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Nanoscience teaching and research program in South Africa

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Since 2012, the National Nanoscience Teaching and Training Platform (NNPTTP), funded by the South African Department of Science and Innovation (DSI), has been responsible for overseeing Africa's first-ever master's in nanoscience program. For over a decade, the NNPTTP has seen the cooperation of four partner universities across South Africa, namely, the University of Johannesburg (UJ), University of the Free State (UFS), University of the Western Cape (UWC), and Nelson Mandela University (NMU), culminating in over 250 graduates trained in either nanophysics, nanochemistry, or nanobiology. Originally established to train professionals for a nanotechnology-based industry, both in South Africa and internationally, the program and platform has evolved into a testament to scientific collaboration. This paper discusses the program's framework, successes and challenges, related research, and future plans.

KEYWORDS

nanoscience, nanotechnology, nanophysics, nanochemistry, nanobiology, entrepreneurship

1 Introduction

South Africa's "Nanotechnology Era" started with the publication of the National Nanotechnology Strategy to Parliament in October 2005 (South African Department of Science and Technology DST. National nanotechnology strategy. Pretoria: DST, 2005). The bill urged the DSI (then the Department of Science and Technology, DST) to develop and build nanotechnology-based infrastructure and training facilities. Starting in early 2006, the government funneled over ZAR 170 million into this initiative, including the establishment of the South African Research Chair Initiative (SARChI), and, in 2007, two national nanotechnology innovation centers (NICs); the National Centre for Nano-Structured Materials (NCNSM) and the DST/Mintek NIC. Both centers have been fully operational since, with the NCNSM, situated at the Council for Scientific and Industrial Research (CSIR) in Pretoria, focusing on materials and energy research. The other, the DST/Mintek NIC is hosted at various national facilities in South Africa, including: Mintek, situated in Johannesburg, the University of the Western Cape (UWC), Rhodes University, and the University of Johannesburg (UJ), and centralizes respectively on health research, sensors, and water research and development.

Whilst both initiatives, SARChI and the NICs, were successful in starting the nanotechnology industry in South Africa, it became clear that there was a major need for trained personnel in the field of nanoscience. Thus, in 2009, a group of researchers were appointed by the DSI to investigate how joint nanoscience graduate programs were conducted between multi-universities and research groups in France, Italy, and Sweden. The led to the establishment of the National Nanoscience Postgraduate Teaching and Training Platform (NNPTTP) in 2010, modeled after the European graduate programs as a large-scale collaborative platform to drive nanotechnology in South Africa. The NNPTTP

acts as the anchor for the registration of the master's in nanoscience curriculum and program between the four universities; UJ, UFS, UWC, and NMU. Notably, the four universities were chosen based on their history of research in nanoscience, with established research groups and expertise, able to supervise the students. This paper delves into the program's structure, accomplishments, relevant studies, and upcoming strategies.

2 Description of the master's in nanoscience curriculum

In 2009, through a series of workshops, the master's in nanoscience program was developed. This massive undertaking saw the collaboration of over 35 participants from diverse fields including chemistry, biotechnology, materials science, and physics, with researchers from UFS, UJ, NMU, the University of Cape Town, Wits University, the CSIR, Element 6 (part of the De Beers Group), iThemba LABS, Mintek, and the National Metrology Institute of South Africa (NMISA), along with representatives and supporters from the DSI. Curriculum development was completed in 2011, with the successful registration of the program with the South African Qualifications Authority (SAQA) and the Council of Higher Education (CHE) at all four partner universities.

2.1 Structure of the course

Several practical considerations were taken into account during the development of the program's curriculum, including duration, which was decided to comprise of 9 months of coursework followed by 15-month of research to produce a mini-thesis. Notably, the NNPTTP consists of one centralized hub (UWC) with the three other partner universities (UJ, UFS, NMU) referred to as the "nodes." Additionally, the program was intentionally designed as a nationwide collaboration, where students would receive training at UWC, the centralized hub, during the 9-month coursework phase that also includes practical work, and then return to their "home" institution (either UWC, UFS, UJ, or NMU) to complete their mini-thesis and graduate from their home institutions.

The idea of establishing a central administrative hub with satellite offices at partner universities quickly emerged. Of the four partner universities, UWC's bid stood out due to the presence of 5 already established, highly specialized nanoscience research entities: The Electron Microscope Unit, the Environmental and Nanoscience Group (ENS), the Nanotechnology Innovation Centre for Bio-labelling, and SensorLab, the Solid-State Physics Research Group, along with the South African Institute of Advanced Materials Chemistry (SAIAMC).

2.2 Governance of the NNPTTP

Given the extensive collaboration across the partner institutions, the platform's organizational structure was carefully planned. It comprised a director, administrative staff at the central hub, and university nodes, as well as a steering committee and an advisory board.

The steering committee, composed of senior researchers in nanoscience from each university, plays a crucial role in guiding and supporting both the program and the platform. Meanwhile, the advisory board, consisting of the Deputy Vice Chancellors of Research from each university, a DSI spokesperson, industry representatives, an elected steering committee representative, and the platform director, provides strategic advice for the NNPTTP.

2.3 Course work

The program contains 9-month of coursework, an exception to most master's degrees in the sciences in South Africa where the degree is usually obtained on the basis of a thesis only. The coursework is presented at UWC, with some courses taking place via video-conference from other universities in South Africa, as well as international lecturers.

2.3.1 Introductory courses

It was decided that the students would do research in one of three streams; nanochemistry, nanophysics, or nanobiology. In line with the multi-disciplinary nature of nanoscience, the coursework starts with 'foundation courses' in the fields which are *not* the specialization of the student, e.g., a nanochemistry student will receive introductory courses in both nanophysics and nanobiology. Students also receive a series of lectures in the "Concepts of Nanoscience" as well as a Management course. The latter is unique for a science-based course in South Africa, and has three main components; project management, business management, and entrepreneurship. The aim is for students to be encouraged to consider their research not only academically, but from a business sense.

The course on "Concepts of Nanoscience" also includes general aspects relevant to all students, such as the general history of nanoscience and nanotoxicity. One additional possibility that is being considered, is to expose students to industry during this period.

2.3.2 Advanced courses

Once the foundation courses are complete, the students receive advanced coursework from various lecturers in their field of specialization. These are presented by members of the 4 universities, external experts in South Africa, as well as international lecturers. The physics lectures discuss some quantum mechanics and its relevance to nanostructures, structural properties in nanophysics, the different type of nanomaterials as well as the synthesis and characterization methods to study these nanomaterials. The biomedical course includes the synthesis of nanoparticles, physiological responses to nanomaterials, diagnostics and biomedical applications of nanomaterial devises. Some lectures on nanomedicine and the use of nanomaterials for diagnostics are also included. The advanced nanochemistry lectures includes methods to synthesize nanomaterials, such as thin film deposition methods, properties of nanomaterials and synthetic nanomaterials. Advanced characterization techniques are described in some depth. Application of nanomaterials in energy (such as fuel cells and photosynthesis), health (sensors, drug delivery, etc.), catalysis and environmental analysis are included.

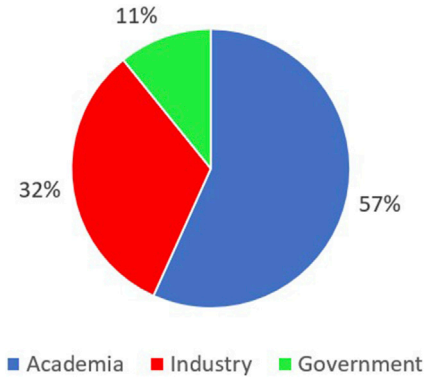

FIGURE 1
Workplaces of graduates.

2.3.3 Practical work and visits

All the advanced courses are supplemented by practical work. Since the research instruments at the different universities differ, the students visit each of the 4 partner campuses to receive a broad idea of the available research equipment. For example, the students in both the nanophysics stream and the nanobiology stream spend time at the Centre for High Resolution Transmission Electron Microscopy (CHRTEM) at NMU. Likewise, the nanochemistry students spend time at UJ, and the nanophysics students also visit UFS where the physics group has some research equipment unique to South Africa. These visits add considerably to the cost of the program in terms of flights and accommodation at the nodes. However, there is general agreement that the exposure to the resources available in South Africa is extremely valuable as state-of-the-art equipment is not available at all institutions.

3 Research component

The research projects chosen by the students are dependent on availability of supervisors at their home institutions. Some students work in the same research group, but, in general, the students work on a wide range of topics. Some of the themes at the different universities will be described below including selected references to publications of the groups where students of the nanoscience program are co-authors. The agreement between the universities specifies that students should not change to different universities to do their research in order to protect the partners from losing students. However, when there are well motivated reasons, students have been allowed to switch to a different university for their research projects.

3.1 University of Johannesburg

UJ has a very strong nanochemistry group. Research involves a wide spread of fields including polymer nanocomposites, water remediation, and carbon nanomaterials (Raseruthe et al., 2021). The core emphasis of nano-materials research at the University of Johannesburg's Department of Chemistry revolves around advancing water purification techniques through diverse methodologies. The research spans electrochemistry, membrane purification science, and the identification and removal of pollutants using innovative nano-enabled degradation mechanisms. Additionally, their efforts extend into nano-focused energy research, where they explore novel approaches to energy generation and storage on the nanoscale.

3.2 University of the Free State

UFS has strong research groups in both nanophysics and chemistry. The physics department performs research in the degradation of phosphors for field emission displays, as well as the development of materials for nano solid-state lighting (Menon and Swart, 2020). The research group has the ability to synthesize and deposit thin films of various types of semiconductor nanoparticles, which will enhance the color, luminescent intensity, and lifetime of such displays. Students have worked on several aspects of these nanophosphors, as well as a wide range of applications including CO_2 capture (Abraha et al., 2021).

Most of the research in the chemistry department focuses on the synthesis and characterisation of Metal Organic Framework nanoparticles and their application in gas adsorption, heterogeneous catalysis and drug delivery. Over the last 6 years the research projects diversified to also include organic-, analytical- and inorganic chemistry. This led, amongst others, to the synthesis of magnetic nanoparticles for the extraction of contaminants from water, tailored graphene oxide for catalysis, functionalised nanodiamonds for cancer treatment and Cu and Ag nanoparticles with anti-pathogenic properties (Mphuthi, Maseme and Langner, 2022).

3.3 University of the Western Cape

The department of physics and astronomy at UWC has a long history of research in thin film physics, with a bespoke multi-process zone chemical vapor deposition system (Mazibuko et al., 2019) where solar cell research based on nano-crystalline silicon and multi-dimensional (3D and 2D) perovskites are studied. Students are involved in modeling (Fourie, Square and Arendse, 2022), the deposition and subsequent characterization of the samples (Magubane et al., 2023) and its incorporation into functional devices (Ngqoloda et al., 2020).

The chemistry department has a strong history in nanoscience research including the Sensor Laboratory (See *Electroanalysis*. 2020; 32 (12). doi:https://doi.org/10.1002/elan.v32.12 for several articles by this group) and environmental research. The SensorLab, focuses on research in smart materials, electrocatalysis, sensors and electrochemical energy. The focus is on designing 'smart' nanomaterials (polymeric, dendritic, graphenated and carbon nanotube composite systems) (Mabokela et al., 2021; Somo et al., 2021).

The Environmental and Nano Science (ENS) group looks at beneficiation of industrial wastes to form zeolites (Ndlovu et al., 2023) being the ultimate nanomaterials useful for environmental remediation and water treatment, as well as synthesis and

application of many other nanomaterials such as selective nanofiber (Totito et al., 2023) composite membranes, photocatalysts (Mouele et al., 2023), thin films (Rossouw et al., 2022; Dinu et al., 2023) and nanoparticles (Pereao et al., 2017; Böke et al., 2023).

The nanobiology-focused researchers work on several different fields. Researchers within the School of Pharmacy are developing nanomedicines for the treatment of infectious diseases such HIV and tuberculosis (Mhambi et al., 2021). Researchers within the Department of Biotechnology who are also affiliated to the DSI/Mintek NIC (Biolabels Unit) are developing diagnostic and therapeutic systems to address major health concerns such as cancer, obesity, and several infectious diseases that plague Africa. An overview and appraisal of the research activities of the DSI/Mintek NIC (Biolabels Unit) and its contribution towards capacity development within Africa was recently published (Sibuyi et al., 2022). Several researchers also work in the field of green nanotechnology, which involves the use of plants to produce nanoparticles that are not only biocompatible but also demonstrate a range of bioactivities that can be exploited in medicine (Mukhoro et al., 2018).

3.4 Nelson Mandela University

NMU has well established research programs in nanophysics, nanochemistry and nanobiomedical sciences. The Centre for High Resolution Transmission Electron Microscopy (CHRTEM) supports all three programs with nano and atomic resolution electron microscopy. Research carried out at CHRTEM covers a wide range of key technologies such as nano particle catalysts for coal-to-liquids processes, improved materials for use in conventional and high temperature nuclear reactors as well as accident tolerant nuclear fuel designs (Kratochvílová et al., 2020), novel titanates to be used as absorbents for radionuclide and heavy metal ions present in aqueous phases, radiation effects and atomic resolution imaging of extended defects in ceramics, semiconductors and diamond.

NMU is strong in nanobiomedical applications of nanoscience such as the application of gold nanoparticles (AuNPs) and its toxicology (Adewale et al., 2019) especially on the brain (Pereira et al., 2021). The synthesized AuNPs are evaluated for their efficiency towards breast cancer and colon cancer. With the support of the HRTEM Centre the uptake and localization of the gold nanoparticles in different cell lines have been demonstrated. Another focus area of this group is the use of lipid nanoparticles for wound healing.

4 Results and successes

The master's in nanoscience program and the NNPTTP is acknowledged to be successful and has achieved its objectives as originally envisaged in 2010. Graduates from the course are working in industry, government laboratories and around more than half in academia as indicated in Figure 1. Many of the alumni in academia are on the lecturing staff of universities in South Africa, at least one at the professorial level. One graduate started a successful nanotech company in England.

5 Future plans

After over a decade, the DSI continues to provide funding for the platform and program. However, they have expressed a desire for additional funders and increased emphasis on commercialization. The primary goal of the nanotechnology initiative in South Africa has always been to promote the generation of companies and employment opportunities.

Discussions with students indicate that many are interested in becoming entrepreneurs but most have not considered the possible applications of their research towards this goal. Thus, the advisory board has decided that the course should strengthen the entrepreneurial content of the course (Dikweni, Makgabutane and Mhlanga, 2023) and also consider exposing students to industry during their studies. A "Pitch" competition, wherein students propose potential business ideas using their research, was held in 2023. The program is pursuing opportunities of collaborating with companies in the Nanotechnology field. The aim will be to foster collaboration between researchers at universities and the R&D departments of companies. The idea is to encourage companies to fund student bursaries or running costs for the master's projects and to give students greater exposure to nanotechnology companies.

Other plans include the possibility of making the present advanced courses available as online courses. This would allow students in the nanoscience field who are not registered on the course from partner universities, as well as other universities in South Africa and, indeed, Africa, to benefit from the program.

6 Nanotechnology industry in South Africa

The efforts of government and private companies have led to some commercialization in the nanoscience field in South Africa. The following are some examples of nanotechnology specific companies where graduates of the teaching program are employed:

- Medical Diagnostech[1]
- Stellenbosch Nanofiber Company[2]
- Synexa[3]

Most of these companies are in either the nanobiology or nanochemistry field. Sabinano[4] is an example of a nanophysics-based company in South Africa which supplies graphene and carbon nanotubes. Hence, there has been success in building a nanotechnology industry. Many pharmaceutical companies have a presence in South Africa and are, in principle, also interested in nanotechnology.

1 http://medi-tech.co.za

2 www.SNC.co.za

3 www.synexa.co.za

4 https://sabinano.co.za

Previously, through the NNPTTP, the DSI supported a program of internships to help graduates from the program to gain experience and find employment at relevant companies. This program was quite successful and there are graduates working at the companies listed above. The DSI plans to resurrect this program that was stopped a few years ago.

7 Discussion

The nanoscience program has been successful in producing more than 250 nanoscience graduates. About 1/3 are employed in industry, and making a positive contribution to the development of the research and development departments in those companies. The hope is that the program, with the changes outlined above, will contribute to the vision of the DSI as expressed in the original 2005 publication, namely, "through partnerships between business, government, academia and civil society . . . address South Africa's socio-economic development challenges" (DST, 2019). The lack of funding for research in Africa has often been highlighted (Adepoju, 2022). This lack of investment in the Knowledge Economy has meant that Africa is still mostly dependent on the export of raw materials (UNCTAD, 2022). The planned changes will hopefully help to expand the Knowledge Economy in South Africa (Ngongalah et al., 2018).

Author contributions

RL: Conceptualization, Investigation, Resources, Validation, Writing–original draft, Writing–review and editing. JN: Data curation, Formal Analysis, Investigation, Validation, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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