

## NANOSCALE SCIENCE AND NANOTECHNOLOGY EDUCATION IN AFRICA: IMPORTANCE AND CHALLENGES

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### ABSTRACT

Nanoscale science and nanotechnology is a rapidly growing and multidisciplinary field with its footing in chemistry, physics, molecular biology and engineering. It has led to breakthroughs in energy, environmental science, agriculture, biotechnology and several others. It is also capable of making a positive and significant impact on the African continent. However, nanotechnology training and education in Africa appears to be scarce even within its contributory fields like chemistry and physics. A thorough, relevant and comprehensive nanotechnology education across informal and formal lines and at all levels of education is required to develop human capacity and assist the continent respond appropriately to career/business/development opportunities, risks and policy challenges that would arise from present and emerging nanotechnologies. [*African Journal of Chemical Education—AJCE 8(1), January 2018*]

## **INTRODUCTION**

Nanotechnology has witnessed tremendous development and growth over the past decade especially in the developed world. It basically involves the manipulation of materials at the nano-scale which is between 1 to 100nm [1]. The emerging field of nanotechnology has been widely acclaimed as the next route to a technological revolution that might affect every aspect of human life and provide solutions to many problems [2]. While most developed and emerging economies have developed national nanotechnology programs for human capacity development in this area, many countries especially in Africa have showed little or no interest in developing skills in this aspect. The pace at which nanotechnology is developing in the developed world is sharply contrasted by the coldness exhibited by many developing countries in venturing into the field [3].

In view of the foregoing, nanotechnology education might become a very important route by which future generations are raised to take up nanotechnology research and product development and possibly establish the African nanotechnology industry of the future. This review highlights the importance of nanotechnology for Africa's development, need for incorporation of nanotechnology education into our educational systems and its challenges.

## **BRIEF OVERVIEW OF NANOTECHNOLOGY**

Nanotechnology is not completely new as it has been around for many centuries. For instance, glass workers in medieval times incorporated gold nanoparticles of different sizes into glass to produce stained glass windows. The Damascus steel swords (~AD 300-1700) and the Lycurgus cup (~AD 400) are proofs of the ancient use of nanotechnology to create substances with extraordinary properties [4].

Professor Norio Taniguchi in 1974 developed the term, “Nano-technology” as the processing, separation, consolidation, and deformation of materials by one atom or one molecule.” This described semiconductor processes that exhibited characteristic control on the order of a nanometer [5].

Richard Feynman framed the conceptual beginnings when he presented a lecture titled, "There's Plenty of Room at the Bottom" at an American Physical Society meeting at Carlifornia Institute of Technology in 1959 [6].

In the midst of all the progress made in nanotechnology, definition battles have been raging to clearly define boundaries for the field [7], however, a central point is that nanotechnology has become a converging point for chemistry, physics, materials science, biotechnology and engineering to create materials and devices with special properties and abilities.

## **APPLICATIONS OF NANOTECHNOLOGY**

Thousands of consumer goods containing engineered nanomaterials have already found their way to the global markets [8]. Applications of nanotechnology cover a very wide range of fields from electronics to medical to agricultural applications. Electronic applications include single-electron transistors, quantum dots and one-dimensional nanotubes [9, 10]. For environmental applications, nanomaterials have been used for contaminated groundwater remediation [11]. Self-cleaning materials [12], catalyst to reduce car emissions [13] and new oil spill cleaning technology [14] are also based on nanotechnology. To reduce reliance on fossil fuels, highly efficient solar cells have also been developed [15].

In industries, nan catalysts have been favored due to their very large surface to volume ratio. Impact resistant car bumpers, textiles and fashion with special properties have been produced

by nanotechnology [16]. Smart coatings have also been developed for a wide range of applications. Other products like textile fabrics with unique properties have been developed.

Rapid advancements in drug delivery and design have been made possible by nanotechnology [17]. Bone tissue and engineering has been improved with the use of nanoparticles [18]. The ability of nanoparticles to cross the brain barrier has opened up new possibilities for neurosurgery [19]. In agriculture, nano-fertilizers have been developed to enhance soil fertility [20]. Nanotechnology has been applied to enhance growth of some plants and sometimes created alternative route to plant growth [21]. Other applications of nanotechnology can be found in packaging materials with special properties, super plastic ceramics, nano-based sensors and industrial catalysts [22].

## **RELEVANCE OF NANOTECHNOLOGY TO AFRICA**

Nanotechnology has already found its way into the African continent through the use of nanomaterials in the treatment of water through disinfection, purification, and remediation to for improved access to clean water [23]. Disease diagnosis, low cost clean energy and industrial catalysis are also major areas where nanotechnology has been applied in Africa.

Salamanca-Buentello et al. gave the top ten applications necessary for developing countries to achieve their millennium development goals. Top of the list was energy storage, conversion and production. Agricultural productivity enhancement was second on the list. Next was water treatment and remediation. The fourth was disease screening and diagnosis. Fifth and sixth were drug-delivery nano-systems and food processing/storage. Air pollution clean-up ranked seventh and eight was improved construction materials for durable, cheaper housing. Health monitoring

ranked ninth while pest detection and control was the last on the list. In line with the above ranking, we will assess some applications of nanotechnology in Africa [24].

### **Clean energy**

950 million in sub-Saharan Africa have been estimated to lack access to electricity out of 1.6 billion people globally [25]. This is certainly a cause for concern. Several applications have been developed with huge research and technical gaps yet to be filled. Nanomaterials have been developed with significant optimisation of current renewable energy processes like solar and bio-fuels. Lighting materials with plastic and organic pigments at the nanoscale has tremendously enhanced the conversion of energy to light compared with traditional light bulbs [26]. Lithium-ion batteries have also been optimized through the incorporation of nanomaterials to improve storage capacity and increase lifespan [27]. Dye solar cells are also witnessing continuous development by the introduction of nanoscale semiconductor materials [26].

### **Agricultural productivity**

Agriculture is the backbone of many economies in Africa. However, critical issues such as lack of new arable soil, commodity dependence, reduction of the current agricultural land due to competing economic development activities, poverty and malnutrition, require urgent attention in many parts of Africa. In countries where profound structural changes in the agricultural sector have occurred due to the fast adoption of technological innovations, food security, poverty reduction and public health improvement still pose serious challenges. Nanotechnology offers some cheap and efficient solutions to these problems. However, most of these are still at the research level.

Pesticides such as DDT, which have caused serious environmental hazards and have increased public and regulatory awareness of the use of agricultural chemicals [28]. Nanoscale

carriers can be utilized for the efficient delivery of fertilizers, plant growth regulators, pesticides, herbicides and other materials for better productivity. These involve the use of dendrimers, polymers, nanoemulsions and nanomaterials with adjustable and predictable surface attachments [29, 30].

Carriers with improved stability against degradation to reduce the amount required, and minimise environmental problems are also being developed. These advances will result in slow uptake of active ingredients, thereby reducing waste and cost at the same time [31].

Africa can move towards precision farming by the use of handy smart sensors to analyse crop growth, plant conditions and other relevant information so as to enable farmers make accurate decisions for increased productivity [32, 33].

The use of carbon and metal-oxides based engineered nano-particles in crop improvement have been subject of several studies [34]. The water uptake ability of carbon nanotubes greatly enhanced tomato seed germination [35]. Nitrogen absorption, light absorbance and Rubisco activase activity has been enhanced in spinach to accelerate its growth by the use of titania nanoparticles [36, 37, 38]. Disease and stress resistance of plants have been improved by the use of silicon nanoparticles absorbed by plants [39].

### **Water treatment and remediation**

To tackle the very obvious challenge of water scarcity in many parts of Africa and improving clean water supply for domestic and industrial uses, nanotechnology has been identified to present many opportunities as sustainable solutions to the water related challenges in Africa. Nano-adsorbents like metal-based nanoadsorbents , carbon-based nanoadsorbents, polymeric nanoadsorbents have showed great potential for novel, more efficient, and faster decontamination

processes aimed at removal of organic and inorganic pollutants like heavy metals and micropollutants [40, 41].

Nano-titanium dioxide (TiO<sub>2</sub>), has attracted much attention because of its low human toxicity, high chemical stability and cheap price, combined with high efficiency of disinfection and decontamination [42, 43]. The strong antimicrobial activity exhibited by silver nanoparticles has endeared it to many and it is already commercially available in low-cost water disinfection and antibiofouling applications [44]. Ground water remediation through the use of magnetic nanoparticles (magnetite Fe<sub>3</sub>O<sub>4</sub>) for separation of water pollutants like arsenic has been achieved [45].

The environmental disaster caused by oil spills especially in petroleum producing countries in Africa will benefit from the use of magnetic nanoparticles bound to cleaning agents which can be removed completely from the environment by applying a magnetic field [46].

The conversion of sea water into potable water, reduction of hardness, odour, color and heavy metal ions from groundwater have been made possible by nanofiltration [47, 48, 49]. Efficient photocatalytic oxidative elimination of microbial pathogens and micropollutants in water has also been achieved by the use of nanomaterials such as titania nanoparticles [50]. These applications will be very beneficial to tackle the water related problems facing the African continent.

### **Disease screening and diagnosis**

Accurate and rapid identification and quantification of disease is very important for effective treatment. The major challenges for health for Africans pertain to timely and rapid screening to assess population health and also possible on-site diagnosis of diseases for timely and proper treatment. Nanotechnology can enhance current disease screening techniques by improving

diagnosis time, sensitivity, selectivity and availability of testing equipment through significant cost reduction [51].

The wide choice of spectra for nanoparticles and quantum dots has made it possible to visualise multiple targets in the cell using a single excitation source. Quantum dots have been used to produce potentiometric biosensors based on its zero-dimensional electronic properties [52]. Magnetic multiplexed biosensors based on magnetic nanoparticles and gold nanoparticles based electrochemical enzyme bio-sensors are a few of highly sensitive nanosensors [53]. Biochip technology that includes the use of nanosensors for highly sensitive and selective diagnosis and communication of results are applications that will find good use in keeping Africans healthy especially with the low literacy rate [54]. Other nanotechnology applications include micro-arrays, nanobarcode, micro-electro-mechanical systems (MEMS) and nanobiosensors [51].

### **Drug delivery nanosystems**

Nanotechnology has a great potential in revolutionizing the drug delivery and much effort and resources are being invested globally. Clinically useful drug delivery systems with the ability of delivering sufficient amount of drug that will be therapeutically effective over an extended period of time can be developed by nanotechnology [55]. Much advancement has been made howbeit in the research arena. Africa will benefit greatly from highly efficient drug delivery nanosystems in tackling the diseases ravaging the continent.

### **Food processing and storage**

Consumer's choice of fresh, safe and healthy food with longer shelf life, and attractive, easy to handle packaging material is not different with Africans. Nano-materials have been found to impart mechanical strength, better reinforcement and barrier properties in packaging biopolymers like cellulose and its derivatives polyesters [56, 57, 58, 59]. Lighter, stronger plastic

nanocomposites with better heat resistance and barrier properties have also been developed [60]. Nano-clays and silicates have been successfully used in food packaging with improved mechanical and barrier properties and increased thermal degradation temperature and glass transition [61, 62, 63]. The development of the “electronic tongue” by Kraft foods which involves incorporation of an array of nanosensors on the packaging which change colour on the release of gases by the food during spoilage is an important progress in food packaging development [64]. The spraying of nano-laminates made of edible polysaccharides and lipids on food surface to preserve it and improve its flavour, colour and texture is another important application of nanotechnology in food preservation [65].

### **Air pollution monitoring and control**

With rising rural to urban migration, some cities in Africa are facing the risk of overpopulation. Weak policies and poor supervision has also resulted in the bad industrial practices leading to the release of harmful waste into the atmosphere.

Nano-catalysts have been developed to transform harmful vapours from cars and industrial plants into harmless gases [66]. Nanostructured membranes that can separate gases due their very tiny pores have also been developed for air pollution control [67].

### **Construction materials**

Nanotechnology is being applied in construction to enhance the properties and functions of materials. It can generate products with many unique properties such as lighter and stronger composites, low maintenance coatings, lower thermal transfer rate for fire retardants, better cementitious materials and many others. Carbon nanotubes have been combined with cement to enhance its mechanical durability and thermal properties [68].

Self-cleaning concrete, flame proofing and anti-reflection windows have been produced by the incorporation of silicon dioxide nanoparticles [68, 69]. Copper nanoparticles have been proved to improve weldability and corrosion resistance in steel. Silver nanoparticles impart biocidal properties in paints [68].

### **Health monitoring**

In order to safeguard the health of people, prevent the spread of epidemics or new diseases and maintain certain health conditions, health monitoring is of utmost importance [70]. Nanotechnology has been visible in this aspect with products like Nano- Textile Sensors that come with a mobile wireless platform and that is wearable to monitor neurological and cardiovascular disorders [71].

### **Pest detection and control**

Plant pests are a major limiting factor in crop yields. The use of over-the-counter pesticides in large quantity results in an additional cost in crop production and in excess, can lead to environmental pollution. When pesticides last longer at the initial stage of crop growth, this helps in reducing the pest population to a threshold level for a more effective control [72]

Nano-encapsulation has been used to improve insecticidal value by effecting a controlled release of the active ingredient to significantly improve its effectiveness. This method has been found to be cost effective while reducing impact on environment [73].

## **AN OVERVIEW OF NANOEDUCATION**

The rapid advancement in nanotechnology has resulted in a knowledge transfer gap as educators are looking for ways to pass on basic nanoscale science and technology knowledge and skills to the next generation. The speed of nanotechnology development even in developed

countries raises the risk of a shortfall in the required number of skilled personnel for nanotechnology [74]. The strikingly short gap between discovery and application when it comes to nanotechnology and the interconnection with a wide range of fields will require a comprehensive skill-set for high graduate employability in knowledge based industries applying nanotechnology to their processes. Thus, this highlights the importance of high quality education in nanotechnology and nanoscale science. Thus nanotechnology education is the multidisciplinary science education which focuses on nanotechnology and nanoscale sciences with chemistry, physics, mathematics and molecular biology as its foundational courses [75].

### **CURRENT STATUS OF NANOEDUCATION**

There are many institutions around the world offering courses and training in nanotechnology and nanoscale science. Over 200 institutions across the globe offer nanotechnology courses and training. Countries with several nanotechnology programs both at undergraduate and postgraduate levels include Australia, Brazil, Canada, England, China, Russia, India, Switzerland, Netherlands, Germany, Sweden and the United States of America [76]. In Africa, South Africa seems to be leading the way in nanoeducation. However, Africa as a whole seems to be lagging far behind in nanotechnology education [77].

The development of standard curricula and educational modules has been identified as a key element in improving nanoeducation globally. To deal with the multi-faceted challenges facing nanotechnology and the constantly changing terrain of nanotechnology, different approaches to nanoeducation have been developed by diverse education communities [76].

To further enhance the quality of nanotechnology education the following are strategies being employed by different institutions:

- Integrating nanotechnology within mainstream science and engineering courses.
- Developing new multidisciplinary courses
- Substituting mainstream science courses at higher levels.
- Procuring adequate infrastructure and advanced facilities to comprehensively support learning and scholarship;
- Developing an interdisciplinary research opportunities and educational collaborations
- Disseminating best practices;
- Developing student and faculty exchange programs [78].

### **IMPORTANCE OF NANOEDUCATION TO AFRICA'S DEVELOPMENT**

Education has been highlighted as a major tool for growing the fields of nanoscience and nanotechnology. The development of programs across the full spectrum of educational levels has been pursued by developed countries [79, 80]. This shouldn't be different for Africa if the continent seeks to break free from over-dependence on foreign technology to solve its problems. The successful growth of nanotechnology in Africa will require a broad and comprehensive approach to skills training; preparing students for different levels of careers in technical and non-technical positions and helping students establish start-ups based on the unique materials and devices developed by nanotechnology. [74, 81].

Nanoeducation will be immensely help in the development of more knowledge based companies which are important in positioning Africa as a major player in global affairs. It will help Africa in responding appropriately to emerging nanotechnology related social, ethical and

security risks through relevant policy development. Comprehensive nanoeducation backed up by government funding can ensure human capacity development such that African scientists will be empowered to apply nanotechnology tools and techniques using Africa's resources to solve some of the continent's problems.

## **CHALLENGES OF NANOEDUCATION IN AFRICA**

The challenges of nanoeducation in Africa are multi-pronged due to the inter-disciplinary nature of nano-technology, expensive equipment required, speed of development of the field and the lack of political will by most African countries to invest significantly in science and technology [81].

The major nanoeducation challenges in Africa include:

- Building a broad and inter-disciplinary curriculum to develop quality educational and institutional framework.
- Developing standards of learning for nanotechnology.
- Teacher education in nanoeducation.
- Informal education to inform the public on the benefits and risks of nanotechnology.
- Availability of adequate infrastructure and equipment to train students.
- Opportunities for cross-sector training and international experience [82, 83]

### **A broad and inter-disciplinary curriculum development**

One common challenge in view of the multi-disciplinary nature of nanotechnology has been the development of standard curriculum features, with much argument about the effectiveness of integrating nanotechnology concepts into existing coursework versus creating new courses for nanotechnology [84, 85, 86].

Since nanotechnology is still at an infant stage in Africa, it should be taught more from the angle of concept development and qualitative analysis at lower levels rather than mathematical derivations. The task of building a separate curriculum for nanotechnology at the different levels will be tasking and laborious, thus, nanotechnology can be introduced to students at the lower levels as a part of the present traditional education framework. Space can be created at higher levels such as post-graduate courses that focus on nanotechnology.

### **Developing standards of learning for nanotechnology**

For students to be adequately informed about nanotechnology concepts to make them informed citizens aware of the benefits and risks, to enable them fit into the nanotechnology workforce of the future and to help students develop start-ups based on nanotechnology, it is imperative that standards of learning be developed with flexibility to catch up with current trends [84]. Nanotechnology is a rapidly growing field, thus, the adoption of irrelevant or rigid learning standards might amount to a waste of time, resources and energy.

### **Teacher education in nanoscale science and technology**

Parallel to setting relevant and flexible standards of learning is the need for nano-educated teachers. Even in developed countries, teachers have shown a lack of understanding of nanoscale concepts [84]. The professional development of the teacher has been proved to directly impact student learning outcomes and this hasn't been different with nanotechnology [86].

### **Informal education to inform the public on the benefits and risks of nanotechnology**

Learning center environments in the public space and enlightenment programs are ways to promote creative thinking and life-long learning [76]. This could be through science museums, programs on mass-media or open competitions. With over 1,800 nanotechnology based commercial products available on the global market by 2015 [8], the possibility of such products

finding their ways to Africa is very high, thus the need for increased public awareness on nanotechnology related benefits and risks.

Informal education will prepare the public to consider the ethical and societal implications of nanotechnology and make informed contributions on issues related to policy regulations regarding emerging nanotechnologies.

### **Availability of adequate infrastructure and equipment to train students**

Training students on the use of modern nanotechnology tools and techniques will directly enhance their student learning experience and increase their nanotechnology research skills. It will also inspire them to develop creative ideas to meeting domestic needs within the African continent. However, equipment necessary for quality nanotechnology training and education is lacking in many African countries. Microscopes that provide a visualization of phenomena in nanotechnology which can serve as a way to teach nanoscale science to students are not available in many African institutions [81, 83, 84]. The need for upgrade of research facilities in educational and research institutions in Africa is important especially with regards to nanotechnology equipment to help students and researchers gain deeper understanding of nanotechnology principles and techniques [81].

### **Opportunities for cross-sector training and international collaboration**

The multi-disciplinary nature of nanotechnology requires the incorporation of all contributing fields to nanotechnology, utilizing a team of faculty and inclusion of guest speakers from industry in order to create a quality learning experience for students [87]. It will also imbue students with a comprehensive skill-set that will enable them compete favorably in the real world and help them start-up or work in nanotechnology based companies.

International collaboration is important as Africa is already being left behind when it comes to nanotechnology. To catch-up with advances in the rapidly growing field and develop relevant curriculum that includes new techniques and procedures, interaction with researchers from different parts of the world and international training is important for nanotechnology educators [81].

## **CONCLUSIONS**

There is an enormous opportunity for Africa in enhancing education in nanoscience and nanotechnology. Training African students to explore the possibilities and utilise the tools of nanotechnology to address Africa's peculiar problems, enlightening the younger generation to become more informed about the benefits and risks of emerging nanotechnologies and producing youths capable of fitting into the workforce of the future should be the focus of African science educators, governments and grant awarding bodies.

Our traditional chemistry, physics, biology and engineering education frameworks need to be modified to incorporate aspects of nanotechnology at lower levels to make it easier for students to specialise in nanoscale science and engineering at advanced levels.

Funding of nano-scale science and nanotechnology education for better equipped laboratories, broad curriculum development and international training are issues that require urgent attention to enable Africa to respond appropriately to emerging nanotechnologies in terms of human capacity development, growth of the technological sector, quality control, risk mitigation and policy formulation.

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