours on a butterfly's wings are due to the light reflected from nanoscale layers in the structure of the wings. The red and yellow colours seen at sunset are also due to nanoparticles.

But nanoparticles behave like neither solids, liquids, nor gases, and exist in the topsy-turvy world of quantum physics, which governs those denizens small enough to have escaped the laws of Newtonian physics. This allows them to perform their almost magical feats of conductivity, reactivity, and optical sensitivity, among others. 'That's why nanomaterials are useful and interesting and so hot right now,' says Kristen Kulinowski, executive director for education and policy at the Rice University Centre for Biological and Environmental Nanotechnology (CBEN). 'Being in this quantum regime enables new properties to emerge that are not possible or not exhibited by those same chemicals when they're much smaller or much larger. These include different colours, electronic properties, magnetic properties, mechanical properties – depending on the particle, any or all of these can be altered at the nanoscale. That's the power of nanotech' [6].

However, there is a distinction between '*incidental'* and '*manufactured'* nanoparticles [5]. Incidental nanoparticles are those which are not manufactured deliberately, but either occur in nature (as produced by forest fires and volcanoes) or as a by-product of high-temperature industrial processes (such as combustion, welding, grinding and exhaust fumes of cars, trucks and aircraft). Incidental particles are comparatively less chemically reactive and bioactive than manufactured nanoparticles. They do not have the same bioavailability as manufactured nanoparticles and they cannot be taken up by individual cells. Still, the exposure to large levels of incidental nanoparticles in urban air pollution causes increased incidences of disease and even death [5].

Manufactured nanomaterials are those, which are produced deliberately. They include nanoparticles (e.g. metal oxides such as zinc oxide (ZnO) or titanium dioxide (TiO_2), as well as structures created through nanotechnology such as nanotubes, nanowires, quantum dots, and carbon fullerenes (buckyballs), etc. Pathology studies suggest that manufactured nanoparticles are taken up through the human gastro-intestinal tract, translocated through the body, and accumulate in organs where they can have serious long-term health effects, leading to chronic inflammation and even cancer [5].

Therefore, since the market offers nano-enhanced goods manufactured with engineered nanoparticles, the question goes beyond 'to buy or not to buy.' There is something far more fundamental at play. Consumers should have the right to know what is in the goods they buy – and know how they were produced. Full transparency and easy access to detailed information are key to gaining and retaining public confidence in nanotechnologies. It is not enough just to say to someone they should buy organic or natural if they seek such a guarantee - not everyone can afford to do so. The consumer right to information about nanoproducts must revoke debate about pros and cons of these. If some people wish (as some really do) to avoid nanogoods – for whatever reason – they should have the information at hand on the labelling to allow them to do so. Benjamin Franklin was absolutely right saying that sometimes things are difficult to see, but it is even more difficult to foresee things, to predict what impact they might have on us. Invisible nanoparticles quite meet these words.

3 Basic categories of nanotechnology-based consumer products on the market and consumer awareness

Advancements in the fields of nanoscience and nanotechnology have resulted in thousands of consumer products that have already migrated from laboratory benches onto store shelves and e-commerce websites. While much of nanotechnology's potential has yet to be realized, and research is still ongoing on its effects to the environment and human health, products that incorporate nanotechnology have already flooded the market and after more than twenty-five years of basic and applied research, they are gaining in commercial use. The estimation for a nanoproduct value of $1 trillion in 2015, about $800 billion of which was in the US, appears to hold true [31]. The market is doubling every 3 years as a result of successive introduction of new consumer products incorporating engineered nanoparticles but very few of general public realize that the foods we eat, the clothes we wear, the medicines we take, the cosmetics we use, and many other consumer products are manufactured with the use of nanotechnologies. Only a small number of consumers or business executives realize the extent to which nanotechnology is going to change the products they use every day.

Owing to their unique properties, nanomaterials are increasingly used in commercial applications in a variety of fields including, optics, electronics, magnetics, mechanics, catalysis, energy science, agri-food sector, nanobiotechnology, and nanomedicine. Nanomaterials are used to manufacture lightweight, strong functional details, parts and systems for applications in marine and aerospace equipment, and automotive parts. They are also widely used in foods - diet milkshakes, cooking oil, tea and beverages, soft drinks, dairy products, food additives in processed meats, cheeses, as well as in electric home appliances, antibacterial kitchenware, touch screens (iPhone), computer memory, clothing, coatings, wound dressings, dental fillers, toothpastes and toothbrushes, sporting goods and equipment, cosmetics, and many other applications and processes. Because of the high demand, more than a trillion dollars' worth of nanotechnology-based products is expected on the market in the near future [9].

There already exist over 1800+ everyday commercial products that rely on nanoscale materials and processes [8]. At least 400 nanofoods and agricultural products and 300 - 400 nanofood packagings containing nano-ingredients are now on sale internationally. However, it has been difficult to find out how many exactly 'nano' consumer products are on the market and which merchandise could be called 'nano'. To document the penetration of nanotechnology in the consumer marketplace, the Woodrow Wilson International Centre for Scholars and the Project on Emerging Nanotechnology created the Nanotechnology Consumer Product Inventory (CPI) in 2005, listing 54 products [9]. This first-of-its-kind inventory has become one of the most frequently cited resources showcasing the widespread applications of nanotechnology in consumer products. In 2010, the CPI listed 1012 products from 409 companies in 24 countries. Even though it did not go through substantial updates in the period between 2010 and 2013, it continued being heavily cited in government reports and the scientific literature.

The new total of 1800+ products as of March 2015 represents more than a thirty-fold increase over the 54 products originally listed in 2005 – which is not a complete representation of the growth of this market. While not comprehensive, this inventory gives the public the best available look at the 1800+ manufacturer-identified nanotechnology-based accepted consumer products [10]. They are grouped under eight generally accepted consumer goods categories and sub-categories:

- Appliances (Heating, cooling and air conditioning; large kitchen appliances; laundry and clothing care)
- Automotive (Exterior; maintenance and accessories)
- Goods for Children (Basics; toys and games)
- Electronics and Computers (Audio; cameras and film; computer hardware; display; mobile devices and communications; television; video)
- Food and Beverage (Cooking; food; packaging; storage; supplements)
- Health and Fitness (Clothing; cosmetics; filtration; personal care; sporting goods; sunscreen)
- Home and Garden (Cleaning; construction materials; home furnishings; luxury; paint)
- Cross-Cutting (Coatings)

For us, as consumers, the most important categories are Food and Beverages, Health and Fitness, and the Environment. As we can see from the pie chart (Figure 2), the Health and Fitness category includes the largest listing of products in the CPI, comprising 42% of listed products. Within the Health and Fitness category, Personal Care products (e.g., toothpastes and toothbrushes, lotions, and hairstyling tools and products) comprise the largest subcategory (39% of products). The next biggest category is Home and Garden that accounts for 20% of the total. The Food and Beverage category is further subdivided as Food, Cooking, Storage, and Supplements accounting for 11% of the total. The nano-food products include a canola oil, a chocolate slim shake drink, and a nanosized beverage - Nanotea. The nanoproduct Slim Shake Chocolate is pitched at health conscious consumers. The product is described as being "Low in fat and calories", "No artificial sweeteners" and "Tastes delicious". The promotional text advises that this chocolate drink contains "CocoaClusters™" - "The natural benefits of cocoa have now been combined with modern technology to create CocoaClusters".

These so-called NanoClusters are tiny particles, 100,000th the size of a single grain of sand, and they are designed to "carry nutrition into your cells". This nanofood product is available for ordering via the Internet from a USA address [11].

The contribution of nanoscience research in food science and technology is extensively developing in such major sectors as food safety and biosecurity, materials science, and food processing and product development. According to a definition in a recent report '*Nanotechnology in Agriculture and Food*', food is considered nanofood when nanoparticles, nanotechnology techniques or tools are used during cultivation, production, processing, or packaging of the food. It does not mean atomically modified food or food produced by nanomachines [12].

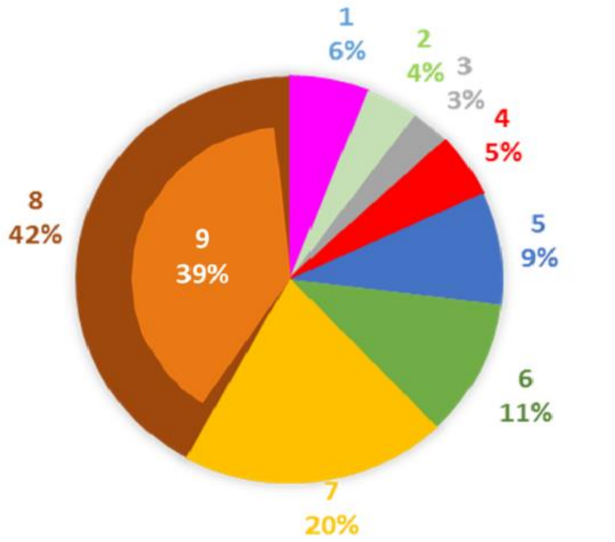

FIGURE 2 Amount of nanoproducts in each major category according to the CPI in 2015: 1-Cross Cutting; 2-Appliances; 3-Goods for Children; 4-Electronics&Computers; 5-Automotive; 6-Food&Beverages; 7-Home&Garden; 8-Heath&Fittness; 9-Personal Care

Nanotechnology has begun to find extensive applications in the area of functional food by engineering biological molecules toward functions very different from those they have in nature, opening up a new area of research and development. Of course, there seems to be no limit to what food technologists are prepared to do to our food.

Nanotechnology will give them a whole new range of tools to attain new extremes in the industry, moving out of the laboratory and into every sector of food production.

The development of foods capable of changing their colour, flavour or nutritional properties according to a person's dietary needs, allergies or taste preferences, such as soft drinks, ice cream, chocolate or chips to be marketed as 'health' foods. Packaging to increase food shelf life by detecting spoilage, bacteria, or the loss of food nutrient, and to release antimicrobials, flavours, colours or nutritional supplements in response.

A significant portion of such products in the CPI (31% of products analysed) utilize nanomaterials – mostly silver nanoparticles, but also titanium dioxide and others – to confer antimicrobial protection. Nanomaterials such as titanium dioxide and silicon dioxide are used to provide protective coatings (15%) and for environmental treatment (to protect products against environmental damage or to treat air and water in the home, 15%). Cosmetic products (12%) are advertised to contain a variety of nanomaterials such as silver nanoparticles, titanium dioxide, nano-organics, gold, and others. A wide variety of nanomaterial compositions (silver, nano-organics, calcium, gold, silicon dioxide, magnesium, ceramics, etc.) are also advertised to be used for health applications, such as dietary supplements (11%).

Dairy products, cereals, breads and beverages are now fortified with vitamins, minerals such as iron, magnesium or zinc, probiotics, bioactive peptides, antioxidants, plant sterols and soy. Some of these active ingredients are now being added to foods as nanoparticles or particles a few hundred nanometres in size. Nanoparticles are added intentionally too many foods for processing and preservation of beverages, meats, cheese, and other foods to improve properties: for example, titanium dioxide (TiO2) is a common food whitener and brightener additive, used in confectionery, some cheeses and sauces [13, 14].

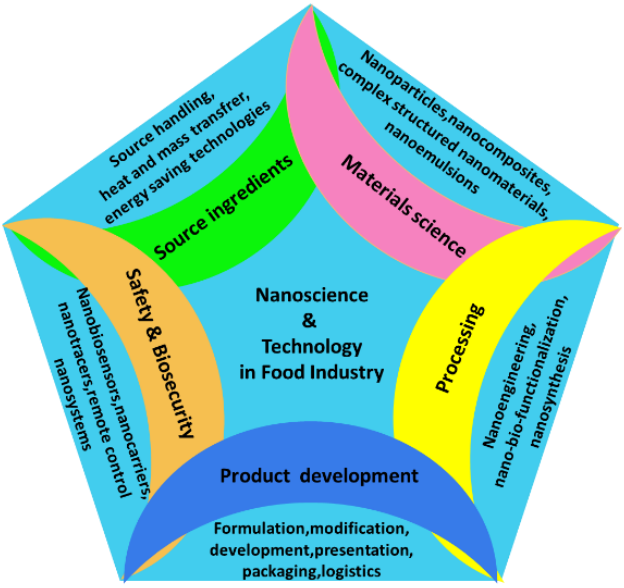

FIGURE 3 Umbrella concept of nanoscience and technology in food industry

German company Aquanova has developed a nanotechnology-based carrier system (using 30 nm micelles) to nano-encapsulate active ingredients such as Vitamins C and E, preservatives and enzymes like co-enzyme Q10 or Omega 3, and fatty acids. They market 'Nova Sol' and claim that the system increases the potency and bioavailability of active ingredients. They offer considerable advantages for meat processors: sausages and cured meat production, to speed up the production process, to stabilize colour and 'improve' taste.

The Daewoo Refrigerator claims: 'Nano silver presents strong disinfection, deodorant and storage power. It also maintains balance of hormone within our body and intercepts electromagnetic waves significantly' [11]. Nestlé and Unilever are developing a nanoemulsion-based ice cream with a lower fat content that retains a fatty texture and flavour. However, the greater potential for cellular uptake of nanomaterials, coupled with their greater chemical reactivity, could also introduce new health risks.

Most of us are familiar with the waxy coatings often used on apples. Now nanotechnology is enabling the development of nanoscale edible coatings as thin as 5 nm wide, which are invisible to the human eye. An edible coating material can be defined as a thin layer of a selected formulation, which is applied directly over food in liquid form by using different techniques, such as immersion, spraying, etc. In addition, an edible film is defined as a packaging material, which is a thin layer placed on or between food components, used as wraps or separation layers [15]. The edibility of films and coatings is only possible when all components including biopolymers, plasticizers and other additives are food-grade ingredients, while all of the involved processes and equipment should be also acceptable for food processing. Edible nano coatings can be used on meats, cheese, fruit and vegetables, confectionery, bakery goods and fast food. They can provide a barrier to moisture and gas exchange, act as a vehicle to deliver colours, flavours, antioxidants, enzymes and anti-browning agents, and can also increase the shelf life of manufactured foods, even after the packaging is opened [16, 17].

Storage includes plastic beer bottles, Miracle Food Storage plastic bags and containers, plastic food wrap, and baby's mugs and milk bottles. There is no need to tap or shake mayonnaise or ketchup bottles now to remove the last of their contents. Several German research institutes, industry partners and the Munich University of Technology have joined forces to develop non-stick nanofood packaging. The researchers have applied thin films that measure less than 20 nm to the inside surface of food packaging. The researchers promote their product as an environmentally friendly solution to reduce leftover traces of condiments in bottles [18].

Nano-CareTM fabrics, sold in Eddie Bauer chinos and other clothing since November 2001, incorporate "nanowhiskers" into the fabric to make it stain-resistant to water-based liquids such as coffee and wine. PPG Industries produces SunCleanTM self-cleaning glass, which harnesses the sun's energy to break down dirt and spreads water smoothly over the surface to rinse the dirt away without beading or streaking. Various sunscreens (Wild Child, Wet Dreams and Bare Zone) incorporate ZinClearTM, a transparent suspension of nanoscopic zinc oxide particles that are too small to scatter visible light as do products containing microscopic particles. Nanotechnology creates added value to these products through a variety of properties – impermeability to gas, water-repellence, and transparency – that manifest only or optimally at the nanoscale.

However, there are concerns that manufactured nanomaterials are released into the environment from waste streams or during recycling. This may present a new range of serious ecological risks. Therefore, it is possible that such packaging may introduce more pollution problems than it solves [14, 18].

Of the 1800+ products listed in the CPI, 47% (846 products) advertise the composition of at least one nanomaterial component and 62 of those products list more than one nanomaterial component (e.g., a product comprised of both silver and titanium dioxide nanomaterials) [10].

Nominally, metals and metal oxides comprise the largest nanomaterial composition group listed in 37% of products (Table 1). Titanium dioxide (TiO_2), silicon dioxide (SiO_2), and zinc oxide (ZnO) are the most produced nanomaterials worldwide.

However, silver nanoparticles (AgNPs) are the most popular advertised nanomaterial, present in 438 products (24%). Silver and titanium dioxide are the nanomaterial components most likely to be combined with other nanomaterials in consumer products, with 35 and 30 product combinations, respectively. Silver and titanium dioxide are paired with each other in 10+ products (cosmetics and electronics). Titanium dioxide and zinc oxide are paired in 10+ products (sunscreens, cosmetics, and paints), whereas the European Commission's Cosmetics Regulation has permitted the use of nanoscale titanium dioxide in sunscreens, but not zinc oxide [19].

TABLE 1 Types of nanoparticles used in the food production chain

Type of nanoparticles	Application	Function
Nano-sized nutrients (powders, sprays, emulsions)	Food additives / supplements / nutraceuticals	Greater uptake, increased absorption of nutrients, better bioavailability and dispersion of nutrients
Metal nanoparticles and metal oxides (silver, gold, platinum, copper, magnesium, iron, iron oxide, zinc oxide, aluminum oxide, titanium dioxide, silicon dioxide, etc.)	Food additives/supplements, drugs, cosmetics, sunscreens	Better uptake, increase reactivity and bioavailability of vitamins and minerals, protein, antioxidants, fibre, enzymes (co-enzyme Q10), prebiotics and Omega 3 (DHA), ensure preservation, improve properties, and provide protective coatings.
	Packaging materials / storage (plastic bags, containers, bottles, food wrap, baby mugs and milk bottles)	Improving quality, extending property limits and durability of contents.
	Equipment for food preparation (antibacterial utensils, cutlery, chopsticks, cookware)	Antibacterial, self-cleaning surfaces rinsing the dirt away without beading or streaking
	Fridges, storage equipment	Anti-bacterial coating of equipment extend storage power, disinfection, deodorant
	Sprays for healthcare	Anti-bacterial properties, better uptake, increase bioavailability
Colloidal metal nanoparticles	Food additives/supplements	Enhance gastro-intestinal uptake, prevent caking, deliver nutrients and prevent bacterial growth
Complex nanostructures and nanodevices	Nanobiosensors/nanochips in packaging	Detection of food spoilage, detection of pathogens; identity preservation and tracking.
	Biodegradable nanosensors	Temperature, moisture and time monitoring / storage conditions
	Hand-held equipment	Detection of contaminants
Incorporated active nanoparticles	Packaging materials, edible nano coatings	Provide a barrier to moisture and gas exchange, deliver colours, flavours, antioxidants, enzymes and anti-browning agents, increase the shelf life of foods, even after the packaging is opened, prevent pathogen growth
Filters with nanopores	Water treatment, purification	Removal of pathogens, contaminants or catalyzing / oxidation of contaminants
	Monodisperse emulsions	Product development
Nano-encapsulated carrier systems, nanoclusters	Food additive / supplement	Targeted delivery of vitamins and minerals, preservatives and enzymes like co-enzyme Q10 or Omega 3, and fatty acids; increase potency, absorption and bioavailability; stabilize colour and 'improve' taste
Nanoparticle-biomolecule corona	Nanomedicine	NP-based targeted drug delivery – better cellular uptake, drug release, and biodistribution profiles

Since 2012, consumer products advertising to contain metal and metal oxide nanomaterials, silicon-based nanomaterials (mostly SiO_2 nanoparticles), and a variety of other nanomaterial components (organics, ceramics, polymers, clays, nanocellulose, liposomes, nano micelles, carnauba wax, etc.) have been growing in popularity. Meanwhile, carbonaceous nanomaterials have remained stable at around 50 products available on the market [10].

CPI is a resource for consumers, citizens, policymakers, and others who are interested in learning about how nanotechnology is entering the marketplace. When used as food additives, drugs, or cosmetics, nanomaterials are regulated under the Federal Food, Drug, and Cosmetic Act (FFDCA). In the European Union, nanomaterials are regulated under the Concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) and the Classification, Labelling, and Packaging (CLP) regulations when those are classified by the Commission as hazardous chemical substances [20].

However, the CPI reports only the numbers of different consumer products and product lines available on the market, so there is no implication on mass, volume, or concentration of nanomaterials incorporated into products or the production volume of each product. Of carbonaceous nanomaterials (89 products), the majority of products listed contain carbon nanoparticles (sometimes described as carbon black, 39 products) and single- or multi-walled carbon nanotubes (CNT, 38 products). Unfortunately, 891 (49%) of the products included in the CPI do not present the composition or a detailed description of the nanomaterial used [10].

Claimed composition of nanomaterials listed in the CPI are grouped into five major categories: not advertised, metal (including metals and metal oxides), carbonaceous nanomaterials (carbon black, carbon nanotubes, fullerenes, graphene), silicon-based nanomaterials (silicon and silica), and other (organics, polymers, ceramics, etc.). Claimed elemental composition of nanomaterials listed in the metals category include silver, titanium, zinc, gold, and other metals (magnesium, aluminium oxide, copper, platinum, iron and iron oxides, etc.). Claimed carbonaceous nanomaterials (CNT = carbon nanotubes).

The fundamental factor driving most nanotechnology applications in foods is the promise for new or improved functionalities of materials and a possible reduction in the use of conventional chemical additives. On an equivalent weight basis, engineered nanoparticles (ENPs) have a much larger surface area due to their very small size and the ability to change their biological and chemical properties. Thus, a much smaller amount of ENPs may be needed to provide the necessary functionality to a material compared to conventional substances. For example, nano-sized water-insoluble substances can ensure their uniform dispersion in aqueous compositions. This makes it possible to reduce the use of solvents in certain applications such as cosmetics, food packaging coatings, paints, and allows the dispersion of food additives such as water-insoluble flavours, colours and preservatives in low-fat products.

Nano-sized nutrients and supplements are also claimed to have a greater uptake, absorption and bioavailability in the body than their bulk equivalents. This fact has evoked a great commercial interest in the use of nano-sized ingredients, nutraceuticals and supplements in food and healthcare applications. Moreover, consumer health has become a marketed commodity – it is everywhere – whatever we buy or consume.

Often, a failure to address even one component can decimate an entire industry. A lack of concern for food security, for example, led to enormous outbreaks of mad cow and hoof and mouth disease. What might have seemed frugal and prudent cost management at the time ended up crippling meat producers.

Safe food is a prerequisite for food security and paramount to the industry. The production, marketing and consumption of safe food are non-negotiable requirements that all partners along the food chain must adhere to, regardless of their place from farm to fork [21, 22].

One of the most promising applications of nanotechnology, known as *nanomedicine*, involves the development of nanoscale tools and devices designed to monitor health, deliver drugs, cure diseases, and repair damaged tissues, all within the molecular factories of living cells and organelles (small, specialized structures in cells which operate like organs by carrying out specific tasks).

Medical applications of nanoparticles (NPs) are wide-reaching as evidenced by their rapid development as therapeutic and diagnostic agents. In particular, significant advances have been made in cancer therapy by pursuing NPs as drug delivery systems. One of the most important challenges affecting NP-based drug delivery is the formation of the “biomolecule” or “protein” corona [23]. As NPs enter physiological fluids, proteins and other biomolecules such as lipids adsorb to their surfaces with various exchange rates leading to the formation of the biomolecular corona. As a consequence, the “synthetic identity” of the NP is lost and a distinct “biological identity” is acquired. This new identity governs how the NP is “seen” by cells and subsequently alters the way in which NPs interact with cells. The biomolecular corona has been demonstrated to have a major impact on the biological behaviours of nanoparticles. Nanoparticles functionalized with disease-specific targeting ligands are positioned to revolutionize the treatment of debilitating diseases such as cancer by achieving targeted and selective cellular interactions [23- 25].

Notwithstanding the fact that no one has yet invented a little machine that will swim through our body and mechanically strip away plaque from our inner arterial walls, nanotechnology is poised to have an enormous impact on the diagnosis and treatment of disease. Nanotechnology has the real potential to revolutionize a wide array of medical and health applications, tools and procedures so that they are more personalized, portable, cheaper, safer, and easier to apply. In order to understand better how nanotechnology could revolutionize such diverse areas, we need to review a bit of fundamental physics.

Two sets of theories relate to this question: classical mechanics, which governs the world of our immediate perception (e.g., an apple falling from a tree to hit Newton on the head) and quantum mechanics, which governs the world of atoms and molecules (e.g., electrons tunnelling through seemingly impenetrable barriers). Given enough information about the initial position of an object and the forces acting upon it, classical mechanics allows us to determine with certainty where that object was at some time in the past and where it will be at some time in the future. This is useful because it allows us, for example, to track a basketball to where it will drop from centre field – get into the basket or successfully fly past (at least in theory).

Quantum mechanics does not provide such comforting predictability but does a far better job explaining the strange behaviour of atoms and molecules and allows us to make (at best) probabilistic assessments of where an electron is and what it might do if we poke it with a light probe. The classical world and the quantum world seem miles apart. However, as we move along the scale - from the largest to the smallest, the classical rules eventually give way to the quantum rules. The murky, middle ground in between the two domains is the province of nanotechnology. Moreover, in this transitional regime, a material often exhibits a different behaviour than it does in the bulk, where it is governed by classical mechanics, or as a single atom, where quantum mechanics dominates.

For example, quantum dots, which are semiconducting nanocrystals, can enhance biological imaging for medical diagnostics. When illuminated with ultraviolet light, they emit a wide spectrum of bright colours that can be used to locate and identify specific kinds of cells and biological activities. These crystals offer optical detection up to 1,000 times better than conventional dyes used in many biological tests, such as MRIs, and render significantly more information [8]. Gold nanoparticles can be used to detect early-stage Alzheimer’s disease.

Molecular imaging for the early detection where sensitive biosensors constructed of nanoscale components (e.g., nanocantilevers, nanowires, and nanochannels) can recognize genetic and molecular events and have reporting capabilities, thereby offering the potential to detect rare molecular signals associated with malignancy. Nanotechnology enables multifunctional therapeutics where a nanoparticle serves as a platform to facilitate its specific targeting to cancer cells and delivery of a potent treatment, minimizing the risk to normal tissues. The ability to create unusual nanostructures such as bundles, sheets, and tubes holds promise for new and powerful drug delivery systems [26].

Research enablers such as microfluidic chip-based nanolabs are capable of monitoring and manipulating individual cells and nanoscale probes to track the movements of cells and individual molecules as they move about in their environments. Research is underway to use nanotechnology to spur the growth of nerve cells, e.g., in damaged spinal cord or brain cells when a nanostuctured gel fills the space between existing cells and encourages new cells to grow [27].

Nanoceramics are used in some dental implants or to fill holes in diseased bones, because their mechanical and chemical properties can be ‘tuned’ to attract bone cells from the surrounding tissue to make new bone. Some pharmaceutical products have been reformulated with nanosized particles to improve their absorption and make them easier to manage. Opticians apply nanocoatings to eyeglasses to make them easier to keep clean and harder to scratch. With nano-enabled drugs that destroy diseased cells and enable tissue repair, doctors may one day extend life expectancy far beyond our current capabilities – at least in countries wealthy enough to afford the technology.

Diabetes treatment could be improved by injecting a nanoparticle into the blood that was programmed to deliver a dose of insulin automatically upon sensing an imbalance in blood glucose level. Cancer may be treated someday soon with an injection of nanoparticles that latch onto cancerous tissue and cook it to death upon external application of a light source that poses no threat to healthy tissue.

People have always tried to use technological benefits, particularly, to overcome limitations of the human body, compensating the missing parts by artificial means. Still, cyber-ware is going into the past, because nanotechnologies really offer amazing benefits. Thanks to a new nano-surgical technology which opens up the possibility that a prosthetic hand looks, moves and feels like the real one, has a sense of touch and is controlled by the brain. Tiny, invisible brain cell implants can enhance memory, change mood, and control artificial arms, legs and other parts; they can store information equal to several big libraries. An eye implant makes it possible for a blind person who has never seen sunlight, to read books and help himself in everyday life. An invisible cochlear nano-implant (a spiral-shape tube-like part of the inner ear) is introduced into the ear that allows deaf people, who have never heard the birds singing, to hear music and to distinguish a range of sounds. Molecular-size nano-robots can search for and destroy cancer cells and, being inhaled, they can clean lungs and remove tumour [28-30].

In the light of scientific and technologic advances, it is not surprising that many people are beginning to think that health can be purchased. The health marketplace abounds in products of every description to satisfy people's desires. It is overcrowded with nano products many of which are questionable. The vast majority of mail-order health products are fakes. The common ones include weight-loss products (mostly diet pills), hair restorers, wrinkle removers, and alleged sex aids. Many worthless devices are claimed to synchronize brain waves, relieve pain, improve eyesight, relieve stress, detoxify the body, boost the immune system, and prevent diseases.

Our market abounds in products offering magic effects – being able to prevent ageing, boost energy and enhance physical performance. Thousands of supplements are marketed with false claims that they can improve vision, joint flexibility, synchronize heart rhythms, relieve stress or treat numerous health problems including cancer. The media have a tremendous influence. Radio stations and television channels broadcast health-related news, commercials, commentaries, infomercials, and talk shows. Advertising should also be regarded with caution. Some of them just attempt to exploit common hopes, fears, and feelings of inadequacy, hopelessness, and despair [31].

Consumer health goes far beyond the decision to buy or not to buy. The ever increasing perplexity of the health care delivery system, the prevalence of myths and misconceptions about health, disease, and remediation, the widespread usage of unproven health products and services, and the rapidly escalating costs of health care show evidence of the need to educate people in the proficient, judicious and economical utilization of health information, products, and services [31].

Consumer health encompasses all aspects of the marketplace related to the purchase of health products and services and has both positive and negative aspects. Positive aspects include knowledge and understanding that enable people to make medically, scientifically and economically responsible choices, while negative aspects comprise unwise decisions based on lack of knowledge, deception, quackery, misinformation, or other factors leading to unpredictable effects.

Thousands of self-instructional products and programs are marketed with false claims that they can help people lose weight, stop smoking, quit drinking, think creatively, raise IQ, restore hearing, cure acne, relieve depression, enlarge breasts, enhance athletic performance, and do many other things. Magnets embedded in clothing, mattresses, or other products are falsely claimed to relieve pain, regulate blood flow, strengthen immunity, and provide other health benefits [31].

Nanoparticles in sunscreens is another problem that raises questions of safety. Two increasingly popular sunscreen ingredients are zinc oxide (ZnO) and titanium dioxide (TiO_2) which block UV light, making them suitable for use in sunscreens. Large bulks of these particles in sunscreen reflect light and appear white on the skin, and so they are not popular with consumers. Nanoparticles do not reflect sunlight, making the lotion appear transparent when rubbed into the skin. Studies now demonstrate that skin penetration of ingredients can occur: small amounts of zinc from sunscreen were found in the blood and urine of human trial participants. New research shows that zinc from the sunscreens reaches the bloodstream and has the potential to cause damage to DNA and cells. The European Union's high level Scientific Committee on Consumer Products has warned that existing research into skin penetration by nano-ingredients is inadequate and that further studies taking into account effects on skin penetration need to be undertaken [32].

Such a seemingly useful and friendly material as silver, in its nano size (AgNPs) causes worries because of a very extensive use, just to support the idea that the very best thing reduced to absurdity can become dangerous. Since silver nanoparticles have unique biological properties and possess dimensions below the critical wavelength of light, it renders them transparent, which makes them very useful and significant for consumer products, food technology (e.g., food processing equipment, packaging materials, food storage), textiles/fabrics (e.g., antimicrobial clothing), and medical applications (e.g., wound care products, implantable medical devices). In addition, nano-silver has unique optical and physical properties that are not present in bulk silver, and which are claimed to have great potential for medical applications (e.g., diagnostics, drug delivery, and imaging).

Today, about 370 tons/year of AgNPs are produced and used worldwide in industrial products (Nowack et al., 2015; Stensberg et al., 2015) reported that an estimate of 1,150 tons of AgNPs was used in 2015. They also reported that the number of products that contain AgNPs has increased from 30 in 2010 to over 500 at the beginning of 2015 [32].

Silver nanoparticles are extensively used for the production of catheters, electric home appliances, and biomedical implants [5]. Because of their well-known antiseptic activities, silver compounds are used in clinical settings to prevent skin infections, such as in the treatment of burns (e.g., silver sulfadiazine) and as coatings on various surfaces such as catheters [5]. Metallic silver appears to pose minimal risk to health, whereas soluble silver compounds are more readily absorbed and have the potential to produce adverse effects [34].

Millions of people die each year from infections picked up in hospitals. This is a shocking loss of life. Overuse of antibiotics has contributed to the problem, by promoting the development of more powerful bacteria that are resistant to antibiotics. Now, leading microbiologists have warned that the rapid rise in household antibacterial products containing nano-silver could put more lives at risk. Dozens of socks, shoe pads, sports clothing, towels, and bedding now marketed as ‘anti-bacterial’ or ‘odour controlling’ use nanoparticles of silver to kill the bacteria that cause odour. Similarly, antibacterial soaps, acne treatments, toothbrushes, hairbrushes, mattresses and cots, computer keyboards, refrigerators and other appliances, pet products and even water flasks contain nano-silver [35, 36].

The current and former Presidents of the Society for Microbiology have told that overuse of nano-silver in consumer products could breed bacterial resistance to antibiotics and other drugs undermining the immune system. If we start using nano- silver quite broadly in the environment, then not only will we have bacteria that are resistant to nano-silver, then they will already be multi-drug [antibiotic] resistant as well. Our immune system will degrade and no medicine to withstand viruses will be available [35, 36].

Although research and development of environmental applications is still a relatively smaller area of nanotechnology work compared to other directions of R&D, it is growing rapidly, and nanomaterials promise just as dazzling an array of benefits here as they do in other fields. Nanotechnology will be applied to both sides of the environmental spectrum, to clean up the existing pollution and to prevent its generation. It is also expected to contribute to significant advancements in the environmental monitoring and environmental health science in the near future [36, 37].

Contaminated soil and groundwater are among the most urgent issues, and there has been considerable progress in nanotechnology-based remediation methods. With one of dozens of nanoremediation methods, the iron nanoparticles, for example, contaminants can be neutralized into benign compounds in a few days. It takes much less time to achieve remediation goals than with conventional technology, which can take years using biological processes. The implementation is very simple – the nanoparticles are suspended in a slurry and are basically pumped directly into the heart of a contaminated site, while current methods often involve digging up the soil and treating it [36, 37].

Population growth, urban migration, and the effects of extreme events associated with climate change make water availability an increasingly pressing issue. In environmental remediation applications, nanotechnology could help to meet the need for affordable, clean drinking water quantity and quality through rapid, low-cost detection of impurities in it as well as filtration and purification of water. For example, researchers have discovered unexpected magnetic interactions between ultrasmall specks of rust, which can help remove arsenic or carbon tetrachloride from water; they are developing nanostructured filters that can remove virus cells from water.

Over 96% of the water on earth is seawater, and desalination offers an opportunity to convert previously unusable saline water to fresh water, so researchers are investigating a deionization method using nano-sized fibre electrodes to reduce the cost and energy requirements of removing salts from water.

Nanoparticles are planned to be used to clean industrial water pollutants in ground water through chemical reactions that render them harmless, at much lower cost than methods that require pumping the water out of the ground for treatment. Researchers have developed a nanofabric ‘paper towel’ woven from tiny wires of potassium manganese oxide, which can absorb 20 times its weight in oil for clean-up applications.

New nanotechnology-enabled sensors and solutions are developed to be able to detect, identify, and filter out, and/or neutralize harmful chemical or biological agents in the air and soil with much higher sensitivity than is possible today. Researchers around the world are investigating carbon nanotube ‘scrubbers’ and membranes to separate carbon dioxide from power plant exhaust. Researchers are also investigating particles such as self-assembled monolayers on mesoporous supports (SAMMS™), dendrimers, carbon nanotubes, and metalloporphyrinogens to determine how to apply their unique chemical and physical properties for various kinds of toxic site remediation.

There is really an opportunity with this new technology, to make nanoparticles without waste, in an environmentally friendly way, so that we do not have to worry about the emissions and we don’t have to worry about the clean-up afterwards.

There are diverging opinions in the nanotechnology industry with regards to labelling nano-engaged products, ranging from ‘If it’s a nano-scale material, people should know, hands down’ to not supporting labelling because ‘it wouldn’t accurately inform consumers of anything and would be bad for business because it would scare consumers’ [38].

Appropriate nanomaterial labelling containing sufficient technical information (i.e., at a minimum, nanomaterial composition, concentration, and average particle size) would better inform consumers and highly benefit researchers interested in understanding consumers’ exposure and nanomaterial fate and transport in the environment.

The positive attitude to nanotechnology is based not on knowledge but on hope and fascination. The perceived risk is low because of a lack of vivid and frightening images of possible hazards. If news flashes were to link nanotechnology to concrete hazards or actual harm to people, attitudes might suddenly change [39]. In the case of nanotechnology, there is currently only limited knowledge available regarding the potential health, safety, and environmental impacts of this technology.

4 Towards an open dialogue with consumers on the benefits and risks of nanotechnology-engaged products

Since applications of nanotechnology will quickly penetrate all sectors of life and affect our social, economic, ethical and ecological activities, the general public’s acceptance is compulsory for further developments in the field of nanotechnology and its applications. This acceptance will be influenced by the degree of public awareness of many innovations in science, and particularly, in nanotechnologies.

Still, skepticism might occur mainly due to the unpredictability of their properties at the nanoscale and the fragile public confidence in technological innovation and regulatory systems.

Food occupies a privileged position in all cultures and all considerations.The food and beverages sector is a global multi trillion-dollar industry. Leading food corporations are investing billions and billions of dollars with the ultimate goal of gaining competitive advantage and market share. For the industry where competition is tough and innovations are vital, nanotechnologies have emerged with the potential to advance the production of improved quality food with functionalised properties.

As in other sectors, nanotechnology is promising to revolutionize the food industry from targeted crop pesticides, food production, processing, packaging, transportation and storage to the development of new food tastes, textures, flavours, colours, peculiar properties, and innovative food packaging applications. As a converging technology, nanotechnology through integration with biotechnology, chemistry, and information technology is enabling the development of miniaturized devices, such as nanobiosensors to detect pathogens and contaminants during food processing, packaging, transportation and storage, which is supposed to enhance safety and security of food products.

There is an opportunity, as well as a risk, in the application of nanotechnology to food and healthcare products. Currently, nanotechnologies are being incorporated into commercial products at a faster rate than the development of knowledge and regulations, hence it is important to mitigate potential health and environmental risks associated with their manufacturing, application and disposal. Although plenty of studies have been conducted on the influence of nanomaterials on food and healthcare products quality, it is a highly complex question and a huge gap in knowledge still remains.

Since hundreds of products containing nanomaterials are currently available commercially, this situation clearly necessitates investigation of the exposure and toxicity of these materials. Scientific data compiled to date demonstrate that adverse effects due to exposure to nanoparticles cannot be excluded. Much more information is required to be able to estimate the potential risks of exposure to nanoparticles to both man and the environment. The focus is on free, non-degradable and insoluble nanoparticles found in medical applications, food, consumer products and the environment. Filling these gaps will help with the development of safe products and simplify the consumption of nano-enhanced goods.

Nanomaterials in food and healthcare products are often listed in combination (for example, calcium and magnesium in dietary supplements, nano-ceramics and silver in water filtration products, cosmetics and humidifiers), which demonstrates the use of nanohybrids [40] in consumer products. It also indicates that the use of nanotechnology-based consumer products at home may, in some cases, lead to multiple exposures from a combination of nanomaterial compositions. These instances suggest the need to examine nanomaterial toxicity effects that could be synergistic, additive, or even antagonistic.

A recent study in *Environmental Science & Technology* showed that zinc oxide nanoparticles were toxic to human lung cells in lab tests even at low concentrations. Other studies have shown that tiny silver particles (15 nm) killed liver and brain cells from rats. These particles are more chemically reactive and more bioactive because of their size, which allows them to easily penetrate organs and cells. Products should be at least labelled so consumers can choose whether they want to be part of this experiment [41].

Since metals and metal oxides are the most common nanomaterial compositions in consumer products, they are also the most likely materials to which consumers will be exposed during the normal use of product via dermal, ingestion, and inhalation routes. Products containing nanomaterials of unknown composition are most likely to lead to exposure via the dermal route.

The assessment of food or food ingredients includes details of the composition, nutritional value, metabolism, intended use and the level of microbiological and chemical contaminants. Where appropriate, this might also include studies into the potential for toxic, nutritional and allergenic effects. Details of the manufacturing process used to process the food or food ingredients are also considered, because novel food production processes can render a food 'novel' if it alters the final composition of the food [22].

For most of us, the notion of quality of life is closely connected with the notion of quality of food, healthcare, and the environment we live in. The European Union (EU) Parliament's Environment Committee voted on March 4, 2015, to prohibit foods and supplements containing nanomaterials until they undergo validated new risk assessment, are proven safe for the human health, and subjected to obligatory labelling on products. Foods and nutritional supplements produced using nanotechnology should undergo specific risk assessment, with possible health effects determined, before being put on the European market, claimed the European Parliament's environment committee. Foods for which production processes require risk assessments – including nanomaterials – should therefore not be authorized until they are approved by the European Food Safety Authority (EFSA), say MEPs. Special attention should also be paid to food packaging containing nanomaterials, to prevent them migrating into food. And in line with the precautionary principle, all novel food should also be subject to post-market monitoring, they add. They call for severe controls including the principle '*no data, no market*' [22].

Since then, scientists have gathered more and more evidence that nanomaterials now in use in foods, agricultural products, supplements, healthcare products, and other consumer goods – like **CNTs**, **nano titanium dioxide (TiO_2)**, **nano zinc (ZnO),** silicon **dioxide** (**SiO_2**), c**erium dioxide (CeO_2)** and **nano silver (Ag),** - can be highly toxic and bring new risks to human health and the environment. While the effects of physiochemical properties on toxicity of nanoparticles appear unclear, the results of a recent in vitro cytotoxicity study suggest that **single-wall carbon nanotubes** (**SWCNTs**) are more toxic than multi-wall carbon nanotubes (**MWCNTs**).

It has been well demonstrated that carbon nanotubes (**CNTs)** are indirect genotoxins. They primarily cause DNA/chromosomal breaks via reactive oxygen formation. In addition, CNTs can directly interact with the centrosome structure of dividing cells and induce DNA damage. The primary properties of CNTs associated with their toxicological mode of action are currently being investigated, which may help with predicting their toxicity, or workplace classification banding based on associations between the properties and biological responses.

A number of organisations established by authorities or industry for engineered nano materials (ENMs) have recently established exposure standards for CNTs (e.g., workplace exposure standards (WES). Using different studies and different adjustment factors to account for uncertainty, the derived standards for long term exposures have been established in the range from 0.0003 – 0.034 mg/m^3 [42].

A number of *in vitro* and *in vivo* investigations have shown that **titanium dioxide (nano-TiO_2)** has genotoxic potential manifested primarily as DNA strand breaks in the Comet assay (this is the single-cell gel electrophoresis assay (SCGE), an uncomplicated and sensitive technique for the detection of DNA damage. The term 'comet' refers to the pattern of DNA migration through the electrophoresis gel, which often resembles a comet. This has been concluded to occur through secondary genotoxic mechanisms (oxidative stress) and not direct interaction with the genome. Current opinion remains that TiO_2 carcinogenicity is related to pulmonary overload. A two stage skin carcinogenicity assay showed nano-TiO_2 does not have tumour promotion potential. A number of agencies have derived provisional health-based workplace exposure standards (WESs or similar standards) for TiO_2 NPs. They range in value from 0.017 – 0.3 mg/m^3 [42].

The toxicological database of **zinc oxide (nano-ZnO)** is not as extensive as some other nano-metal oxides (nMeOs). As with other nMeOs, nano-ZnO in *in vitro* cell culture systems is able to cause cytotoxicity (being toxic to cells) and indirect DNA damage via oxidative stress. This appears to be mediated by zinc ions within the cell after the nano-oxide has been translocated from the media into the cell. Toxicity information for workplace assessment has proved that at high concentrations the expected lung inflammation and cytotoxic responses are observed [42].

While the available astute studies with nano-ZnO show increased metal concentration in various tissues, plus or minus indications of tissue damage, their usefulness is diminished by lack of evidence that the nano-ZnO has actually been absorbed from the gastrointestinal tract. In this milieu nano-ZnO is likely to be extensively solubilised. The studies of the use of nano-ZnO in sunscreens have been able to show small fractions (<0.001%) of the dermally applied zinc (either in nano or sub-micron form) absorbed into blood. Furthermore, the absorption continues for some days after the repeat applications stop and the skin has been washed. It cannot be determined whether the increased blood zinc is the result of zinc ion or nano-zinc absorption [42].

When silicon binds with oxygen, it creates a compound called **silicon dioxide** (**SiO_2**). Another name for silicon dioxide is **silica**, which includes its various compositions, both natural and synthetic. Silica has three broad categorizations: crystalline, amorphous and synthetic amorphous. The most common form of crystalline silica is called quartz, which is found in the rocks and sand that make up 90 % of the Earth's crust. Silica, or silicon dioxide, is found in a variety of forms in our environment, as it is ubiquitous. It is naturally found in the earth, in our body tissues and in our food [43].

Silica nanoparticles are used by many industries including drug, cosmetic and food industries. Most commercially used silica is created by crushing or milling it from natural sources. Depending on its form, amorphous silica has a wide range of physicochemical properties. Just as it appears in multiple forms, it has a variety of uses and can be found in many products. Its appearance in food can be due to multiple reasons. Amorphous silica is used as a supplement additive as an anti-caking agent, since silica absorbs excess moisture and prevents ingredients from sticking together when supplements are exposed to moist or humid conditions without interfering with the active ingredients. It can also be used as a food additive as a carrier of flavours and fragrances. Silicon dioxide and silica gel are used as pesticides, so it may be found in food due to exposure to crops, food handling and food preparation.

Various products contain silicon dioxide due to its uses in multiple industries. They can be found in drugs (such as alprazolam by Actavis, oxycodone hydrochloride by Actavis and Xanax by Pfizer). They are also used in supplements (such as silica complex and cosmetics including toothpaste, insecticides and biomedical applications) [43].

The health risks associated with silicon dioxide vary and are dependent on many factors, especially the form of silica. Additional factors include qualities such as the size, specific surface area, coating, number of particles, concentration and duration of exposure. One of the concerns about the silica nanoparticles is that they are able to pass the blood brain barrier, which usually keeps harmful substances from getting into the brain [43].

Those most at-risk for adverse health outcomes correlated with silicon dioxide exposure are occupational industry workers in fields that breathe in large amounts of crystalline silica dust, particularly in the crystalline forms of quartz and cristobalite, as these have been deemed carcinogenic. Although the mechanisms of this toxicity are not clear, there is a lot of work that demonstrates this correlation. Crystalline silicon is associated with silicosis, which is a lung disease caused by inhaling tiny bits of silica over a long amount of time [43].

Silica exposure has also been associated with rheumatoid arthritis, small vessel vasculitis, autoimmune diseases and kidney damage, but there have been contradicting studies about kidney damage. A 2012 study published in the journal Renal Failure found a positive and consistent association between silica exposure and chronic kidney disease (CKD). This study found that occupational exposure to silica is associated with about a third of an increased risk in CKD, and with the duration of the exposure, the risk for CKD increased [43].

Despite many reports and research studies, there is inconsistent and contradictory research on silicon dioxide's safety. This may be due to the fact that it appears in various versions and most of the research conducted has been on crystalline forms and just recently started on amorphous forms. There is not enough evidence yet to conclude that amorphous silica is correlated with the health risks that crystalline silica appears to have. According to the Food and Drug Administration, silicon dioxide and silica gel as food additives are generally recognized as safe (GRAS), meaning that the average consumer will only ingest small amounts without adverse health effects.

Cerium dioxide (CeO_2) nanoparticles have low solubility and are potentially retained in the lungs. High inhalation exposures have resulted in pathology changes in the lung typical of particulates. Biokinetic studies have been performed by measuring the fate of cerium, rather than the nanoparticle *per se*. However, because they are poorly soluble and stable, it is presumed by investigators that tissue cerium concentrations are associated with particulates. Soon after inhalation of moderate amounts of nanoceria, approximately 25% is excreted in faeces, of this more than 90% is in the first 24 hours. This indicates the clearance from the lungs is rapid and gastrointestinal absorption is limited [42].

Once in the systemic circulation, CeO_2 nanoparticles may be widely distributed with the highest tissue concentrations found in the reticuloendothelial system (a part of the immune system). Inhalation and intra-tracheal investigations indicate a typical oxidative stress and inflammatory response associated with bio-persistent particulates, including formation of pulmonary granulomas. It is not surprising for a particle producing oxidative stress after entering cells that nanoceria can cause DNA strand breaks in *in vitro* systems [42].

Intravenous studies with **silver nanoparticles (Ag-NPs)** show silver accumulating in the liver, spleen and kidneys but increased concentrations in other organs are also noted. There is a growing body of evidence indicating that the toxicological effects of Ag-NPs may be influenced more by silver ions than their nano-form. For Ag-NPs there are a number of short-term (10, 28 and 90 days) repeated exposure inhalation studies available. Some of these have been conducted according to OECD inhalation guidelines designed to generate safety data for chemicals. While there are clear dose-related increases in blood and tissue silver concentrations, it appears significant effects (alveoli inflammation and alterations in lung function) only occur in the lungs. Silver ions and Ag-NPs can form DNA adducts (by-products) and micronuclei in a concentration-dependent manner, with silver ions being more potent.

We do not yet know how nanoparticles will affect the way they are transported, and hence their biological and environmental fate. The risk, therefore, is that these materials will have as yet unanticipated impacts on human health and the environment. Preliminary studies in the field of nanotoxicology (an emerging science which looks at the potential for nanotechnology to cause adverse effects) have indicated that some nanomaterials may have toxic effects. In particular, a number of studies have noted the potential for carbon nanotubes (cylindrical nanoforms of carbon which are characterized by their extraordinary strength and unique electrical properties) to exhibit toxic effects in the lung comparable to those of asbestos (UK RS-RAE, 2004). Such studies have raised serious concerns as well as recent calls for a moratorium (FoE Australia, 2008).

To date, there have been no documented cases of adverse health or environmental effects directly attributable to nanotechnology [3]. However, numerous concerns have been raised by scientists, advocacy groups and the general public alike that the specific properties of nanomaterials arising from their small size – the same properties associated with their tremendous potential and numerous possible applications and benefits – may lead to different interactions in humans at the cellular level and with the environment.

The assessment of nanomaterials will follow the guidance issued by the European Food Safety Authority (EFSA) in May 2015. The FSA carried out research into consumer awareness and attitudes to nanotechnologies in the food sector. The research revealed that consumer awareness about nanotechnologies in relation to food was generally low. Consumers were concerned about safety, particularly long-term safety, and impacts on the environment. There was a greater acceptance of certain types of potential applications than others and a general scepticism about industry's motives for developing these technologies. Overall, consumers wanted more information and transparency [21].

In 2016 a EC-funded project 'Europeans and Nanotechnologies' bringing together 17 partners from 11 countries was undertaken by *NanOpinion* with the aim of monitoring public opinion on what Europeans expect from innovation with nanotechnologies (NT). In order to carry out this study, different modes of public participation have been organised. The project is aimed at citizens with a special focus on hard-to-reach target groups, i.e. people who do not actively show interest in science [44].

NanOpinion used an innovative outreach approach, focusing on dialogue, to monitor Europeans' opinions on NT across Europe. It included surveys, social media, discussions, street labs, events in public and semi-public spaces, etc. A total of 8.330 people filled in the questionnaire and approximately 15.000 citizens were engaged in more than 20 live events, including activities in the streets, debates and workshops. Besides, a total of 1.556 students were engaged in school activities and NanOpinion contents on social media reached thousands of users too. In parallel, the media partners published 6 supplements and 161 articles, on blogs and microsites, reaching hundreds of thousands of visitors. The research has demonstrated that less than 50% of Europeans are informed about nano and about 60% heard about it. The majority of the population (88%) consider that labelling of nanoproducts is important. In general, Europeans have a positive attitude to nanotechnology (about 70%) but do not feel themselves competent to discuss it [44]. There is certainly evidence to suggest that some dimensions of nanotechnology may pose potential risks to human health, worker safety, and the environment. However, at this time we cannot yet fully appreciate the precise nature, magnitude or frequency of such risks. The burgeoning field of nanotoxicology has begun to address these questions; however there remains a substantial gap between this field of academic research and the research that is of relevance to risk regulators and policy makers.

As nanomaterials are finding new applications every day, care should be taken about their potential toxic effects.Yet in some countries (Australia, USA) laws do not require food companies to conduct new safety tests on nano ingredients before putting them in foods or to label nano ingredients. Therefore, it is impossible to know how many nanofoods are now on sale, and which foods contain nano, or for consumers to choose whether or not to buy nanoproducts or to eat nanofoods.

5 New technologies and responsible scientific consumption in constructing consumer identity

A prominent feature of the modern society is the pervasiveness of the consumer culture. People's behaviours, activities, and possessions are organized around their consumer identities – the multifaceted labels by which their 'self' is recognized by themselves and members of society. Marketing professionals strive to influence consumers toward choosing and purchasing a particular brand of their product, at a particular time and place. To succeed, they have to have a clear understanding about what makes people want to buy and consume. However, the modern consumer is not an isolated individual making purchases in a vacuum. Rather, we are all part of a contemporary phenomenon that is often referred to as a global consumer society where all people have become increasingly interconnected and interdependent due to the fast scientific and technological advancements in all spheres of life including such areas as information and communications technology.

The growing use of communication devices brings a number of challenges to making information disclosures effective (e.g., on the screens), which can either facilitate or constrain the advancement of any innovation by consumers. The dynamic and innovative character of modern consumption enables consumers to gather, compare, analyze, review, and share information about goods and services and fosters the development of new business entities, some of which promote goods manufactured with the use of innovative technologies (e.g., a huge market of nanotechnology enhanced products). This aspect could potentially raise greater awareness of the fact that we are all part of a single global community that shares a common consumer identity as a background and destiny [45]. Yet, in a contemporary consumer culture, people no longer consume for merely functional satisfaction, but consumption becomes meaning-based, and a person's consumption culture is often perceived as a symbolic resource for the construction and maintenance of consumer identity.

All of us are consumers: we consume goods, services, natural resources, hence our consumer identity is a major factor making up our human commonality and the most essential factor that unites all people of the world into a global consumer society (Figure 4). But against the background of this commonality, we develop different consumption practices and we have different living standards due to various reasons – both objective and subjective. Objectively, we are all exposed to approximately similar conditions. Still, on the subjective side, it is to a great extent our intellectual power that shapes our decision-making, our consumption choices, our life styles, and contributes to the quality of life [45].

It means that today, in a highly technological business world, we need to have enough scientific literacy, knowledge, skills and confidence to effectively construct our responsible scientific consumption practices with the intention to contribute to innovations, new technologies admission, sound business practices and facilitation of responsible and informed policy making to satisfy the requirements of individual consumers as well as contributing to the improvement of the quality of life in general.

In the past, a nation's quality of life and competitive power was mostly determined by its geographical position and the size of population. The advent of technological age has changed the balance of power among nations, and today even a small nation can achieve abundance, economic strength, and high standards of living through its industrial and technological achievements. The rise of consumer culture, the creativity of public, and the increased scientific literacy can move ahead the development and manufacturing of new products through the use of and commercializing new advanced technologies, since a scientifically literate public can better contribute to the potential for achieving a more affluent society by introducing technology and developing added value in manufactured goods.

FIGURE 4 Constructing responsible scientific consumption practices

Technology does not stay at the idea stage; it is converted into marketable products. The fast scientific and technological advancements in all spheres of human activity, including biomedical engineering, computer and communications technology, biotechnology, and nanotechnology call for fresh reflections on what it means, in the 21st century, to be a consumer, and for ethical judgments on how we might shape our scientific responsible consumption on the way to sustainable future consumer society.

What is important for a contemporary consumer to be able to cope with all the tasks imposed by new technologies and scientific advancements in order to make independent knowledgeable decisions? But what if those decisions are influenced by producers and aggressive marketing of businesses?

Education, as a major catalyst, has to help people become effective, scientifically literate, knowledgeable decision-makers and responsible consumer-citizens. The cost is much greater if it does not.

We want our students to leave university with a clear understanding of the scientific, political, legal, economic and ethical functions of the society they live in, and with the moral awareness and social responsibility to thrive in it. Social responsibility is an ethical framework and suggests sustaining the equilibrium between the welfare of the society and the environment. Responsible consumption remains a crucial way of organizing people's place in the contemporary technological consumer society. It will undoubtedly continue to change the quality of life across space and time in the twenty-first century.

New technologies and, particularly, nanotechnologies have emerged on the market with the changing of consumer status from passive to active and the coming out of the new 'intellectual consumer'. The new intellectual consumer expresses a responsible behavior towards his consumption practices and develops a knowledgeable and thoughtful approach to his consumption. A new consumer is perceived as intellectual because he possesses different kinds of knowledge and knows how to select, organize, combine and integrate this set of knowledge within his environment – which can be defined as a contextualized know-how. A new consumer is intellectual, competent, technologically and scientifically empowered, which is fundamental to both the future sustainable global society and the quality of life of every individual [45].

This is why we need to consider the role of new technologies in students' daily lives, in shaping responsible attitude to the consumption practices, and their implications for classroom performances. How closely, for example, should students' worlds outside the classroom match what occurs in the classroom? Why is it important to develop intellectual, responsible attitude to consumption? Intellectual, *responsible consumers* are people showing power of the mind to reason and apply knowledge, who are capable of *choosing* through connecting, of *buying* through thinking, of *consuming* through awareness, of *changing* through understanding [45].

6 Knowledge management as a means of social change: Who needs nanotechnology education?

According to Petrides&Nodine (2003) knowledge management (KM) brings together three organizational resources – people, processes and technologies – to use and share information more effectively. Knowledge has become the most valuable resource concerning the use of technology as a tool for achieving an improved standard of living for all people.

However, there is no monolithic thing called technology. Rather there are various technologies that converge or compete to fit into what can be called an ecosystem of technological and societal arrangements. Societal and technological arrangements co-evolve. This co-evolution happens most favourably in an educated, intellectual, and affluent society that is tolerant of change and divergent views. By fostering an educated, intellectual society, it creates conditions that foster responsible moral and social behaviour of the individual and contributes to shaping intellectual humankind [46].

Important questions have been raised about nanotechnology's potential economic, social, and environmental implications by prominent technology leaders, nanotechnology boosters, scientists, policy officials, and environmental organizations. But there is very little knowledge in wider European society about what nanotechnologies are and what impact they might have on how we live. Many experts acknowledge that uncertainties prevail about this.

Nanotechnology based on multidisciplinary research provides an abundance of potential applications. While advocates preach a revolution, e.g. in chemical production methods, medicine, material science, and energy systems, critics warn about unknown side-effects, e.g. allergies, and deliberate misuse of the technological solutions developed. Higher education has to be at the heart of these processes, ensuring accessible information that will allow people to better understand what nanotechnology is, how it will be applied, and its implications for society [47].

The central question on nanotechnology education is 'Do we need nanoeducation?' To answer this question, we should first find out who needs nanoeducation? What is the interest in nanoeducation from those who have expressed the need? What kind of education is needed - expertise, skills, level? For what kind of jobs are skills and knowledge of nanotechnology needed?

Nanotechnology has shaken the world and the advanced countries are investing billions of dollars for its R&D and industrial applications. For example, USA cumulative investments in nanotechnology-related research since 2001 now total over 24 billion dollars (including the 2017 request) [48]. This support reflects the continued importance of investments to significantly improve our fundamental understanding and control of matter at the nanoscale and to translate that knowledge into solutions for critical societal needs. Environmental, health, and safety research since 2005 now total nearly $575 million; education and research on ethical, legal, and other societal dimensions of nanotechnology since 2005 total more than $416 million [49]. Similar amounts are being spent on nanotechnology by Japan, Russia, China and European Union. Nanotechnology has therefore been taken up in these countries as an important national requirement.

Nanotechnology is already evolving toward becoming a general-purpose technology by 2020 [50]. The National Science Foundation (NSF) has estimated that by 2017 the world will require about 2.000.000 multidisciplinary trained nano-technologists, including Europe with about 3-400,000 nano-specialists with 10 million new jobs. Therefore, modern technology requires educated work-force and responsible consumers and hence imperative for educated population. The needs of new emerging technologies and a beneficial state of consumer society are compatible in this case.

The basis of any reflection whether personal or social, rests on an enlightened and critical intellect. Given its ubiquitous nature, nanotechnology is an essential component of multidisciplinary education on the way to intellectual global society. It motivates the young adult to shape his thought process, to favour opportunities that refine his critical judgment and allow him to look upon the society of which he is a full member with a clear and constructive eye. He will then be ready to play his role as a knowledgeable citizen and contribute to the on-going intellectual growth and wellbeing of his community.

Sustainability is defined as a long-term maintenance of responsibility, which has environmental, economic and social dimensions and encompasses the concept of responsible management. In its turn, responsible management rests on knowledge and understanding of new technologies and scientific advancements fostering the societal development.

To create a sustainable, democratic, technologically empowered and intellectual global society, higher education has to be at the heart of these processes and play a double role. First of all, it has to provide a top-level multidisciplinary education to produce a highly educated workforce. Secondly, to educate the general public by ensuring accessible information that will allow people to better understand what nanotechnology is, how it will be applied, and its implications for the society and personal life.

Society belongs to all of us. What we put into it creates what we get out of it (Figure 5). Society is best when we all join in, when we all bring our knowledge, energy, inquisitiveness, creativity, and judgment to it [51].

FIGURE 5 Input-Output technological knowledge society development

But if we, as citizens and consumers, are ignorant and scientifically illiterate, what kind of input can we provide and how can we affect policy making and expect a dignified output? Here another question arises: Does higher education today fulfils its role as a major catalyst to provide the necessary knowledge and relevant skills mix for our students to be prepared to join the highly technological global economy to ensure sustainable society development and be able to manage innovations for the improvement of the quality of life? [51]

Universities play a crucial role in generating new ideas, in reflecting on new technologies, in accumulating and transmitting knowledge, thus, creating knowledge-added value. Knowledge-added value refers to the contribution of educational factors (e.g., innovative courses, new technologies, foreign languages to be able to work in multicultural organizations) used in raising the intellectual capital, thus, increasing the value of a person.

Outside of economics, added value refers to 'extra features' of a person that go beyond the standard expectations and provide something 'more' while adding intellectual capital to the cost of a person. Value-added features (in fact, professional competences) give competitive advantage to outperform others due to the raised intellectual capital and personality features that include multidisciplinary convergent knowledge, cognitive abilities and strategies, practical research skills and professional aptitude, entrepreneurship, personal responsibility, flexibility, positive attitudes, emotions, ethics, and motivations [51].

However, unless fundamental changes are made in the educational models, curricular and infrastructure to institutionalize the convergent education, to reverse the general erosion of science, technology, engineering and math (STEM) and to address the specific growing need for the convergence with humanitarian education, there will not be a counterbalance of techno sciences and humanosciences in the society. The convergence does not suggest the creation of a kind of education where literary intellectuals understand quantum theory or the nature of neutron stars and scientists in lab overalls spend their free time reading John Ashbery or Dostoevsky. It would be unwise to expect the creation of such a culture.

The talk is about convergence that is essential for the modern society consisting of people who live and work in a knowledge economy forced to confront diverse kinds of knowledge from unrelated fields in their everyday work. Even today, we feel the mistakes and failures of education with a sharp divide into humanities and hard sciences, which has threatened by the prospect that engineering spreads from biology up through the human sciences and arts. Computer technologies serve as a bridge to join the concepts of physics, mathematics and logics with the classical world. Yet it can also serve to carry philosophical and artistic thinking into the scientific community.

Nanotechnology is inherently interdisciplinary, touching upon just about every field of science and engineering, and provides many points of entry for students in non-technical fields, who will find plenty of opportunities to debate its social, moral, ethical, legal and economic impacts. Finally, nanotechnology is now, and it is bound to become a major factor in the world's economy and part of our everyday lives in the near future. The science of the very small is going to be very big, very soon. Therefore, there is an opportunity to equip students with the background and perspectives that will prove useful as they have their way into the future abundant in nanotechnologies. Given its potential impact on society, and the growing public debate over nanotechnology's benefits and risks, both science and non-science majors alike should have at least a passing understanding of what nanotechnology is.

Thus, higher education must, in one way or another, come to terms with new emerging technologies and identify the paramount place that nanotechnologies have taken in the society. It will offer an opportunity for students from a wide range of disciplines to learn about nanoscience and nanotechnology, to explore these questions, and to reflect on the place of the technology in the spheres of their major, their personal life, and in the global society. Therefore, the presence of new technologies - as *means* (sources of information), *object* (area of cognition and activity), and *context* (the environment where education/training takes place) - in the sphere of contemporary higher education is undeniable (Figure 6).

FIGURE 6 New technology as means, object, and context of contemporary higher education

The learning context of nanotechnologies could be presented as the 'Nanotechnology Education Tree' with at least four main branches - comprising Ecological, Health and Medical, Consumer Goods, and Information Communication Technologies - they touch everyone's life, they are understandable and contextually accessible. It would provide an introduction to nanotechnology and how it can be applied in different business and industry sectors. It would also convey information on societal aspects, potential risks, the need for standards, some of the myths surrounding nanotechnology, and a timeline of some of the key developments. Contemporary top-notch education presupposes the engagement of all students into the research of the nanoworld, irrespective of their major. There is a special merit in such a research – that is a high degree of task authenticity, globality, integration with other subjects and involvement of all the aspects of the individual's personality, previous experience and knowledge [52].

Responsible consumption is based on understanding of advantages and threats of new technologies [45]. The European Commission highlights the need to promote the interdisciplinary education and training together with a strong entrepreneurial mindset. It is emphasized that the need for nanotechnologists will not only be confined to the industrial and R & D sectors but will be needed practically in all spheres of life [50].

Experts have estimated that marketing of nano-based industrial products will have risen to some 2-3 trillion dollars by 2017, and nanotechnology is going to dominate the socio-economic life of the world for the next 40-50 years [50]. It requires a lot of resources on the consumer side (intellectual, psychological, economic, etc.) to adjust to the rapid changes in the social and business environment by bridging the gap between the change in attitude to new technologies and the change in consumer behaviour. To a great extent, bridging this attitude-intention behaviour gap is stipulated by the increase of consumer awareness and the raise of the knowledge level.

Therefore, shaping intellectual, responsible consumption practices based on knowledge and awareness is viewed today as the development of civic skills contributing to the sustainable future by enabling people to make their own informed decisions about highly complex technological problems of the day, to take responsibility for their health, their own lives and to contribute to the wellbeing of their communities.

To fulfill the task, it is the job of our higher educational systems of the 21st century to prepare young citizens for the challenges and controversies of the rapidly changing and diverse consumer societies and highly technologically empowered business world. It is the role of higher education to develop skills and values required to enhance democratic life for everyone and to make their informed consumer voices heard in policy decision-making. Democracies need knowledgeable problem solvers and responsible decision makers on the way to social justice - as the fair way in which human rights are manifested in the everyday lives of people at every level of society. Social justice may be broadly understood as the fair and generous distribution of the results of economic growth. Although maximizing economic growth appears to be the primary objective for the adoption of new technologies, but it is also essential 'to ensure that this growth is sustainable, that the integrity of the natural environment is respected, that the use of non-renewable resources is rationalized, and that future generations will be able to inherit a beautiful, flourishing and prosperous planet from our hands' [53].

The conception of social justice must integrate numerous dimensions, starting with the right of all human beings to benefit from a safe and comfortable environment, from the achievements of new advanced technologies, and from knowledgeable decisions in policy making. This entails the fair distribution among countries and social groups of the cost of protecting the environment and of developing safe technologies for production and safe products for consumption, ensuring everyone a decent standard of living, which is an inseparable part of the notions of a knowledge society and knowledge economy.

All these tasks cannot be fulfilled based on separate areas of discovery, technological inventions or scientific disciplines. There is the emergent need for the systems convergence of multidisciplinary knowledge and new technology for the benefit of society, which is the core opportunity for the progress in the 21st century.

7 Convergence of Science, Technology, and Society: Nano-Bio-Info-Cogno-Socio-Humano sciences and technologies – a way to NBICSH society

Higher education today is not seeking the ability to perceive hidden connections between disciplines. It seems, thus, unrealistic to think of nanotechnologies as of a single technology and to consider nanoeducation totally the privilege of natural or technical sciences. Alexandersson (2012) [54] argues about the division of education on theoretical and practical subjects and emphasizes that the ultimate goal of higher education for sustainable development is to empower citizens with the perspectives, knowledge, skills, and understanding of new sciences and technologies for helping them adjust and live in democratic sustainable societies. A growing gap between technology use and technology understanding in a consumer society creates a need to educate students and the general public about new emerging technologies - the backbone of a strong economy.

A frequent topic in scientific and scholarly discourses today is the *convergence* related to technical sciences (or techno-sciences) and humanitarian sciences (or humano-sciences). The examples of such rapidly developing valuable convergences in knowledge-science-technology-engineering-society are manifested in the creation of universal databases, cloud computing, unmanned vehicles, human-robotics systems, mind-cyber physical systems, research programmes on space and fundamental particles. A familiar example of such a convergence is the development of a cell phone. A wide range of technologies including high frequency communications and packet switching protocols (for connections to global networks); materials science and nanotechnology (for CPUs, data storage, touch screens, antennas, etc.); and cognitive science and human-computer interface technologies (for the user interface) converged to create a 'smart phone'[55].

Another simple example is the creation of educational programmes where computer technologies/robotics converge with humanitarian/linguistic technologies to entertain, nurture, and shape societal knowledge. Entirely new disciplines have appeared – synthetic biology, nanophotonics, and quantum communication. However, the concept of convergence is also used to describe the integration of scientific disciplines to solve common problems through interdisciplinary cooperation (e.g., nanobiotechnology), the solution of which separate sciences cannot resolve. The integration of biomedicine with physics and engineering has already affected human health care systems. In order to advance faster, these sciences have to converge, complementing each other, to form new sciences, based on the teachings of each constituent part, but serving innovatory purposes [56].

At the core of the new concept are interrelations, interconnections, synergies or syntheses between broad fields of disciplines, research and development, such as nanoscience and nanotechnology, biotechnology and the life sciences, information and communication technologies, cognitive sciences, neurotechnologies and even humanities - fostering social responsibility. Robotics, Artificial Intelligence and other fields of research and development are also taken into account. Innovative and converging technologies have therefore been characterised as a platform for exploring the future impact of all sciences, technologies and engineering on the sustainability of the society.

The notions of the future knowledge society and knowledge economy, which are inseparable from the concept of innovation, pervade science, engineering, technology, social spheres, and humanitarian areas and appear repeatedly, whether we consider an ancient civilization, the human body, or a comet. The concepts are directed to establishing and developing innovative bonds and interconnections among multiple disciplines from contributions based on smart technologies, on the convergence of techno-sciences and humano-sciences (Figure 11.7) [52, 56].

The problem really demands a scrupulous consideration. Products are made for consumption and as other complete technical solutions, they are to be evaluated and analysed: possible improvements, strengths and weaknesses, benefits and risks are to be identified and considered. And in these processes, scientific knowledge integrating both technosciences and humanosciences is of paramount importance. The development of new products and the relevant technologies are inherent in the natural sciences – technosciences, while all the processes relating to the economic management, consumption and disposal of these products link with economic and management sciences, i.e. humanosciences. To put it simply, technologies do the right things and humanities do the things right! [53].

Contemporary higher education model should be directed to the convergent knowledge through an extensive review of technosciences and humanosciences. At the beginning of the educational process, these two domains operate with near independence (Figure 7). However, as a person reaches the stage of high level of techno-scientific proficiency combined with socio-cultural and ethical knowledge, the overlap area approaches totality, so that both future technoscientists and humanoscientists develop a common language and common understanding to deal with complex technical, social, ethical, legal, political, business and other life support problems on the local level, transcending to European and global levels.

In the model (Figure 7), the citizen is not a mere consumer of scientific knowledge, but a person whose voice and knowledgeable opinions are heard and valued in policy-making and governance. The aim is at developing not only scientific competence but also at the global personality development of the student through the experience of interdisciplinary learning (attitudinal change to new emerging technologies, to nanoproducts, to intercultural cooperation, to global societal problems, to each other, and to the process of learning – i.e. motivation, awareness, and social scientific responsibility). And if the educational process is strategically targeted, we can view education as a contribution to a scientifically literate, knowledge society (*local-European-global*) where younger generations are able to take responsibility for its sustainable development [52].

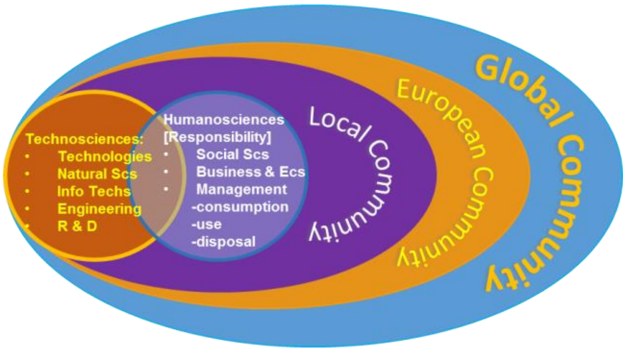

FIGURE 7 Convergence of technosciences and humanosciences for sustainable knowledge global society

Nanoscience and nanotechnologies in their application contexts affect medicine and health care, the environment, working conditions, food production, agriculture, industrial production, social interactions, law enforcement, and has a huge impact on other major areas of life, thus, significantly shaping society and social systems. In fact, these areas, to a great extent, touch the humanitarian side of life (i.e. concerned with or seeking to promote human welfare). Therefore, non-technical students who are not engaged in in-depth study of mathematics or technical courses should get the general knowledge of nanoscience, nanotechnologies and their implications in the society as a result of integration of the humanities with technosciences. At the same time, nanoscientists, students, and nanoproduct developers with a technical background possess the knowledge about the technologies they are working on, but seldom address ethical, legal or social implications. Therefore, the ability of nanoscientists, students, and engineers to comprehend societal demands and expectations, to recognize the moral responsibility for their fulfilments, and to understand the economic and environmental contexts of their work is of crucial importance.

In many scientific fields, much of the most exciting discovery potential is located between the boundaries of traditional disciplines. Already today, a great deal of novel multifunctional nanomaterials, advanced nanodevices, new nano-based products and processes are designed and developed by team efforts of materials' scientists working with chemists, biologists, physicists, information technology experts, geologists, physicians, environmentalists, sociologists and engineers. It is thus apparent that we need to create new types of universities, which have '*departments* *without walls*' to explore convergence as a way of enhancing the impact that nanotechnology can have on scientific discovery and solving critical problems [9, 52].

The perspective of a new technological revolution and the formation of a knowledge society implies transformative convergence among seemingly separate scientific disciplines, technologies, and social areas of human activity as a holistic system providing the clue for societal challenges and resolving problems that isolated disciplines cannot. This process is associated with the convergent development of Nano-Bio-Info-Cogno-Socio-Humano sciences and technologies – ultimately resulting in NBICSH society (Figure 8).

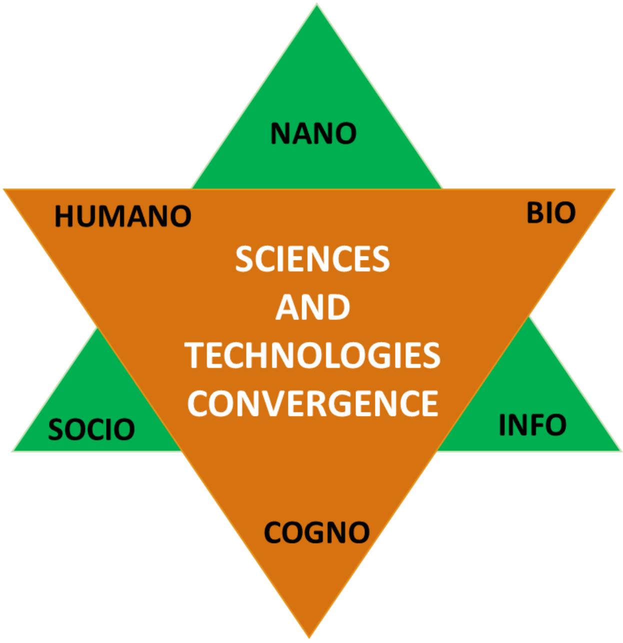

FIGURE 8 Convergence of Nano-Bio-Info-Cogno-Socio-Humano Sciences and Technologies (NBICSH)

This convergence would allow us to create a counterbalance, based on which it is only possible to anticipate future challenges and adequately respond to them, making responsible decisions. Without that counterbalance, we risk getting scientists without conscience, technicians without taste, and policy-makers without responsibility. Without that convergence there will be no robust workforce with the potential to change the society for the better [51].

The convergence of NBICSH sciences and technologies envisions a number of radical transformations in human endeavours:

- Empower people with the multidisciplinary knowledge providing added-value through the convergence of NBICSH technologies and create new sciences, industries and jobs at their frontiers and interfaces.
- Expand human physical and cognitive potential, significantly improving lifelong wellness (nanomedicine, nanoprosthetics).
- Improve manufacturing technologies for higher productivity, healthier goods, and economic efficiency.
- Ensure dignified quality of life for all, providing fair access to natural resources, food, healthcare, knowledge, safety and security.
- Advance the new participative democracy of the society through the convergence of technosciences and humanosciences, engaging general public in educated problem-solving forums and responsible decision-making legislatures to improve the efficiency of societal governance.

The convergence places an emphasis on humanitarian applications of new technologies by focusing on the role of nanotechnologies in tackling society's grand challenges such as safety, health and the environment. This new approach to teaching about technologies will also engage and inspire those students who have typically been excluded from the process by the traditional educational experience.

Additionally, there is a hope that such an approach will better prepare a new generation of specialists to address major societal problems in the future, maintaining, at the same time, an awareness of political, economic, ethical and social constraints on technologies. Undoubtedly, education in this case is to be guided by teams of teachers from a diverse array of disciplines. Science and technology teachers will have to learn humanities and social sciences. Humanities and social science teachers will have to learn sciences and technologies, promoting inter-disciplinarity [52].

The European Union is stimulating the development of nanoscience education in universities to address complex issues and to solve multidisciplinary problems. From a practical stance, nanotechnology is widely considered to be 'the next big thing' and is well worth learning more about it, in order to get a knowledgeable understanding of what place for nanotechnology might be allocated in our lives.

The values and ethical imperatives of the modern society in relation to advances in science and technologies, including information, self-organisation, integrity, security, ecology, and the formation of new priorities, take place under the influence of a new – synergistic - methodology, the implementation of high technologies and social transformations under conditions of global information accessibility, international cooperation, and expanded global educational environment.

Nanotechnology can bring substantial changes to the sustainable development and social culture of the society through the NBICSH sciences and technologies, at the same time manipulating the way people communicate and think. Higher education and new technologies have to be synergistically interwoven. The concept of the role of higher education in the creation of new technological and cultural synergies to change human understanding of the new technologies and social practices is the problem of developing an innovative culture implying 'Global Citizenship Competence' (GCC) (see Figure 9).

FIGURE 11 Global Citizenship Competence (GCC) model [34]

8 Global Citizenship Competence - the vision for educational change

Our world has become a global interdependent community. Since nanotechnology is starting to play an extremely important role in the socio-economic development of all countries, it is imperative for higher education that emphasis be placed on producing a properly educated, qualified and trained manpower possessing competences that would allow them to cope with challenges in their professional and personal lives encouraging both greater self-sufficiency and more deliberative decision-making.

Most of today's higher educational institutions are awash in technology but the outcomes for students remain little changed from 20 years ago. The problems are not in our technology but in our universities, including the issues of what we teach and how we teach. Today the educational outputs, the performance – are crucial factors to be in demand. Business companies want to have the best – those who are talented, those who have innovative ideas, creative thinking. Yet this will not be developed by chance, but by strategic, targeted education. The necessity to reconsider the academic outcomes in higher education has stimulated the development of 'Global Citizenship Competence' (GCC) model to provide the vision for educational change. It is a student-centred and world-minded concept from the perspective of NBICSH sciences and technologies and global citizenship, the implementation of which can contribute to the formation of a scientifically grounded structure of contemporary higher education (Figure 11.9) [57].

Based on the EU definition of the concept of competence and taking into account external and internal factors, personal qualities and features, and context as an essential condition for competence implementation, it is possible to define the concept of Global Citizenship Competence as an objective characteristic determined by the integrated personal system of mental structures and abilities. It assumes mobilization of interdisciplinary convergent knowledge, cognitive skills and strategies, advanced practical abilities and aptitudes based on new technologies application, as well as social and behavioural components comprising responsible attitudes, regulated emotions, values, ethics, morality, and motivation, all of which are functionally directed towards a positive result achievement in a particular context [57].

As we can see from the model, the functional orientation of GCC (need, demand of certain qualities for a particular activity) and context (the environment in which a person fulfils his activity) can change. However, the inner structure (comprising innovative knowledge, cognitive skills and strategies, advanced practical abilities based on new technologies application, responsible attitudes, regulated emotions, motivation, values and ethics) remains constant.

The model encompasses the principle of 'bearings' driven by the need for enhancement and knowledge added-value – that is the core of the human thinking and behaviour, which is also reflected in life-long learning and social activities. The focus is on producing students who are broad-minded, technologically empowered, possessing global systems thinking, critical thinking, and contextual thinking (learning transfer), as well as organization and communication skills, problem-solving and decision-making abilities, thus, contributing to the convergent/interdisciplinary skills development [57-59]. It prepares them to follow the evolution of knowledge and technologies, to be active responsible citizens today and speak knowingly on questions dealing with quality of life within their local communities and the global society.

Global Citizenship Competence is directed to an active interdisciplinary learning process based on the convergent NBICSH sciences and technologies education addressing the values of welfare for all, equality, inclusion and cooperation. It presents people with an opportunity to set on an educational voyage that starts from a basic awareness of sustainable human development, the priorities of international cooperation, passes through the understanding of the causes and effects of global issues, of the new possibilities offered by new emerging sciences and technologies, and ends with a personal dedication through informed decision-making. It encourages a full participation of all citizens against exclusion and towards the influence on economic, social and environmental policies at both national and international levels, so that they are fair, sustainable and based on respect for human rights. It is the concept that supports a new model of interdisciplinary education based on the full awareness of the dignity, which is inherent in every human being, on the belonging to a local and global community and on the active commitment to contribute to the society that is more just and sustainable.

Education and personality development are closely interdependent and have very much in common, although pedagogical science distinguishes between these two notions. Educational content includes knowledge and awareness of its place in the scientific environment, as well as learning strategies and metacognitive strategies.

Developmental content deals with the awareness of moral values, norms, rules, laws and ideals. Education has to do mostly with the intellect, whereas personality development appeals to motivational and needs spheres of an individual. Both processes influence consciousness, behaviour, emotions and determine the development of a personality. Furthermore, the entity of the process, the unity of education and personality development constitutes the main methodological principle of education, which is especially topical at present. Hence, Global Citizenship Competence (GCC) cannot be restricted to a separate subject. It has to be pervasive – to constitute an integral part of all education and it has to be lifelong – continuing throughout life.

9 Nanochallenges: Nanomanagement, Nanoeducation, Nanothinking and Public participatory Technology Assessment (pTA)

One decade into the 21st century, people and governments worldwide face decisions involving complex scientific considerations or innovations in technology. The new participatory democracy demands that citizens be asked to make judgments, and even vote, on subjects about which they know very little – the desirability of cloning animals and human beings, creating novel biological organisms, manipulating matter at an atomic scale, eugenics, genetic engineering, GM foods, nanoproducts, and other great moral and economic questions of the day. But the technologies that so radically redefine our standards of living, health and mortality will also profoundly challenge our social support systems and cultural values.

Therefore, educational systems have to produce a steep increase in students' and general public's intellectual potential in order to provide responsible answers to such complex questions, previously the domain of university researchers.

The world has gone through historical processes that are dramatically and rapidly transforming our social, educational, and business environment, producing far-reaching effects on our life styles and our habitat. People all over the world have become increasingly interconnected and interdependent. Educational environment is becoming a new supercomplex system with a constantly expanding and changing intellectual pattern.

In addition, the society has gone through many experiences and technological advancements which are taking us away from 'the world we live in' towards 'the world we want to live in'. Technological progress, especially related directly to basic human rights, needs to be accessible for all consumers and given priority over economic interests, thus contributing to equal opportunities.

On the other hand, current developments in scientific and technological research raise a number of ethical questions comprising responsibility. Areas of research as nanotechnology and biotechnology, regarding food, healthcare and environmental issues, elicit complex and undeniable debates within society today.

Despite steadily increasing dependency of modern consumer societies on nanotechnology, society-wide understanding of these new emerging technologies necessary for informed and critical decision-making is usually lacking. The implications of these processes are critical because the consumption behavior in technologically empowered societies has a profound effect on the present quality of life and that of the future generations. Higher education is the primary agent of transformation towards sustainable development and future knowledge society.

It has been predicted that today school-leavers will have many careers – not just jobs, over their lifetimes, and that more than 50% of the jobs they will be doing do not exist yet. However, one thing is certain – they will be doing knowledge jobs, intellectually more demanding and almost certainly involving interaction with technologies far more sophisticated compared to those existing at present [60, 61].

It is regrettable to recognise that the structure of our universities has changed very little in the past fifty years. What we witness today is that higher education is not about understanding reality but about accumulating knowledge through individual subjects which are disconnected from each other and decontextualized. If we want higher education to become an intellectual engagement that goes beyond the study of specific issues inserted in a single subject within the broader context of compulsory curricula, it needs to adopt the Systemic approach based on NBICSH sciences and technologies education, which corresponds to the educational demands of today and the nearest future.

In fact, this situation has led to a number of important considerations related to the principles of interdependence in nature and society as a holistic system demanding solutions for key educational and societal challenges, which is only possible based on the convergence of multiple knowledge and technology. Convergence is as essential to our future knowledge society as engines were to the industrial revolution [60].

By 2050 UN and other demographic experts estimate that the global population will have reached approximately 9 billion people. New advanced technologies and, particularly, nanotechnologies will be critical to feed, dress, and house this number of people living in the environment stressed by climate change, global economic recession, exponential population growth, widespread fuel and raw materials shortages, environmental deterioration, and societal problems [61].

Some experts point out that the demographic decline in Europe, combined with the lack of vocation in youngsters for hard sciences, will generate a dramatic shortage of qualified workers in less than a generation. This will jeopardize the standard of living of Europeans in key areas such as medical research, healthcare, information technologies, food, and knowledge intensive industries [56].

Nanotechnology – the creation, manipulation, and application of materials at the nanoscale – involves the ability to engineer, control, and exploit the unique chemical, physical, and electrical properties that emerge from the infinitesimally tiny man-made particles but the areas where nanotechnologies are set to make a tremendous difference are expanding alongside with the challenges they pose to society. Challenges in nanotechnologies can be presented in their hierarchical priorities (Figure 10).

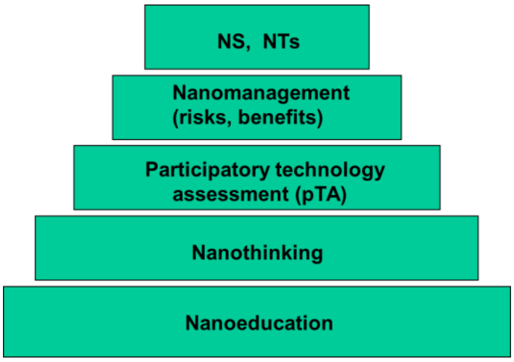

FIGURE 10 Nanochallenges hierarchy

Nanochallenges comprise such basic areas as nanoeducation, nanothinking, participatory technology assessment (pTA), and nanomanagement (incorporating risks and benefits) to contribute to the creation of new branches of nanosciences and nanotechnologies [47].

9.1 NANOMANAGEMENT: RISKS VERSUS BENEFITS

There is irony in the reasoning of some 'smarties', who turn a critical eye towards the term 'nanomanagement' that they correlate with tiny dimensions by analogy with 'micro' and 'macro' instead of implying the direction of activities. Without further much ado about nothing, it should be noted that the term 'nano' (as an abbreviation or scientific slang) is applied to everything that is associated with nanotechnology – nanoscience, nanotechnology, nanoengineering, nanomedicine, nanoproducts, nanoeducation, nanothinking, etc., which, definitely, does not imply that all these phenomena are minute. On the contrary, they promise huge possibilities to capture imagination!

Since nanotechnology is an inherently interdisciplinary field, *Nanomanagement* suggests the organization and coordination of the activities in multiple areas of science, technology and engineering to create a vast technological synergy with educational institutions, R&D, industry, governmental structures, and public authorities in order to achieve defined innovative objectives [4].

Awareness of nanotechnology has dramatically risen in recent years among lawmakers, regulators, and environmental activists alike. However, the question of how best to regulate nanotechnology is not new. It was first raised in March 1989 by David Forrest in a paper originally written for a course on Law, Technology, and Public Policy at the Massachusetts Institute of Technology. As Forrest so elegantly stated almost three decades ago: "*The emergence of new technologies continually forces us to ask whether our laws provide the proper balance between protecting us from potentially harmful consequences of those technologies, and allowing us to reap the benefits. The development of nanotechnology, a molecular-precision manufacturing technology which is surprisingly close to realization, will seriously challenge the ability of our regulatory system to respond quickly and to maintain the critical balance between dangers and benefits*" (Forrest, 1989).

Forrest demonstrates an uncanny degree of foresight, especially given that nanotechnology was at a very early stage of development at the time it was written. Almost thirty years after the publication of Forrest's 1989 paper, there is still much that we do not know about the potential impacts of nanotechnology, and this raises a number of regulatory issues. Questions arise as to which regulatory or policy instruments or approaches are most effective and appropriate for managing the categories of potential risks associated with nanotechnology. For example, should the applications of nanotechnology, either in whole or in part, rely solely on pre-market regulatory risk assessments? Should nanotechnology-enhanced products be subject to obligatory reporting or labelling requirements? On one extreme: should regulatory authorities adopt a wait and see reaction, until further information regarding toxicity and exposure becomes available? On the other extreme: should regulators impose product restrictions or even a moratorium until a full assessment of risk becomes possible?

Regulatory regimes designed to protect human health, consumer safety and the environment in many countries, including the US, and the EU, were accepted long before the prospect of nanotechnology was yet on the horizon. Given the state of knowledge at the time, regulatory requirements were designed to assess the toxicity of bulk (macro and micro), not nano, materials. The issue is that the risk assessment criteria, regulatory oversight triggers, toxicity parameters, and threshold minimums outlined in health, safety and environmental regulations are no longer applicable in the context of nanotechnology-enhanced products.

The broader issues associated with nanotechnology relate to risk governance, which goes beyond the scope of risk assessment and risk management. The term risk management refers to the decision-making process regarding acceptable levels of risk. Traditionally, such decision-making relies heavily on technical evidence obtained through science-based risk assessments.

In the area of environmental regulation, one of the key questions to be addressed pertains to the establishment of a regulatory definition for engineered nanomaterials. In other words, should nano forms of well characterized materials, for example carbon or silver, be defined as 'new' or 'existing' chemicals? Individual jurisdictions' chemicals management frameworks are generally structured in such a way that health and environmental risk assessments must be conducted for any chemical with a new Chemical Abstract Service's number (i.e. one, which is not already included in the jurisdiction's chemical inventory). By this standard, a large number of engineered nanomaterials may be exempt from regulatory scrutiny, even though they may possess distinct properties that could have health, safety, and potential environmental impacts. One issue therefore becomes the challenge of defining under which circumstances a nanomaterial should be considered, in regulatory terms, a new chemical, and then determining how such a chemical should be administratively handled [22].

Nanotechnology presents both an unprecedented challenge and unparalleled opportunity for risk management. The challenge arises because nanotechnology does not fit traditional risk management models, thereby hampering efforts to manage its risks using existing approaches. The opportunity arises because nanotechnology will force risk managers to develop innovative risk management approaches that may be applicable to future emerging technologies. As nanotechnology has emerged from the laboratory into industrial manufacture and commercial distribution, the potential for human and environmental exposure, and hence risk, has become both reality and priority. Nanotechnology risk is dependent upon toxicity and exposure: **RISK = EXPOSURE × TOXICITY** [42, 47].

Nanotechnology risks associated with health hazards can be eliminated, or at least greatly reduced, by minimizing exposure to nanoparticles. Nanoparticle toxicity is complex and multifactorial, regulated by a variety of physicochemical properties such as size, chemical composition, and shape, as well as surface properties such as charge, area and reactivity. As the size of particles decreases, a resulting larger surface-to-volume ratio correlates with increased toxicity as compared with bulk material toxicity. Also, as a result of their smaller size, nanoparticles can pass into cells directly through cell membranes or penetrate the skin and distribute throughout the body. While the effects of shape on toxicity of nanoparticles appears unclear, the results of a recent study suggest that single-wall carbon nanotubes are more toxic than multi-wall carbon nanotubes. Therefore, with respect to nanoparticles, there is concern for systemic effects (e.g. target organs, cardiovascular, and neurological toxicities) in addition to portal-of-entry (e.g. lung, skin, intestine toxicity).

Risk management of nanotechnology is challenged by enormous uncertainties about the properties, risks, benefits, and future direction of nanotechnology applications. Moreover, traditional risk management principles such as acceptable risk, cost-benefit analysis and feasibility (or best available technology) as well as a more recent precautionary principle are all inadequate to the risk management that nanotechnology challenges present due to the pervasive uncertainty and great dynamism of this rapidly developing technology. Yet simply to expect that these ambiguities were resolved by themselves, before attempting to manage nanotechnology risks, would not be reasonable, in particular, because of the growing public concerns driven by risk perception incomprehension concerning exposure, affect, and availability.

However, there is an innovative the so-called 'Soft Law' - Responsive Regulation approaches – a complex regulatory system incorporating several levels of responsibility:

1. Self-regulation (persuasion, warnings) – 'Soft Law'
2. Enforced self-regulation (civil penalties)
3. Command regulation with discretionary punishment (licensure penalties)
4. Command regulation with nondiscretionary punishment (criminal penalties) 'Hard Law'.

This system is incremental, flexible and decentralized to fill the risk management gap [63]. Still, the fate of humankind is not a spectator sport. The health implications of nanoparticles are unknown, the ramifications may be profound, and only lengthy and extensive research efforts can assess the safety implications with any certainty. A more reliable, comprehensive, and cooperative approach is required. Such an approach will not only help manage threatening risks from nanotechnology, but will also serve as a model for managing future emerging technologies.

Public policy has to be grounded on understanding the risks and benefits of new technologies. Uncertainties surround nanotechnology and reinforce the doubts of consumers [64].

9.2 NANOEDUCATION AND THE GLOBAL CONSCIOUSNESS

During the past 10 years, we have seeded many ideas into the global consciousness to stimulate preparing our students and the general public for their future. The world is changing but our education matrix remains in the Industrial version of reality. We are not even close to understanding, nor preparing our students for these major changes they will face in the next few decades. Education must be transformed in the 21st century due to the higher level of knowledge reached by the world societies, accelerating progress in foundational emerging technologies and the creation of new industries and jobs at their frontiers and interfaces, developing information exchange and interaction, improving lifelong wellness and human potential, and advancing a cognitive society. Knowledgeable citizens in a diverse democratic society should be reflective, moral, responsible and active citizens showing enough knowledge, skills, and commitment needed to make the world safe and well secured habitat for all.

Nanoeducation **-** is the new foundation for the integration of all disciplines for the next generation to expand our student's knowledge base and prepare them for a very different future in a global society enhanced by all of the integrated science research now in process [47]. Nanoeducation concept envisions launching a broad-based integration of nanoscale science and engineering (NSE) concepts into the classrooms starting already from the secondary school. As scientists develop the ability to work at levels thousands of times smaller than a human hair, a new world of possibilities and critical concerns opens up. Nanoeducation explores the social, ethical, and personal implications of advances in nanotechnology. The program should be directed to ask policymakers, researchers, and activists to wrestle with difficult but essential issues that will impact the environment, human health, public safety, and individual privacy.

The contribution of nanoeducation courses to the development of the student's personality as a citizen and his intellect as a consumer of the 21st century has to be reflected in the purpose of the courses. The main objectives are to explore the nanotechnology potential benefits and possible risks for human health, safety and security, and the environment; to work internationally with fellow citizens to identify common values and institutions that will protect these values and to make them active.

To fuel students' reflections and curiosity and allow them to cultivate their own citizenship personality, nanoeducation acts as a compass to help them position themselves within the whole of humanity. It is up to them to decide what kind of human being they want to be today, in their own immediate environment. Nanoeducation envisions developing *intellectual attitude to life* in our students.

From this standpoint, students can establish with others a meaningful, fulfilling, and humane relationship. Such activities as creating a forum, for instance, where students can pursue their reflections and discussions with colleagues, as social players and not as mere spectators to discussions about nanotechnology realities of which they know little or nothing, are a good measure of the contribution that nanoeducation courses bring to the development of citizenship awareness among students.

Many companies throughout Europe and the world report problems in recruiting the types of graduates they need, as many graduates lack the skills to work in a modern economy. For Europe, to continue to compete alongside prestigious international institutions and programmes on nanomaterials, it is important to create educational institutions, which would provide a top-level education and the relevant skills mix and would cover education, training, sciences and technologies for research and have strong involvement by European industry. The elements for such a top-notch education are:

- multi-disciplinary skills;
- top expertise in nanomaterials science and engineering;
- literacy in complementary fields (physics, chemistry, biology);
- exposure to advanced research projects;
- literacy in key technological aspects; exposure to real technological problems;
- basic knowledge in social sciences, culture, management, ethics, foreign languages;
- literacy in neighbouring disciplines: international business, law, IT, etc;
- interlinkages between education, research and industrial innovation: students will be ready for what research and development will provide;
- sharing of post-docs, Masters and PhD students to foster the mobility of permanent researchers and professors between different institutions to create 'team spirit' [47].

Companies, universities, governments, research organizations and technical societies must all strive to define their roles in this partnership. The 'output' will be graduates with a new way of thinking, skilful manipulators, synthesizers and creators of new knowledge excellently equipped to solve future complex problems and to work collaboratively.

Nanoeducation is an integrated skills project built around active learning methods to promote an active discussion-based approach to developing responsible scientific citizenship and new emerging consumption practices. It offers an opportunity for students from a wide range of disciplines to learn about nanotechnologies, to explore their risks and benefits and to reflect on the place of nanotechnologies in their personal life, in their future professional practices, and the modern consumer society.

The teaching objective of these academic activities is to create an openness of mind and criticism of thought in students for a very broad range of knowledge. This will help them position themselves within the vastness of current scientific knowledge and technological development that is shaping our modern society – scientific knowledge and development that could have major consequences on the fundamental way we see intellectual consumption, scientific citizenship and the sustainable development of the society we live in.

Nanoeducation envisions teaching students to move with the times and stay abreast of the fundamental knowledge of the day in order to understand what is at stake, and participate in key social debates and informed decision-making. The option offered by a new era of emerging technologies to all of us on the planet today can be spelled out in the words: nanoeducation can be considered a privileged discipline for supporting the development of responsible intellectual citizenship in the 21st century technologically empowered global society.

9.3 NANOTHINKING AS AN EDUCATIONAL CONCEPT OF THE 21ST CENTURY

Data saturation that accompanies our new technologies age has fostered an ever-increasing feeling of dependency among people. The pace of expected adaptation is accelerated to a pace that exceeds individuals' abilities to accommodate. Being on the receiving end of technologies, torrent serves to undermine people's confidence and sense of personal responsibility, giving rise to the sense of helplessness that many people feel as the world enters the age of global 'technologization'.

Nanothinking can serve as the antidote to the sense of helplessness since it is a concept for seeing the 'structures' that underlie complex processes, for a much better understanding how our organism correlates with the outside world, and for discerning how to foster health, safety and the surrounding environment. Our life is reduced due to ignorance and neglect of the elementary things concerning our health. If we do not understand ourselves, we will not be able to change our life for the better.

Nanothinking is a comprehensive systems thinking which offers a language that begins by restructuring the way how we think. It is a dynamic concept where practitioners continually engage in a process of 'seeing wholes' – a perspective that pays attention to the interrelationships and patterns of influence among constituent parts to foster the dissolution of compartmentalization of science and the corresponding compartmentalization of the mind [65].

Contemporary top-notch education envisions causing students think systemically – integrating not only macro-, micro-, but also the nano scale. *Nanothinking* can be defined as '*visualizing matter, structures and processes at the nanoscale.*' *Nanothinking* can be viewed as *the understanding of nanophenomena within the context of a larger whole.* To think nanoscalely – means to put things into a nanoscale context and to establish the nature of their relationships within larger contexts [65].

Nanoscientists are now enthusiastically examining how the 'living world works' in order to find solutions to long-standing problems in the 'non-living world'. The way marine organisms build 'strength' into their shells or insects create the most amazing structures has lessons in how to engineer lightweight, tough materials for vehicles and other applications, or to improve the design and create even better structures for buildings and the environment. The way a leaf photosynthesizes can lead to techniques for efficiently generating, converting and storing renewable energy. Even how a nettle delivers its sting can suggest better vaccination techniques.

Natural systems provide us with solutions, but solutions are usually package solutions with concepts strongly interconnected one with the other. The problem is that too much of our thinking today in business – is poor business based on poor competence. We have one knowledge and we have one market. The time has come to re-think the system. And if we are prepared to re-think (probably due to the crisis) the business world, we will be able to re-think how to put innovative structures and systems into the production process for the benefit of the whole society and every individual.

Education in this highly technological global economy has to play a double role. First, it has to provide a top-level, systemic, multidisciplinary education to graduates able to think innovatively and creatively. Second, to educate the general public, thus, shaping public consciousness.

Public thinking can be formed and expanded through sustained and carefully crafted dialogue, which has to be integrated into educational communication practice. Educational communication has to contribute to developing a new way of thinking – the systemic thinking, with the main strategy – 'how to think' rather than 'what to think'. It is the privilege only of liberal universities not to give the right answers to students but to put the right questions [65].

The development of a new way of thinking envisions bringing the practice of participatory technology assessment (pTA) into alignment with the realities of the 21st century technology – to create a 21st century public consciousness model.

9.4 PUBLIC PARTICIPATORY TECHNOLOGY ASSESSMENT (PTA) IN RISK MANAGEMENT

New developments in technology usually start out with strong public support, as the potential benefits to the economy, human health or quality of life are proclaimed. The ability to create novel biological organisms, manipulate matter at an atomic scale, or intervene significantly (and possibly irreversibly) in the earth's climate system raises a lot of ethical, social, legal and environmental questions that will require broad public discourse and debate. Any technology that promises so much change is bound to generate controversy, because with such awesome power comes the capacity to penetrate beyond boundaries that society has deemed acceptable.

Societal and ethical concerns can rapidly turn any technological philosophy to oblivion. These concerns are often focused on fundamental moral and social perceptions of being human and humanity's relationship with the natural world. The debates surrounding many of the emergent technologies that preceded nanotechnology can help us predict a likely future path for the controversy surrounding nanotechnology. One such example is provided by the debate over GM foods. Genetic engineering promised a revolution in medical care, including the ability to cure or prevent diseases with a genetic basis such as Huntington's disease, haemophilia, cystic fibrosis and some breast cancers. Manipulation of plant genomes promised a revolution in how food is produced, by engineering crops with increased yield, nutritional content and shelf-life.

Not all potential impacts of nanotechnology will be social in nature. After all, the technology is based on the production and use of materials. Therefore, issues of environmental and toxicological effects must also be addressed. History is replete with examples of technologies or materials that were enthusiastically embraced by society, and then found years later to cause environmental contamination or disease. The chemical DDT killed disease-bearing mosquitoes, thus allowing areas with tropical and subtropical climates to be more safely populated and developed, yet was ultimately banned in the US after it was linked to destruction of animal life. CFC-based refrigerants allowed for affordable air-conditioning, yet were ultimately banned after they were linked to destruction of the ozone hole. Asbestos was used as a fire-retardant and insulator in many buildings until it was found to cause a deadly lung disease. Some materials, such as semiconductors, are not in themselves known to be harmful but are produced though environmentally burdensome processes.

Nanotechnology has tremendous potential to improve human health and the environment. However, it could also have unintended impacts. Nanoparticles' ability to penetrate into living cells could be exploited to produce a new life-saving drug, or it could result in toxicity. Nanomaterials could be used to produce cheap and energy efficient filters that improve drinking water quality, or they could become environmental contaminants. Given the breadth of materials and devices that fall under the broad umbrella of nanotechnology, all of these outcomes may result to one extent or another.

Scientists and researchers engaged in nanoscience and nanotechnology research and development constitute a relatively small group compared to the general public. However, the outcomes of their work – innovative materials, systems, devices and technologies have a strong impact on the life of every citizen and the whole human society.

The research into health, safety and the environmental implications of nanotechnology lacks universal strategic direction and coordination. As a result, researchers are unsure about how to work safely with new nanomaterials, nano-businesses are uncertain about how to develop safe products, and public confidence in the emerging applications is in danger of being undermined.

In light of these developments, it is important that the relations between science, technology and society be given proper attention in nanoeducation of general public. It is about ensuring that everyone has the knowledge and skills to *understand*, *engage with* and *challenge* the main pillars of nanoeducation - *society*, *technology* and *processes*.

However, public capacities do not develop unaided. They have to be learnt. If citizens are to become genuinely involved in public life and affairs, a more explicit approach to public education and involvement is required to deal responsibly with new technologies.

In the first place, public concerns include the ensuring of peoples' physical integrity and safety (as the condition of being protected against physical, social, financial, political, emotional, occupational, psychological, educational or other types or consequences of threats).

Technology assessment (TA) is a practice intended to enhance societal understanding of the broad implications of science and technology. This creates the possibility for citizens of the world to influence constructively technology developments to ensure better outcomes. Participatory technology assessment (pTA) enables the general public/laypeople, who are otherwise minimally represented in the politics of science and technology, to develop and express informed judgments concerning complex topics, as well as, to make informed choices. It addresses the context of social desirability of innovations looking into processes of technical modernisation, changes in the interface between humans and machines/products and ethical issues concerned with the boundaries of intervention into the environment and the human body [65].

Therefore, citizens' acceptance is compulsory for further developments in the field of nanotechnology and its applications. Consequently, it is of the utmost importance to educate citizens, and to disseminate the results of nanotechnology development in an accurate and open way so that the general public will eventually transform their way of thinking to accept nanotechnology. In this endeavour, educational institutions have a pivotal role in developing pTA practices by:

- educating citizens (including pupils, students) about science and technology;
- informing the public about the benefits and risks of nanomaterials and nanoproducts;
- evaluating, minimising, and eliminating risks associated with the manufacturing and use of nanomaterials and nanotechnology enabled products (risk assessment);
- exchanging with public authorities for the risk management of nanotechnologies.

In the process, pTA deepens the social and ethical analysis of nanotechnology, complementing the expert-analytic and stakeholder-advised approaches. The Internet and interactive TV capabilities can help pTA be more effective and cost-efficient and would also align with the policy-makers' initiatives to make them more transparent, accessible and responsive to citizens' concerns.

10 Concluding remarks

People are collaborative creatures – it is how we are. We are driven by the need to think for ourselves – it is how we survive. If we remember that, we can have everything that we need to deal with the problems facing the global society. It is our world to shape, not just to take! The time to start shaping the future is always in the present. Yet the future is not just new technologies; health issues, economic trends, population growth, environmental problems – just a few to name. However, to become future-ready, it is worth noting that new technologies - is not everything, but everything without new technologies – is nothing!

Nanotechnology creates massive challenges and massive opportunities in the years to come. It is expected to have a significant impact on every sector of the economy. The ability to create unusual nanostructures such as bundles, sheets, and tubes holds promise for new and powerful drug delivery systems, electronic circuits, catalysts, and light-harvesting materials. As manufacturing methods are perfected and scaled up, nanotechnology is expected to soon pervade, and often revolutionize, virtually every sector of industrial activity, from electronics to textiles, from medicine to agriculture, from the energy we use to drive our cars and light our homes to the water we drink and the food we eat. Nanotechnology is today's version of the space race, and countries around the globe are enthusiastically investing billions of dollars into support of research, development, and commercialization. Today, the long-term goals of nanotechnology development might sound like scenarios straight out of science fiction. However, science fiction may soon become science fact.

In terms of human health and the environment, nanotechnology also presents the same enigma as past major technological advances: there may be enormous benefits in terms of benign applications, but there are inherent risks as well. What will happen when nanomaterials and nanoparticles get into our soil, water, and air, as they most assuredly will, whether deliberately or accidentally? What will happen when they inevitably get into our bodies, whether through environmental exposures or targeted applications? The answers to those vital questions remain largely unanswered, although some latest findings are less than reassuring.

Questions of another sort also need to be answered. Is anyone looking at these health and safety issues? And can enough solid, reliable risk assessment knowledge be gained in time to ensure that the public will be comfortable with the proliferation of the technology? Or will issues of safety and trust, surrounding nanotechnology with controversy, hinder its potential as happened in the past with such achievements as genetically modified organisms (GMOs)? To ensure that nanotechnology is striding confidently and responsibly, with strong public support, it is very important to identify and collect risk data so that questions can be answered and problems addressed early enough on the way of the technology development.

On another level, at the intersection of technology and society, there is a new angle to think of some timeless issues. Is nanotechnology good? What is progress? How much risk are we willing to take? How does politics and society drive technology and vice versa? Why should we care about the societal implications of nanotechnology? These are profoundly important questions the answers to which are to be found on the counterbalance of technologies and humanities. Without that counterbalance, society risks 'scientists without conscience, technicians without taste, and policy-makers without responsibility'.

Values reflect and shape the ongoing social development and debates surrounding nanotechnology should be guided by public participation. The world is undergoing fundamental change that goes to the heart of the individual - society relationship on which the concept of sustainability is founded. Understanding the impact of a new technology on society is vital to ensuring that development takes place in a responsible manner. Scientific knowledge is expected to play some role in educating citizens about their powers and responsibilities. In this case, the citizen is not a mere consumer, but a person whose opinions are valued.

Education should help students and general public to develop thoughtful and technologically knowledgeable identifications with their cultural communities, nation-states, and the global community. It also should enable them to acquire a clear understanding, attitudes, and skills needed to act to make the nation and the world more scientifically literate and just. It is of the utmost importance to educate the general public, and to disseminate the results of nanotechnology development in an accurate and open way so that people will eventually accept nanotechnology.

Convergence of the humanities with techno-sciences, envisages the development of systemic, multidisciplinary knowledge instilling that:

- knowledge should have a social purpose – to improve life conditions based on the abilities to cope with and perhaps anticipate changes imposed by techno-scientific developments;
- learning should comprise the acquisition of advanced practical skills and the abilities to forecast the socio-ethical values of techno-scientific developments;
- learning requires an action scale in order to develop skills and abilities to assess the significance of new techno-scientific developments, and thus, be engaged in educated problem-solving and responsible legislative decision-making;
- education has to be emotive as well as cognitive promoting systems global consciousness;
- education should recognize pluralism and diversity developing perspective consciousness;
- education should have a global perspective and involve the study of major technological global challenges, as well as to promote environmental awareness;
- education should have a futuristic range and process mindedness, implying that learning and personal development are continuous and with no fixed destination.

A democracy needs an educated citizenry. To participate in a democracy influenced by technology not only do citizens need to know how to understand the multiple technological perspectives that they encounter, they need to feel an obligation to explore multiple perspectives to fully understand the society they live in and make informed decisions. When we do not pay close attention to the decisions we make, when we fail to educate ourselves about the major issues of the day, when we choose not to make our voices and opinions heard, that is when democracy breaks down.

Nanotechnology is expected to have a significant impact on every sector of the economy through the use of nanostructured materials in medicine, the enhancement of consumer products, means of soil and water purification, the production of clean energy and reduction in energy consumption, the creation of nanobiosensors, new materials for optics, photonics, nanoscopic magnets, the development of new techniques for the fabrication of large-scale structures, the replacement of silicon-based technology for electronics and computing, etc.

We are facing unprecedented global challenges such as the depletion of natural resources and climate change, pollution, scarcity of clean water, providing food and energy to a growing world population and poverty. These problems are directly linked to the current development of nanotechnologies for manufacturing products and producing energy. The exploitation of nanotechnology and nanomaterials is the key development that can significantly address these global problems by changing both the products and the means of their production and addressing pressing needs in welfare, healthcare, security, safety, communications and electronics.

Nanotechnology is a double-edged sword – on the one side there are benefits, on the other side- risks. Still, we have to weigh all pros and cons of this technology. We all have learned how to cope with television, mobile phones, and even airplanes in a safe way because we need their benefits. A synonym for uncertainty is ignorance. We face risk because we are ignorant about the future. If we were omniscient, there would be no risk. Because ignorance is a personal experience, risk is necessarily subjective. When we put a number on risk, this number says as much about us – how little we know – as it says about the world around us.

Unfortunately, the nanotechnology questions to be answered are so numerous that it will take years to compile the relevant data. Key concepts in the coming years include expanding our knowledge of nanoparticles and making this knowledge readily transparent and available, identifying and where necessary taking appropriate risk management measures, contributing to this field by supporting research and development and promoting cooperation between governments and NGOs, scientific communities and educational institutions, manufacturing and trade industries.

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