The Need for Promoting
NANOTECHNOLOGY AWARENESS IN HIGHER EDUCATION

Leonardo Santiago, M.B.A.
Estudiante Doctoral
Programa Graduado de Administración y Supervisión Educativa
Facultad de Educación
Universidad de Puerto Rico, Recinto de Río Piedras
santiago@uprrp.edu

Gerardo Morell, Ph.D.
Catedrático
Departamento de Ciencias Físicas
Facultad de Estudios Generales
Universidad de Puerto Rico, Recinto de Río Piedras
gmorell@uprrp.edu

SUMARIO

Ante las rápidas transformaciones que se espera que experimente la civilización tecnológica de nuestros días, se hace cada vez más necesario preparar a nuestra población estudiantil universitaria para que sea consciente de los cambios que implicará la emergente era de la *nanotecnología* a lo largo de sus vidas. Estos cambios, además, conllevarán el surgimiento de nuevos retos filosóficos y sociológicos derivados e impulsados por la misma, y que hacen necesario explorar a cabalidad la estrecha relación que existe entre el acceso a la tecnología y la plenitud del desarrollo de la vida humana. Por lo tanto, resulta imperativo diseminar ampliamente a través de la comunidad universitaria de aprendizaje, sin importar su especialidad, qué es la *nanotecnología* y sus implicaciones. De esta forma, podrán adaptarse a los nuevos desafíos y transformaciones, manteniéndose competitivos profesionalmente. El ambiente es propicio para que todos los miembros del mundo académico se unan para explorar las múltiples conexiones que tiene la *nanotecnología* con todos los aspectos del quehacer humano, para guiar

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la sociedad a cultivarla éticamente y disfrutar responsablemente de los muchos beneficios que se derivarán de ésta.

Palabras clave: nanotecnología, educación superior, nanociencia

ABSTRACT

While we experience the dawn of the Nanotechnology Era, it is our duty to help our students become aware of the rapid transformations that the technological civilization will undergo in their lifetimes. New philosophical and sociological challenges will be derived from the societal transformations propelled by *nanotechnology*, and the tight relationship between access to technology and human fulfillment in life will have to be explored and discussed in great detail. It is therefore imperative that all students, whatever their major, learn about *nanotechnology* and become aware about its implications early in their lives. Such awareness will help them remain attentive to the fast developments that will take place as they grow and mature, which in turn will empower them to take the necessary steps to remain competitive in their professional lives. The stage is set for all members of the academia to join in and explore the multiple connections of *nanotechnology* to all aspects of human endeavor, and to lead the society into ethically harvesting and responsibly enjoying the many benefits that will be derived from it.

Keywords: nanotechnology, higher education, nanoscience

Science is just beginning to learn how to directly manipulate objects at the atomic level. This trend is producing profound changes in our world, and is bound to drive humanity into a whole new age that will be known as the Nanotechnology Era. The change will be so dramatic that, within a few decades, those of us who grew up during the Semiconductor Era and enjoy many technological advances —such as computers, the Internet, cellular phones, and many others that make us feel very proud of our level of development— will look back upon this moment with the same feelings we have today toward medieval times, when technology was more primitive.

The question we must then be asking ourselves is: What is nanotechnology? An outstanding characteristic of nanotechnology is its interdisciplinary nature. Therefore, in order to be fair, its definition should not be bound to the particular interests of a given science field or to the mission of a particular science-advancement institution or agency. Instead, we need a thorough description of what nanotechnology encompasses and its implications in the short-, medium-, and long- terms.

The American Physicist and Nobel Laureate, Richard Feynman was the first to envision nanotechnology. In 1959, he suggested that devices and materials could be produced to atomic specifications someday: "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom." Following this line of thought, nanotechnology is an interdisciplinary field of scientific research that targets the development of very small functional materials, devices and systems through control of matter directly at the atomic scale —that is to say, on the nanometer length scale— and exploitation of the corresponding novel phenomena and properties (physical, chemical, biological, mechanical, electrical...) that matter exhibits at the nanometer scale. To roughly picture the challenge posed by nanotechnology, the diameter of a human hair is around ten thousand nanometers and, therefore, huge by comparison.

In order to speak properly and to give an accurate picture of the current situation, at this point in history, nanoscale research is focused on developing nanoscience for the most part, while developing some nanotechnology along the way. The reason is that we have to first develop the tools for nanoscale manipulation, which would require deeper theoretical understanding of matter properties and interactions at the atomic scale. The common use of the term "nanotechnology" reflects the optimistic outlook currently shared within the scientific community in the sense that the nanoscience required to propel nanotechnology will be developed in the medium-range term. This belief is backed by impacting developments that have taken place during the last ten years, one of which is the fabrication of carbon nanotubes of a few nanometers in diameter (Smoley, Rice University) and the characterization of their individual properties (Dresselhaus, MIT). Nowadays, similar results are routinely reproduced and published in the open scientific literature. Some other much-debated recent scientific developments, such as the human genome project and cloning technology, can also be counted among the early steps of nanotechnology alongside carbon nanotubes.

When Feynman proposed the possibility of nanoscale manipulation of objects back in 1959, the idea was merely taken like an interesting digression of a prominent scientist. He was in fact pointing out of where to move on in terms of research over the next decades. The device miniaturization methods of the Semiconductor Era are impressive, and yet crude and imprecise at the atomic level. If we could rearrange the atoms in coal, for example, we can make a diamond; if we could rearrange the atoms in sand (and add a few other trace elements), we can make semiconductors for computer chips. The development of nanotechnology will let us make computers at a manufacturing cost of less than a dollar per pound, operating at frequencies of tens of gigahertz or more, with linear dimensions for a single device of roughly ten nanometers, high reliability, and low energy dissipation operation. This will foster a revolution in computer hardware beyond our imagination, and will also let us create an entire new generation of products that are cleaner, stronger, lighter, and more precise. Nanotechnology will also feature the development of molecular-size medical devices that can be programmed for detecting, repairing or destroying specific types of tissues. These medical nano devices will revolutionize medicine by replacing much of the biochemical therapies (medicines) commonly used today. Just imagine receiving an intravenous solution containing nano machines targeted for safely unclogging your arteries, repairing your cornea, or destroying a tumor, with no side effects and no co-lateral damage to healthy tissues.

Still in the early 1980's, when Eric Drexler, a nanotechnology pioneer, dared to publish his vision, the response was skeptical. For many scientists, the whole idea seemed too good to be true, while many others declared the whole plan to be impossible. The development of science, however, cares little for our fears or educated analysis, and instead follows its own path. For over a decade, scientific research has been steadily pointing out that, although it will take time to develop, nanotechnology is not only possible but almost unavoidable.

It took decades for most of the research community to accept the feasibility of the nanotechnology vision. Reaching such a consensus has proven to become a big step towards developing it. A critical mass of scientists already exits all around the globe successfully pushing their respective governments into sponsoring nanotechnology projects. Japan, Korea, India, and the European Union, have approved billionaire budgets for nanotechnology. The United States alone assigned $500 million to the National Nanotechnology Initiative in January 2000, giving thus a strong indication of understanding the critical role that it will play in future development.

The impact of this federal decision is already being felt in the academia at the graduate level, with nanotechnology research centers flourishing in universities all around the nation (including the University of Puerto Rico), and in the research and development divisions of technology-oriented companies around the globe (e.g. Motorola, Samsung, Philips). It is our responsibility to keep our students up to the times they live, and it is therefore our duty to help them become aware that nanotechnology is rapidly transforming our technological civilization. They should know that those who study science or engineering today will be —most likely— working in some area of nanotechnology as part of their graduate research or when they graduate, and that field is not even described in their textbooks. Their professional careers will have something to do, one way or another, with nanotechnology because it will have something to do with all technologies and all facets of life. That this is the case becomes clear as we describe the three broad research areas that can already be distinguished within nanotechnology:

1- "Wet Nanotechnology" refers to the study of biological systems that exist primarily in a water environment. The functional nanometer-scale structures of interest are genetic material, membranes, enzymes and other cellular components. The success of this nanotechnology is largely demonstrated by the existence of living organisms whose form, function, and evolution are governed by the interactions of nanometer-scale structures.

2- "Dry Nanotechnology" derives from surface science and physical chemistry, and focuses on the development of structures in carbon (e.g. fullerenes and nanotubes), silicon, and other inorganic materials. Unlike "wet" technology, "dry" techniques admit the use of metals and semiconductors. The active conduction electrons of these materials make them too reactive to operate in a "wet" environment, but these same electrons provide the physical properties that make "dry" nanostructures promising as electronic, magnetic, and optical devices. Another objective is to develop "dry" structures that possess or mimic the self-assembly attributes that the wet ones exhibit.

3- "Computational Nanotechnology" enables the modeling and simulation of complex nanometer-scale structures. The predictive and analytical power of computation is critical to the success in nanotechnology: nature required several hundred million years to evolve a functional "wet" nanotechnology; the insight provided by computation should allow us to reduce the development time of a working "dry" nanotechnology to a few decades, and it will have a major impact on the "wet" side as well.

These three branches of nanotechnology are highly interdependent. The major advances in one of them have often come from application of techniques or adaptation of information from one or both of the others. The interdisciplinary nature of nanotechnology and the interdependence among its branches imply the need for scientists and engineers who can think transdisciplinarily while working in multidisciplinary teams. Our students deserve to be informed ahead of time about the fact that these qualities will make them more competitive in the world they will join after graduation. That is why they need to be educated in environments that promote transdisciplinary thinking and team work.

The effects of nanotechnology, however, are not limited to science and engineering. A great challenge is there in empowering educators to instruct their students into the whole new paradigm that nanotechnology represents, so that the benefits and advantages derived from it are properly and efficiently harvested by all socioeconomic levels of our society, and by other societies as well. New philosophical and sociological challenges will be derived from the societal transformations propelled by nanotechnology and from the increasing sense of human interdependence resulting from it. The tight relationship between access to technology and human fulfillment in life will have to be explored and discussed in great detail. It can already be foreseen that propositions along the line of adding "technology access rights" and "technology literacy rights" to the political constitutions will be discussed in the political arena of democratic nations. The way we interrelate with one another and the way we do business will change. Knowledge will be a precious commodity more than ever. Moral issues such as the need and convenience to share knowledge and technology will become crucial for the preservation of humankind. It is therefore imperative that all students, whatever their major, learn about nanotechnology and become aware about its implications as early as they are ready to gain some level of understanding. This awareness will help them remain attentive to the fast developments that will take place as they grow and mature, which in turn will empower them to take the necessary steps to remain competitive in their professional lives.

While nanotechnology comes uninvited (but deliberately provoked) into our civilization and promises to take us to a new unsuspected technological level, an increasing awareness of the need to develop more efficient science teaching practices in higher education is sweeping our Nation. We must not overlook the fact that these two events are highly correlated. The reason is that nanotechnology will develop only as fast as society empowers all of its members for participating as knowledgeable efficient producers and informed responsible consumers of its technological products. Unfortunately, introductory courses in science and mathematics fail to yield satisfactory levels of science literacy all across the United States. In this state of affairs, it is not a surprise that the situation of science and math education in Puerto Rico, gauged by the large attrition rates in gate-keeper courses and the shrinking numbers of students majoring in these fields, is similar to the national trend.

In light of the transformations triggered by the dawn of the Nanotechnology Era, the obstacles posed by the general lack of science literacy among college students can be turned into a challenge and an opportunity to employ macro concepts connected to nanotechnology in order to create excitement around scientific developments, while improving the appreciation and understanding of science and technology, and of their consequences over all other areas of society. The National Science Foundation (NSF) is leading the way in this direction with a project focused on Nanotechnology Undergraduate Education (NUE), which funds initiatives that make emphasis on one or more of the following three critical points:

1- The urgent development and wide dissemination of teaching modules of nanoscale science and engineering that can easily be incorporated into existing undergraduate courses.
2- The incorporation of undergraduate research opportunities based on nanoscale science and engineering into the curriculum at all levels, particularly during the first and second years of study.
3- The planned coordination of text, software, laboratory, demonstration experiments and web-based resources in the teaching of introductory undergraduate science and math courses that deliberately address nanotechnology aspects or issues in connection to any particular field of study.

This and other similar projects, which are being launched from different agencies (Department of Education, NASA, Department of Energy, National Institutes of Health), will result in widespread introductory courses to generate enthusiasm, facilitate understanding, and encourage participation in the sciences while introducing all the students, science and non-science majors, to nanotechnology and its implications.

An idea that we promote to immediately start inserting the University of Puerto Rico into nanotechnology at the undergraduate level is the creation of a multidisplinary group of professors and graduate students interested in working out specific strategies for incorporating nanotechnology discussion into the college experience. This group would have the mission of creating a variety of forums to encourage students, professors, and the general public to explore some of the legal, ethical, political, and social implications of nanotechnology. Those activities would build upon available resources, such as fact sheets and "ethics labs", and would be aimed at discussing the implications of nanotechnology products as they become available. The primary goals of such activities would be along these lines:

- To make connections between science and society to help students and professors in developing an awareness of the wide impact of nanotechnology.
- To generate informed interest groups in nanotechnology to encourage participation in and implementation of new discoveries in the field.
- To demonstrate that integrated studies of art and science can facilitate learning for students with diverse learning styles and interests while generating meaningful discourse on innovative scientific advancements.
- To promote the use of teaching tools designed for exploring and demystifying the processes underlying leading-edge research and development.

The stage is set for all members of the academia to join in and explore the multiple connections of nanotechnology to all aspects of human endeavor and to lead society into ethically harvesting and responsibly enjoying the many benefits that will be derived from it.

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