Nanotechnology and Nanoethics in Engineering Education

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ABSTRACT

Nanotechnology can improve many physical, chemical, physicochemical, and biological properties of materials, which can be very useful for many industries, including biomedical, aerospace, textile, cosmetic, manufacturing, oil, agricultural, defense, and electronic. However, nanotechnology products (or nanomaterials) also can be hazardous materials because of the way they are manipulated on an atomic scale. Since nanomaterials, such as nanotubes, nanoparticles, nanowires, nanofibers, nanocomposites, and nanofilms, are all new materials produced with entirely new manufacturing techniques, there are no specific rules and regulations for many of them. In the present nanoethics study, we will provide a detailed report of the ethical, social, philosophical, environmental, safety, and other legal issues of nanotechnology and its products, which can be very useful for the training and protection of students, as well as scientists, engineers, policymakers, and regulators working in the field.

Keyword: Nanotechnology, nanoethics and recent developments.
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1. INTRODUCTION
1.1 Background

Nanotechnology is the creation of materials, components, devices and/or systems at near atomic or molecular levels. Usually, one of the dimensions of nanoproducts is between 1 nm and 100 nm length in scale. This emerging technology involves fabricating, imaging, measuring, modeling, and manipulating matter at this scale. The goal of nanotechnology is to control individual atoms, molecules, or particles to significantly improve the physical, chemical, physicochemical, and biological properties of materials and devices for various purposes. It includes a broad range of highly multidisciplinary fields, such as engineering, materials science, colloidal science, physics, chemistry, pharmacy, medicine, and biology [1].

A number of nanotechnology products (or nanomaterials) are in the form of metals and alloys, ceramics, polymers, composites, and combinations of these forms, and they vary in size and shape, such as nanoparticles, nanotubes, nanowires, nanofibers, nanofilms, and nanocomposites. Nanomaterials have unique properties that are completely different from their bulk forms. They are used in diverse applications, including electronics, sports equipment, aircraft and spacecraft, clothing, personnel care, coatings, filtration, energy production, biology, and medicine [1-3]. Table 1 gives some of the properties of nanomaterials and their applications [11].

Table 1: Some of the major properties of nanomaterials and their applications.

Surface Properties	**Application examples**
• Mechanical properties (e.g. tribology, hardness, scratch-resistance)	Wear protection of machinery and equipment, mechanical protection of soft materials (polymers, wood, textiles, etc.)
• Wetting properties (e.g. antiadhesive, hydrophobic, hydrophilic)	Antigraffiti, antifouling, Lotus-effect, self-cleaning surface for textiles and ceramics, etc.
• Thermal and chemical properties (e.g. heat resistance and insulation, corrosion resistance)	Corrosion protection for machinery and equipment, heat resistance for turbines and engines, thermal insulation equipment and building materials, etc.
• Biological properties (biocompatibility, anti-infective)	Biocompatible implants, abacterial medical tools and wound dressings, etc.
• Electronical and magnetic properties (e.g. magneto-resistance, dielectric)	Ultrathin dielectrics for field-effect transistors, magnetoresistive sensors and data memory, etc.
• Optical properties (e.g. anti-reflection, photo- and electrochromatic)	Photo- and electrochromic windows, antireflective screens and solar cells, etc.

Nanomaterials are used for various reasons [1]:

- Miniaturizing materials and devices into key thrust areas.
- Developing functional and sensitive sensors, power sources, communication, navigation, and related systems with very low mass, volume, and power consumption.
- Revolutionizing aircraft, and spacecraft, and other transportation vehicles.
- Developing ultra-small probes on planetary surfaces for agricultural applications and control of soil, air, and water contamination.
- Collecting data for analysis, simulation, and modeling.

- Producing near-zero waste manufacturing (which is environmentally friendlier due to fewer materials used).
- Conserving the limited source of materials available on earth.
- Improving homeland security and defense against chemical and biological threats.
- Enhancing physical, chemical, and biological properties (e.g., reduced imperfections) for scientific studies and new product development.
- Curing deadly diseases of any kind.
- Attending to other important priorities including medical diagnostic and treatments; sustainable energy; and clean air, water, and food.

Recent studies have shown that nanomaterials can be found in air, water, soil, plants, and, subsequently, human and animal bodies; therefore, there is enormous public debate about the toxicological and environmental effects of direct and indirect exposure of nanomaterials [4-7]. These invisible nanomaterials can bring risk factors during their fabrication, transportation, handling, usage, waste disposal, and recycling [6-9]. Some nanoscale materials can enter the body using a variety of routes, such as inhalation, ingestion, and/or contact through skin, and they can persist in the system for longer periods of time. Several kinds of sicknesses can be expected from exposure to nanomaterials, including asthma, bronchitis, lung and liver cancer, Parkinson's and Alzheimer's diseases, Crohn's disease, heart disease, and colon cancer [5,6]. Nanoethics is the area of ethics that relates to the study of nanotechnology and its products, and provides guidelines for training, prohibition, and restraint in the use of these materials. Overall, these risk factors and public concerns should be minimized before nanomaterials are used in a number of different applications.

1.2 Surface Chemistry of Nanomaterials

Surface chemistry, which involves surface potential, surface shape/morphology, particle size, reactivity, and surface area, is the main factor in the toxicity of nanoscale materials [6]. Nanomaterials can react with the body, stay inert, and/or interact with the system based on their surface properties [9]. As is known, nanoparticle properties are entirely different than their bulk-sized counterparts [5]. Because of this, the toxicity of nanomaterials could also be different. A previous study has shown that nanoparticles with a higher surface area have a higher toxicity to human and animal cells than nanoparticles with a lower surface area [8].

Surface charge is another important factor in the toxicity of nanomaterials. Surface charge and zeta potential mainly regulate the stability of nanoparticles in an aqueous medium [6]. Usually at a lower surface charge and zeta potential, nanoparticles tend to agglomerate and form a larger cluster, which are generally less toxic than the individual nanoparticles since the smaller particles can diffuse into the body faster than the larger particles and reach very sensitive areas, such as the nervous system, bone marrow, brain, lymph nodes, spleen, and heart [5]. Individual nanoparticles can also create oxidative stress in the body, which in turn weakens it and causes sickness in the long term [8].

2. ISSUES IN NANOETHICS

Although nanomaterials have superior properties, they can have harmful effects on the body due to the way they are manipulated on an atomic scale. They are also new materials that are produced by entirely new manufacturing techniques, so there are no specific rules and regulations that cover them and their manufacturing processes [11-15]. Hence, these uncertainties bring nanoethics into nanotechnology research, development, and education to seek and examine the potential risks and rewards of the applications of nanomaterials, as well as societal, economical, moral, health, and other broader human implications of the advances of the technology. The following issues (e.g., health and safety, social and philosophical, environmental, educational, and other legal issues) involving nanotechnology may be very useful for training and protecting undergraduate and graduate students, as well as scientists and engineers in academia and industry, policymakers, and regulators working in the field.

2.1 Health and Safety Issues

Health issues involving nanotechnology involve the possible effects of nanomaterials and nanodevices on human health. Extremely high surface area nanomaterials are much more readily absorbed by the body than larger-sized particles, through inhalation, dermal exposure, and ingestion (Figure 1) [18,19]. Nanoparticles can enter living cells via endocytosis, membrane penetration, and transmembrane channels, and cause cell death and abnormality [18]. How these nanoparticles interact with the organism must be addressed by scientists [13]. Recently, a huge debate has ensued regarding the extent that nanomaterials and devices will benefit or pose a risk to human health. Generally, health issues are divided into two aspects: (a) positive effects of nanomaterials to cure deadly diseases, such as cancer, heart attack, and Alzheimer's disease; and (b) negative effects of nanomaterials that cause the deadly diseases mentioned above [5].

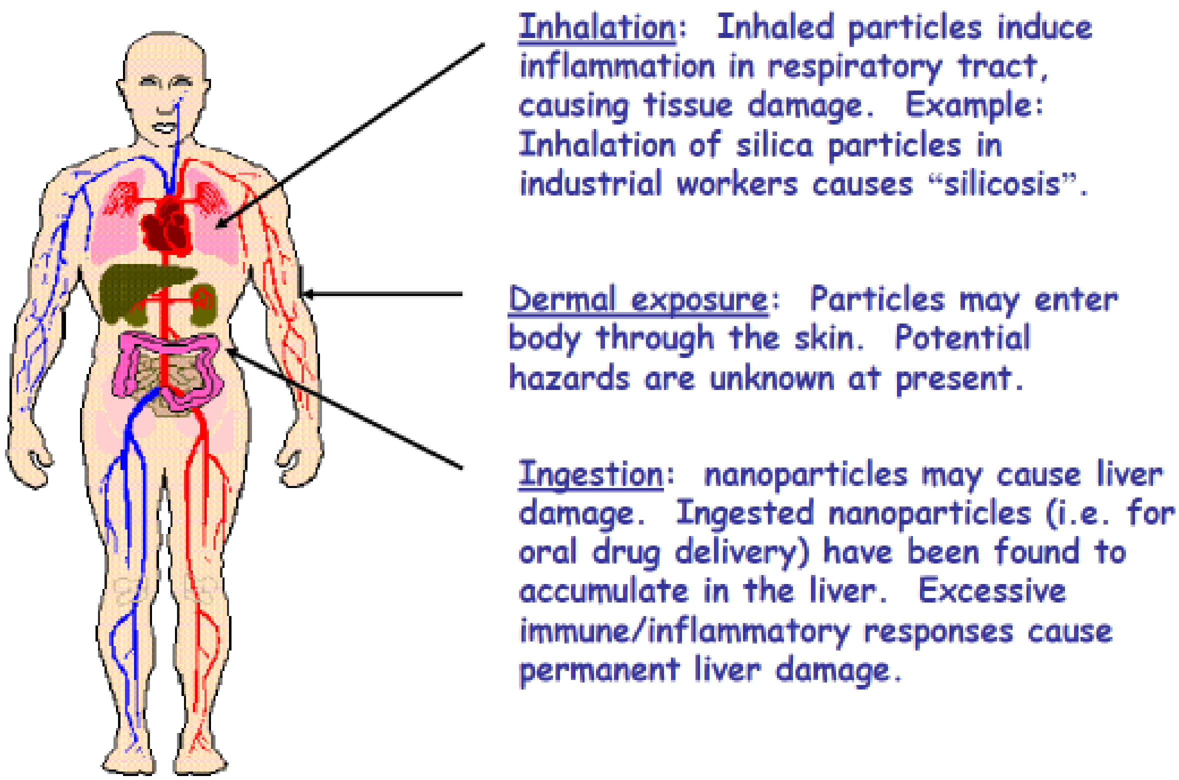

Figure 1: Body entrances of nanoscale materials causing potential hazards.

It is known that several nanomaterials are safe and are used for various applications; therefore, it is important to clearly differentiate those nanomaterials that cause disease or health concerns. For example, some free carbon nanotubes (CNTs) are highly toxic and can cause asbestos-like effects in the human body. However, CNTs that are incorporated into polymeric materials to make nanocomposites are not as toxic and can be tolerated, or the risk of CNTs can be minimized in other substances [5,6]. This issue can be generalized for other nanomaterials as well. In addition, different surface treatment methods, such as surface modification and functionalization, can reduce the toxicity of the nanomaterials [5]. Overall, this will reduce the health and safety concerns of nanomaterials.

Some key questions of nanoethics with respect to safety include the following: What are the potential health and safety risks with nanotechnology applications, and who is responsible if something happens? What are the rights of individuals affected by nanotechnology products and processes? and How do we protect society from the risks of nanotechnology? [15]. Figure 2, which shows a nanosafety policy and the path that individuals can follow, indicates that basic research is needed to understand the behavior of nanomaterials in the human body and the environment. As can be seen, all of the elements provide a safer nanotechnology practice for the producer, as well as the user and the environment.

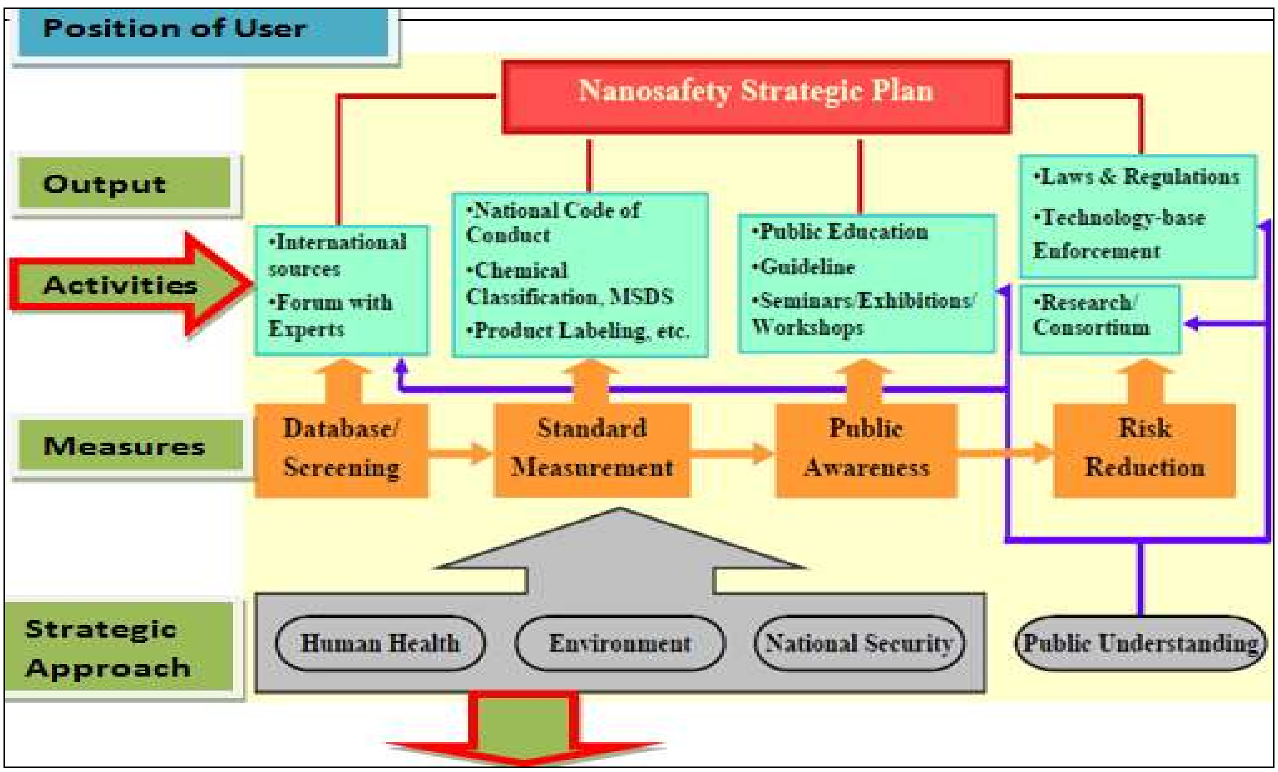

Figure 2: Nanosafety strategy framework for producers, users, and the enviroment [15].

2.2 Societal and Philosophical Issues

Nanomaterials can be in different forms and have been utilized for over a decade. The use of nanomaterials (currently more than 1,000 nanoproducts in the market) has been continuously increasing around the globe because of rapid developments in this field. Without these materials, the quality of the life would most likely be lower, and life expectancy would probably be shorter. Major applications include biodevices and biosensors, implants, protection equipment, antibacterial materials (especially silver nanoparticles), drug delivery, and cosmetics [1-4]. All of these materials and devices are usually subjected to the same requirements as new drugs that are put out on the market. Table 2 provides the ethical issues pertaining to workplace situations involving nanomaterials [17].

Nanoscale materials involve broader societal issues and pose several social challenges during the growth of nanotechnology and its products. Societal risks involving nanoproducts have been increasing for more than a decade since many new products are being marketed continuously. Social scientists and organization workers in the field recommend that the social issues be well understood and that all risks and impacts of the technology be well defined for the public. They also suggest that the public participate in every decision made by scientists and government agencies on nanotechnology and its products [13-15].

Table 2: Ethical issues pertaining to workplace situations involving nanomaterials.

Work-related scenarios	Ethical principles involved	Decisionmaking issues
Identification and communication of hazards and risks	Responsibilities of scientists Nonmal eficence Autonomy Respect for persons	Extent to which strengths and weaknesses of data are identified Degree of participation in public discussion Accuracy of communications Timeliness of communications
Workers' acceptance of risks	Autonomy Respect for persons Justice	Extent of inclusion of workers in decisionmaking
Selection and implementation of workplace controls	Nonmaleficence Beneficence Respect for persons	Level of control technologies utilized
Medical screening of nanotechnology workers	Autonomy Privacy Respect for persons	Appropriateness of the rationale for medical screening Extent to which participation is voluntary Maintenance of privacy test results
Investment in toxicological and control research	Nonmaleficence Justice Respect for persons	Adequacy of investment

More than 800 nanorelated patents were granted in 2003, and the numbers have been continuously rising since then. Some of the major corporations, such as NEC and IBM, hold the basic patents on nanoscale invention and discoveries on CNTs, which has the highest interest in nanotechnology study [13]. It is reported that CNTs have been used in every basic science and other research and development worldwide because of their extraordinary physical, chemical, physicochemical, and biological properties [1]. However, rules and regulations have not been well defined regarding the manufacturing and marketing of CNTs, which may cause unexpected situations in the future. This can also affect students, engineers, scientists, and workers in the long run. Thus, governments, universities, and industries should be responsible for making all rules and regulations on CNTs, as well as other nanoscale products, for our own safety.

2.3 Environmental Issues

Nanopollution is a generic name for all the waste generated by nanomaterials and devices during the manufacturing process, which also raises a deep concern about the limitation of an economic cost-benefit analysis [13]. The Manhattan project (Lewiston, New York) and California (Silicon Valley) are two examples where local citizens have spoken out on not wanting to live near these highly polluted areas [12]. Nanowaste can also be more dangerous than other conventionally used waste materials because of its size, shape, surface energy, and surface reactivity.

During the manufacturing, transportation, and waste disposal processes, nanomaterials can contaminate the air, water, soil, and food supply (e.g., vegetables, fruits, and animal products). Nanoparticles can also remain airborne for hundreds of kilometers and penetrate human, animal, and plant cells, thus causing many known and unknown side effects [2]. The most human-made nanomaterials do not appear in the environment, so living organisms may not have an appropriate immune system to deal with these nanoscale products [13]. Figure 3 shows the exposure of humans and the environment to nanomaterials at different stages of a product's life cycle [20]. This figure clearly defines the life cycle of nanomaterials from their beginning as raw materials to their disposal in landfills.

Since there are so many uncertainties involving engineered nanomaterials, the entire life cycle of these nanoscale materials must be evaluated, including manufacturing, packaging, transportation, storage, application, potential abuse, and disposal [7]. Material types, processing techniques, specific applications, and degradation levels and mechanisms should be studied well in order to precisely identify the environmental and ecological impacts of nanoproducts.

Nevertheless, nanoscale materials have a great potential to benefit the environment and humans. For instance, nanoscale membranes and nanoparticles that have an extremely small pore size and high surface area are suitable materials for the removal of unwanted particles and ions (heavy metals and their ions) from the drinking water, which has been a serious issue in underdeveloped and developing countries [7.22]. The nanoscale process will be more efficient at removing suspended particles and ions in the water, and faster and inexpensive compared to the traditional precipitation and filtration methods [9].

Furthermore, nanoscale materials can potentially have great impact on clean energy production around the globe. Many research programs have focused on clean energy generation from solar cells, fuel cells, and environmentally friendly batteries, which reduce the dependence on fossil fuel and nuclear energy.

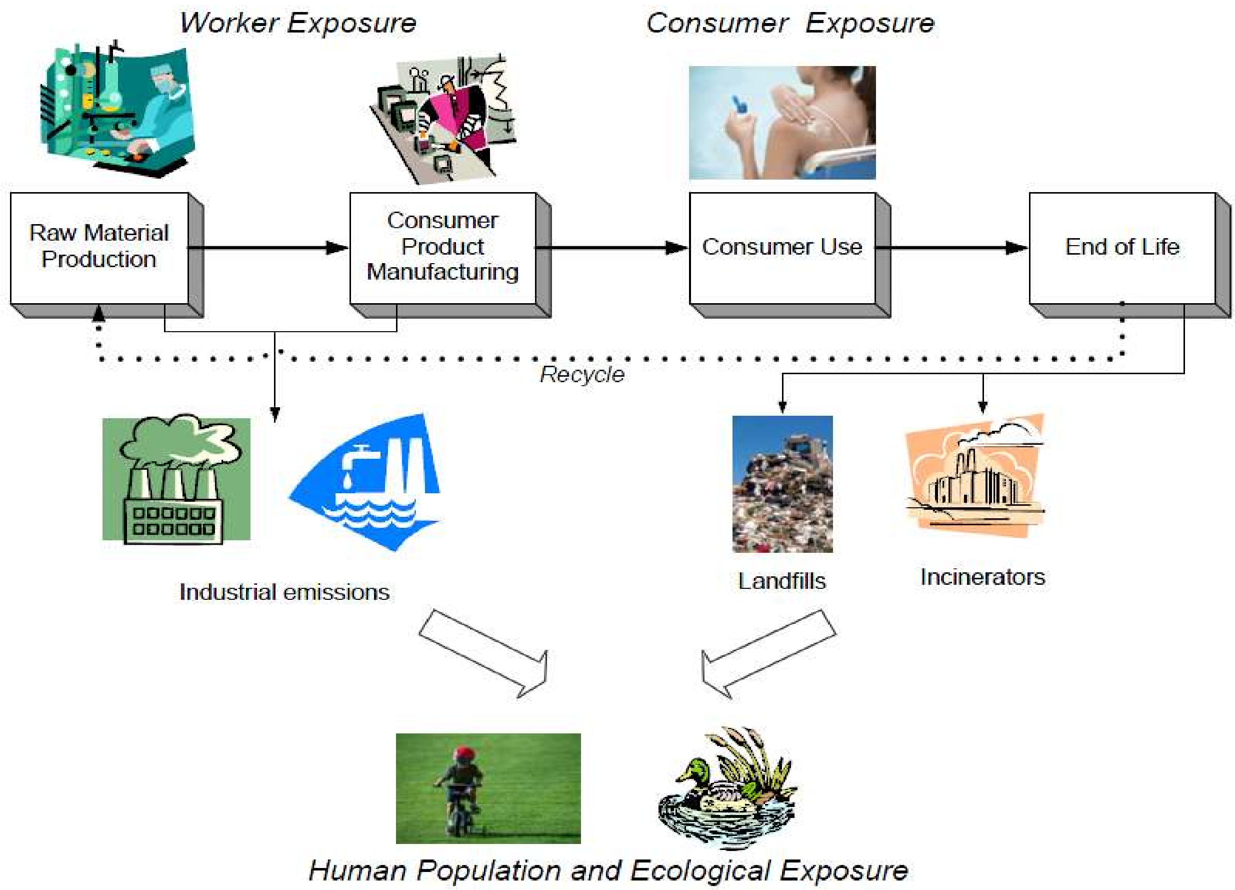

Figure 3: Exposure of humans and the environment to nanomaterials at different stages of a product's life cycle.

2.4 Educational Issues

Nanotechnology offers amazing benefits to human life and the environment, but it can lead to educational consequences. Research and development on nanotechnology and nanoproducts have been growing rapidly for more than a decade; however, the educational progress has not been as fast as the technological development. In other words, technical training is not sufficient for individuals working in the field; parallel training is required, which will be useful for the societal and ethical implications of the technology [21].

Providing interdisciplinary and multidisciplinary training of nanoethics for students and scientists, as well as technologists, engineers, medical practitioners, social scientists, workers, and humanists in every discipline will offer great benefits. This training can be accomplished through new class developments, seminars, conferences, invited talks, and other individuals who are experts in nanotechnology and nanoethics. For the undergraduate and graduate students who are preparing themselves for careers in nanoscale science and technology, whether as biologists, chemists, physicists, or engineers, new courses should be introduced to provide a needed focus on nanoethics. These courses should be taught by different professors from various departments, and should be mandatory for students working in the field of nanotechnology.

In addition to these measures, other actions may include television, media, and online news to inform students and the public. A departmental website should be prepared and should continuously upload and display the most-current information. Government agencies, such as the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), the National Institutes of Health (NIH), the Department of Health and Human Services (DHHS), and private companies (IBM, GE, GM, etc.) should have financial support and actively participate in the educational issues of nanoethics.

2.5 Other Issues

Although nanoethics is a new field of study, it also deals with many other legal, regulatory, moral, security, personal activity, technoculture, and transformational issues. Nanotechnology poses several challenges to external legal and regulatory issues, and these challenges will continue as the technology advances. A variety of nanodevices and products produced by nanotechnology will require new rules and regulations. Many government agencies, such as NSF, FDA, EPA, NIH, will have their own regulatory approaches, all of which will improve the safe practice and use of nanoproducts in the future [1].

3. CONCLUSIONS

Nanomaterials and devices can greatly benefit human life as well as the environment because of their extraordinary physical, chemical, physicochemical, and biological properties. Some nanoproducts are completely safe and will degrade without harming the body or environment after their use. However, some nanoproducts are highly toxic and can cause serious diseases to humans because of their surface potential, surface shape/morphology, surface reactivity, particle size, and surface area. Nanoethics deals with all of these harmful effects of nanotechnology and nanoproducts in order to create a safer work environment for students, scientists, engineers, and other individuals participating in nanotechnology research, development, and education.

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