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SCIENCE AND TECHNOLOGY EDUCATION CURRICULUM REFORMS FOR THE NANOSCIENCE AND NANOTECHNOLOGY (NST) REVOLUTION

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Abstract- Understanding the new discoveries and technologies resulting from modern science, including nanoscale science, requires a population with a high degree of scientific literacy. This paper explores the implications of national initiatives to prepare students with the science and engineering knowledge necessary to function in a highly technological society and to maintain the momentum of discovery and innovation that will sustain the nation's economic prosperity. Nanoscience can serve as a catalyst to reconsider how to bring about deep reform of science and technology education and public policy in support of science education goals. The capability to generate knowledge depends upon the up-to-date education, training and lifelong learning of researchers, engineers and other skilled personnel. Mobility across borders and disciplines and between academia and industry improves the quality of education and training, particularly in nanotechnology where progress is fast and interdisciplinary plays a determinant role.

Keywords- science education, education reform, teacher preparation, nanoscience, nanotechnology

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Introduction

The emerging field of nanoscience and nanotechnology is leading to a technological revolution in the new millennium. The application of nanotechnology has enormous potential to greatly influence the world in which we live. From consumer goods, electronics, computers, information and biotechnology, to aerospace defence, energy, environment, and medicine, all sectors of the economy are to be profoundly impacted by nanotechnology [1].

The terms nanoscience and nanotechnology are often used in confusing ways, the present researchers will use the following nomenclature: *nanoscale* will refer to the complex of scientific phenomena and technological applications at the nanoscales of length and time; *nanoscience* will mean the multidisciplinary studies at the same scale, and *nanotechnology* will make reference to the applications of nanoscience [2]. Nanoscience or nanotechnology seeks to exploit the unique properties of matter as it is so small, it can be measured in nanometers (nm), normally in the range 1 to 100 nm. Important properties materials such as electrical, optical, thermal and mechanical are to a greater extent determined by the way atoms and molecules assemble on the nanoscale into large structures.

Increased interest in research and development in nanotechnology is likely to change the traditional practices of design, analysis, and manufacturing for a wide range of engineering products. This impact creates a challenge for the academic community to educate science and engineering students with the necessary knowledge, understanding, and skills to interact and provide leadership in the emerging world of nanotechnology.

Nanoscience represents a theoretical and procedural convergence of quantum physics, molecular biology/biochemistry, computer science, chemistry, and engineering. Technological innovations arising from nanoscience are likely to be commercialized as greater control over atom-by-atom and molecule-by-molecule construction occurs [3].

Examples of such anticipated innovations in a variety of areas include the following: Environmental: Rebuilding the stratospheric ozone layer with the assistance of nanobots. Medical: Developing techniques in nanosurgery; repairing defective DNA.

Electronic: Developing molecular circuit boards; improving the storage of data; developing molecular computers.

Materials science: Replicating valuable products (e.g. food, diamonds); improving the quality and reliability of metals and plastics (e.g., using various novel applications of carbon nanotubes, development of high-strength, iron-based glassy nanomaterials with significant tensile ductility and novel work hardening ability); manufacturing "smart" materials (e.g., biomimetics, "shape memory" alloys) [3,4].

Whilst most of the international commentary on the relevance of nanotechnology to developing countries has focussed on applications to assist sustainable development in social development cluster areas, Chinese, South Korean, Malaysian and Thai governments were reportedly focusing 2003-2007 nanotechnology funding on materials research [5]. In Thailand, the initial focus has been on applying nanotechnology to value-add to existing export industries and develop waterproof, more durable silks; smart packaging to monitor and maintain the state of food; more productive wine fermentation; self-sterilising rubber gloves; and new car body materials [6]. With this in mind, Barker, et al [7], suggest that most government investments are aimed at improving national corporate competitiveness in nanotechnology [7]. Some governments are focussing efforts towards nanotechnology because they have recognised lost opportunities at the dawn of earlier technologies such as the Human Genome Project, ICT and biotechnology [8].

Bainbridge, [9] suggested that among the expected breakthroughs in nanoscience and nanotechnology were orders-of magnitude increases in computer efficiency, human organ restoration using engineered tissue, “designer” materials created from directed assembly of atoms and molecules, and the emergence of entirely new phenomena in chemistry and physics.

The impact of these scientific advances requires a commensurate response in the educational community to help students develop new frameworks for making sense of the world. The current education system is not only failing to produce a populace scientifically literate enough to understand these scientific advances; it is also failing to prepare a workforce for new jobs and professions that have emerged.

In this paper, the current status of NST education in Africa and Zimbabwe in particular is discussed. A methodological framework is proposed to integrate nanotechnology into the mainstream science and technology curriculum.

Disciplinary Basis of Nanoscience

Nanoscience should be taught in an interdisciplinary fashion, but that practical concerns may dictate integration into disciplinary courses. In the current curriculum, the core sciences most relevant to understanding the importance of large variations in scale are physics and chemistry. The role of scale in biology (as opposed to biochemistry or biophysics) has idiosyncratic characteristics that we have not addressed, though it was generally acknowledged that within the living cell, nature provides a perfectly elaborated and highly evolved model of how nanomanufacturing occurs.

It is thus most important that physics and chemistry courses bring up a discussion of scale, and perhaps of the properties of the nanoscale at some level of detail, since they can do so in a smooth manner. Other sciences, in particular biology, that deal with particles in the nanoscale range could highlight other core nanoscale concepts (for example, protein self-assembly and molecular fabrication) whenever appropriate.

It should be remembered that science preparation for teachers often takes place in community colleges or in lower division college courses, and that the connections, or lack thereof, between disciplines that these teachers will be able to make in the future will depend on the views of science acquired in these courses. Teacher education devoted to nanotechnology is unlikely to happen in the near future; so it is incumbent upon those teaching science courses for teachers to lay firm groundwork.

Our conjecture is that integration across sciences-using the nanoscale as a prompt to highlight fundamental science concepts, given its necessary display of the interrelated features of those concepts, will result in better science understanding by teachers, particularly by those that often are called to teach outside their areas of expertise.

Conceptualizing the Nanoscale

There is no conclusive evidence of conceptual science learning during the existing nanotechnology show-and-tell activities at all levels. Given the intuitive disconnection between the macro nature of objects used in such demonstrations and the nanoscale of the phenomena, misconceptions may arise. Evidence of learning, with both positive and negative effects, would have significant implications for education funding and practice; we are all proceeding in the absence of such knowledge.

As stated before, objects and concepts at the nanoscale are hard to visualize, difficult to describe, abstract, and their relationships to the observable world can be counterintuitive. When helping students understand the role of scale in science, the use of analogies involving scale may confuse students as much as it may help them; analogies should be evaluated before their use because of the scientific misconceptions they may generate.

In general, student intuitions based on macroscale experiences can lead easily to the wrong conclusions for the nanoscale. A typical example is in the teaching of chemistry where observations are macroscopic scale and yet the explanations of these are at a much smaller scale. Nakhleh in [1] revealed that students have problems in understanding the behaviour of atoms and molecules.

It is therefore imperative that the experiences relate to multiple scales and that connections to properties be highlighted and reinforced repeatedly. Simple demonstrations, such as placing large objects in stations that “increase” by a power of 10, do not lead to the expected understanding of what is important in the nanoscale. On the other hand, “powers of ten” videos are popular. There are several Web sites devoted to their use in education.

Good formative assessment of learning in this domain would be welcome. Educators feel that students would benefit from visualizations of scale (not only nanoscale, but atomic and micro scale as well) based on models and simulations depicting matter aggregates that fall below the visible range. And, the relationship between structure and function could be addressed more effectively by focusing on properties as a function of scale, rather than scale by itself.

It is important to have students experience nanoscience phenomena, rather than depend only on analogies to help students develop intuitions about scale. Furthermore, it is important to design activities so that phenomena are under student control, rather than under instructor control. The ability for students to verify what an instructor shows or tells them is critical.

One suggested model for laboratory exercises would have students use a remote scanning tunnelling microscope (STM) to make a sample, and have other students use the remote atomic force microscope (AFM) to verify and measure the sample. In this way, students would address not only issues of scale, but also scientific issues of repeatability and validation of results.

Teaching Nanoscience

Our capability to generate knowledge depends upon the up-to-date education, training and lifelong learning of researchers, engineers and other skilled personnel. At the same time, mobility across borders and disciplines and between academia and industry improves the quality of education and training, particularly in nanotechnology where progress is fast and interdisciplinarity plays a determinant role [10].

Currently the Nanoscience void is the main challenge to impart adequate education and professional training. The revolution that nanoscience and nanotechnology bring to diverse areas of human endeavour requires a commensurate response in the educational community to increase students' understanding of core concepts in the field [11].

The following questions were presented by Sabelli, et al [2] for consideration in designing nanoscale curricula and learning modules:

1. What levels of understanding about nanoscience are reasonable to expect of students within each identified learning contexts, such as high school chemistry?
2. Where is the appropriate placement of nanoscience curriculum within each of the traditional disciplines and in high school, college, and undergraduate science?
3. What is the most effective method to produce, disseminate, and offer support for nanoscience curriculum?
4. How much theory is needed to teach to reach a certain level of conceptual understanding?
5. How should one balance theory with experiential activities at different levels of education?
6. How much (and in what sense) does authenticity matter for learning?
7. What leads to better student understanding: demonstrating individual concepts or incorporating them into one realistic example?

A challenge faced in teaching nanoscience is that such a programme is capital intensive. Most academic and research institutions especially in the developing world, cannot afford such expensive pieces of equipment as electron microscopes (SEM, TEM) and other sophisticated spectroscopic equipment. The use of internet resources such as setting up virtual laboratories, may reduce costs associated with procurement and maintenance of capital equipment. The complex environment of standard nanolaboratories and the amount of time required to understand the infrastructure is another major disadvantage [12].

Status of Nanoscience and Nanotechnology (NST) Education

The academic community is reacting slowly to prepare the workforce for emerging opportunities in nanotechnology [1].

It has no alternative, but to educate science and engineering students with necessary knowledge, understanding, and competence to respond in the new world of nanotechnology. A recent estimate of people needed for nanotechnology in years 2010-2015 is 0.8-0.9 million in the United States, 0.5-0.6 million in Japan, 0.3-0.4 million in Europe, 0.1-0.2 million in the Asia-Pacific region without Japan, and about 0.1 million in other regions [13].

The aim of nanotechnology education is to provide an interdisciplinary education to students with a comprehensive understanding of such natural sciences as physics, chemistry, biology, and engineering sciences that include mechanical, electrical, and information technologies. Nanotechnology education should be integrated into mainstream science and technology curricula. Universities should reform their courses and create new ones to prepare students for the arising and challenging opportunities in nanotechnology [13].

Challenges for Nanotechnology in Developing Countries

The correlation between lower average incomes and lower government spending on R&D [14] and healthcare [15], presents an initial challenge for nanotechnology to even be considered in less-developed countries. Infrastructure, human and policy capacity, cost, intellectual property rights, education relating to academics and the public, brain drain, trade barriers and the political context, constitute further barriers, although these are not unique to nanotechnology [16].

The greatest lesson nanotechnology can learn from biotechnology is that there should be a democratic and more widespread participation in discussions concerning society as suggested by [17]. To avoid a 'Genetically Modified Organism-style' backlash but simultaneously ensure legitimate handling of public concerns, developing country representatives must play a significant part in global nanotechnology discussions. Observations made by Maclurcan [18] are that developing countries have not been participating fully in nanotechnology discussion forums, as shown in the [Table-1].

Table 1- Breakdown of country representation at the International Dialogue on Responsible Research and Development of Nanotechnology (IDRRDN) and the North-South Dialogue on Nanotechnology (NSDN)

Developed Countries			Developing & Transitional Countries		
Country	IDRRDN	NSDN	Country	IDRRDN	NSDN
United States	7	10	South Africa	2	5
Italy	1	72	Argentina	1	2
Japan	5	1	India	1	2
United Kingdom	1	3	Mexico	2	
Taiwan	3	1	South Korea	2	
Canada	3		Brazil	1	1
Australia	1	2	Czech Republic	1	
France	2		Egypt		1
Slovenia		2	Israel	1	
Belgium	1	1	Malaysia		1
Germany	1	1	Nigeria		1
Switzerland	1	1	Romania	1	
Austria	1		Russia	1	
Ireland	1		Uruguay		1
The Netherlands	1				
New Zealand	1				
Total	30	92	Total	13	14

Indicators on nanoscience and nanotechnology R&D, such as publication statistics, patents on nanotechnology and research funding clearly show that the African continent, Republic of South Africa excluded, is yet to fully embrace the technology [19]. Zimbabwe, through the Ministry of Science and Technology Development, the Research Council and Zimbabwe Academy Sciences has made a number of public pronouncements on embracing nanotechnology as technology of the future but more needs to be done in terms of curriculum development, human resources development and R and D funding. The report on the first national workshop on nanotechnology held in Harare, May 2010, identified the need to increase R and D funding to at least 1% of the GDP for the country to be able to benefit from this and other emerging technologies.

Achieving a high degree of excellency in nanoscience and nanotechnology education would require implementation of strategies that among others should include:

- Setting up of an Advisory Council on nanscience nanotechnology at national level
- Setting up a technical committee at university level to advice on the implementation of an effective teaching approach

- Putting in place or extending collaboration with research centers within and outside the university and also with industry to include experimental course and teaching of research experience required in a nanotechnology program
- Initiating inter university collaboration and a center at national or regional level to share the facilities and teaching experience and
- Initiating web base teaching program as a way of cutting infrastructure related costs.

Conclusions

Nanotechnology is a very actual fast advancing range; therefore creative and critical thinking and life-long learning should be given the highest priority. It is necessary to prepare students with an ability to design, analyze and manufacture nanostructures and nanosystems, to create devices in nanoscales for innovative applications of nanotechnology in all spheres of our economy and industry. Nanotechnology education should be integrated into mainstream science and technology curricula. Government, industry and universities have to collaborate closely among themselves in order to educate students in nanotechnology.

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