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Teaching undergraduates nanotechnology

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ABSTRACT: Education in science and technology at universities is currently facing several problems. One of the first nanotechnology undergraduate degrees in the world was established at Flinders University, Adelaide, Australia, in 2000. This article focuses on some of the problems encountered and solutions developed at Flinders University as part of the Bachelor of Science in Nanotechnology (Honours). In this article, the authors present their experiences in developing and delivering this degree in a climate where *traditional* physical sciences are under considerable strain. Also discussed will be the motivation for this initiative, the structure of the established course, as well as the relevant educational issues that relate to its development. The article also outlines some of the concepts and tasks related to the core subjects in the nanotechnology degree offered at Flinders University.

MOTIVATION

It is a common problem around the globe that interest in science is waning [1]. Interest of the wider community towards science is at a low-point, especially in the case of physical sciences like physics and chemistry. One, notable, exception to this trend is forensic science, where young people are still keen to undertake tertiary studies. The root of this sustained interest in forensic science can perhaps be traced to a *lifestyle* issue; the popularity of television shows such as the *X-Files*, *Crime Scene Investigations*, and a myriad of murder mystery shows have undoubtedly had a considerable impact upon the image of forensic scientists in the mind of the general public. As scientists, we may decry the accuracy to which our disciplines are depicted in these shows, but the simple facts are that young people watch and enjoy these shows, thus developing an interest and curiosity towards science. However, the problem remains on how to gain and sustain the interest of future university students in studying science.

A second problem for much of university education is its perceived lack of applicability to the real world and its poor ability to prepare students for employment for anything other than research in fundamental science.

INTRODUCTION

Flinders University, Adelaide, Australia, has a strong track record in offering cutting edge degrees in areas like biotechnology and Information Technology (IT). Bachelor degrees were established in both of these areas at the critical time when they were emerging technologies with clear economic and cultural potential for Australia. Biotechnology was first offered at Flinders in 1990 and was the first degree of its type in Australia. With the success of these early ventures, Flinders subsequently developed other so-called *niche* degrees, for example, the Bachelor of Technology (Forensic and Analytical Chemistry) and the Bachelor of Science (Marine Biology). The common theme amongst these degrees is that they are consistently oversubscribed.

In the middle of 1998, a proposal was put forward by the then Departments of Chemistry and Physics to the Faculty of Science and Engineering to establish a new undergraduate course in nanotechnology. The first intake of students to the course occurred in 2000. The new degree not only sought to teach students a new field of science but also tackled the following educational issues that have long been problems in university education: What is the relevance of basic science knowledge to the long-term goals of the students? How can students acquire the *non-scientific* skills is areas like economics or business, or *generic* skills like teamwork, oral presentations, report writing and rational argument required to be successful? Finally, can all of the knowledge acquired during a university degree be drawn into a cohesive package for students at the course's end? Given the current large student numbers at universities, it is vital that these issues are addressed in a course [2][3].

SPARKING STUDENT INTEREST IN SCIENCE

There are many reasons for the declining interest in the physical sciences. There is no glamorous image in the media portraying the *lifestyle* of a physical scientist in the same way as for a forensic scientist. While this is the most obvious difference, it is not the prime reason for the lack of interest. Firstly, the physical sciences are perceived as difficult, especially given that a firm grounding in mathematics is essential. Many current high school students struggle with mathematics and hence scientific pursuits are made even more difficult. Secondly, students see very limited, poor paying career options in the sciences. This is particularly true in comparison to other endeavours, such as law, medicine or business, which seem to attract a considerable portion of high achievers in the physical sciences from high school.

While these are contributing factors, the main reason for the lack of interest stems from the general perception that there is nothing left of interest, or benefit, in the realm of *hard* physical sciences. There are a number of examples to illustrate this point. In the post-war years, especially when the space race was in full swing, or the semiconductor industry was beginning to develop, interest in physics and chemistry was perhaps at its highest point. There were obvious, interesting and worthwhile challenges for science that captured the public's imagination. This is certainly true of the space race: what more provocative image for science than a live TV broadcast from the moon? In recent times, this focus has shifted, and the *soft* biologically oriented sciences are now perceived as the key to the future. Clearly, these issues are, to some extent, driven by the demands and agendas of industrial and political concerns. The general perception today of the physical sciences is that all of the interesting problems have been solved, and that physical science will not contribute to society in such a significant way in the future.

This perceived lack of interesting problems and applications leads then to a lack of interest. This has put many science departments and, in particular, physics departments under tremendous pressure. This problem is especially acute in Australia where student numbers directly determine the vast majority of income for a university, faculty or department.

This is where nanotechnology enters the picture. Nanotechnology has appeared in a variety of media over the last few years, so clearly interest is growing. Most scientists know that physical science is a thriving and constantly developing area. While many of these advancements are critical for future endeavours, they do not necessarily capture the imagination of the general public or, specifically, young students. Nanotechnology is, in some sense, the stuff of fantasy that can stimulate public interest. It is a technology that is still in its infancy, yet will clearly shape our futures with wide ranging applications from human implants to quantum computing. Nanotechnology does have the potential to solve difficult and currently unsolvable problems with the most mind-boggling and, in many cases, beautifully simple solutions. Nanotechnology is a captivating example of the importance, excitement, need and challenge for the physical sciences that can again be brought into public view. Given this, interest in these sciences can be rekindled.

The course at Flinders has constantly been over subscribed by a factor of 3 for first preferences (people naming the course as their first choice) and a factor of 6 for people naming the course as one of their preferred options. It is worth noting that a requirement for entry into the course is high school level chemistry, physics and mathematics, so students entering have a strong physical sciences background. Clearly, the first hurdle has been cleared: people are interested in nanotechnology and the physical sciences.

COURSE DESIGN

Structure

In developing the course structure for nanotechnology, there was acute awareness that the science content should not be decreased with respect to a *traditional* science degree in physics or chemistry. Indeed, to give students anything less than a very firm underpinning in all the basic areas of chemistry, physics and biology would do them a great disservice, as this knowledge will be the basic understanding needed in the careers for which they are preparing.

This raises the first issue faced in designing a nanotechnology degree. The field is currently in its infancy and is incredibly broad, spanning chemistry, physics, biology, mathematics and engineering. This is, in fact, probably an incomplete list but it makes the point: how do you possibly teach all of these areas to students in a four-year honours degree? The simple answer arrived at during the course design is, you do not, and after four years of experience, this is still believed to be the case. Given the expertise at Flinders and the emerging strengths of nanotechnology research in Australia, the course was divided into two streams: biodevices and nanostructures. The structure of the entire course is given on the Flinders University Web site: http://www.scieng.flinders.edu.au/courses/nanotechnology/

The biodevices stream is centred across chemistry and biology. It starts from the point of the classic glucose biosensors [4]. It then moves to more novel, self-assembled biosensors, such as the AMBRI ion channel biosensor [5]. From there, the use of biological elements as building blocks is tackled, etc. The nanostructures stream is centred across chemistry and physics. It concentrates largely on the roles of surface science and light in forming and probing nanostructures, such as quantum dots, nanoparticles or atomic arrays [6-8]. Just as importantly, some of the topics will concentrate on the applications of these structures. The light aspects of this stream are introduced for two reasons. First, photonics is an active research area and is rapidly developing a strong industrial base in Australia and, hence, it can provide graduate employment opportunities. Second, developments in photonics in the near future are moving into the realm of nanotechnology.

Significant parts of the two streams are common. Indeed, this reflects the fact that some basic mathematics, physics or engineering, chemistry or biology are fundamental to understanding how to build structures – even those on a nanometre scale. The physics and engineering aspects address the forces that make stable structures, while chemistry and biology specifically look at the possible building blocks for those structures. In the future, there is a real possibility that the two streams may merge into one as the directions of nanotechnology and its applications become more focused. In both streams, at least two-thirds of students' time is still dedicated to basic science, whether it is cell biology, thermodynamics or electromagnetism. The other two main components of the course are enterprise management related topics and topics specifically called nanotechnology as indicated by the NANO prefix in their number.

The enterprise management topics are non-science topics in areas like economics and commerce. As well, in the honours year, students write a business plan based on a commercial idea that they initiate. The main reason for the inclusion of these topics is that it is believed that many students will have career paths that lead them into industrial settings where business skills are highly rated alongside traditional science skills. Further, given the infancy of nanotechnology, it is believed that graduating students will play a key role in the development and commercialisation of the technology in Australia. The topics in the course are meant to give students a basic (but by no means complete) introduction to business and management issues. Two of the topics will be touched on in more detail later.

The nanotechnology topics strive to take the basic science presented in each year and apply that knowledge to specific examples of nanotechnology. It is hoped that this has the effect of tying all of the basic sciences together for students and shows them that the sum of the parts does make the amazing experiments that underpin nanotechnology applications possible and understandable [9]. Of course, with any luck, an underlying effect here is that students' interest in the basic science is also stimulated so that it holds some relevance to them.

Process

Students arrive in the course with quite strong science backgrounds. Prerequisites for the course are final year chemistry, physics and mathematics. Existing skills are built on in three main ways. Firstly, student interest in their basic science programme is maintained by showing them the relevance of the topics from the outset of the course. Secondly, the first year of the programme is designed to help students learn how to acquire and assess information independently. Finally, the important issues, both scientific and non-scientific, that students will face as part of the course and beyond are addressed repeatedly in both a formal sense through lectures, etc, and in an informal sense through group work, presentations and debates [2][10].

Content

There are a variety of educational issues faced in developing the topics for the course. In addressing these it was hoped to address some issues that currently face perhaps most university degrees. Starting afresh was an advantage in this respect as new topics could be designed to meet particular goals and address different difficulties that students might face.

NANO 1101: NANOTECHNOLOGY I

Students have to make one choice in first year depending on the stream they think they will follow in second year and beyond. Basically, the decision is to do mathematics and follow the nanostructures stream or do biology and follow the biodevices stream. This decision must be made halfway through first year. This is not an ideal situation: this decision should be delayed until the beginning of second year. Unfortunately, no way, so far, has been found to implement a structure to achieve this.

Given that students must make this choice, Nanotechnology I is offered in the first semester of first year to help define the broad areas of the two streams for students. This is done through two projects: one based on the ion channel sensor and the other on quantum computing [5][11]. Students work in groups of six and, at the end of the project, present both a written and oral report. As part of this process, students maintain work logbooks to enforce the importance of recording their activities, whether in be in a laboratory recording data or a literature search [12]. Students do all of the research on the project topic and critically evaluate the information that they find with the help of a group leader. This starts to develop team skills, critical evaluation, report writing skills and oral presentation skills that are highly valued in the current employment market [10].

However, more importantly, it starts students thinking about the scientific issues that are important in nanotechnology. How can structures of nanometer-sized dimensions be built and examined? What are the possible applications and uses of these structures? Can a student understand the intricacies of a quantum computer at the first year level? Of course not; however, given that they have now discussed the issues in quantum computing, they will understand the importance of basic quantum mechanics. The approach of presenting the big picture conceptualises the micro learning that students undertake in individual topics, meaning that when core topics are undertaken in second and third year, students appreciate their relevance and importance. This is vital given that relevance is a major motivational factor in student learning. In essence, answering the question, *why do I have to learn this?*, is the aim. Often in current university education, this question is answered in a student's final year and many university lecturers seem to be upset that a student would query why they need to know something before then. This does not seem like an unreasonable request and this topic is used in an attempt to show students the importance of the basic sciences in larger issues.

NANO 1102: PROFESSIONAL SKILLS FOR NANOTECHNOGISTS

NANO 1102 is the first *non-science* topic that students undertake and its prime goal is to introduce some non-science issues that will, in all likelihood, be important in their careers. These issues are tackled in three ways. Firstly, a variety of scientists are invited to talk to the students regarding their own careers and the important skills – both scientific and non-scientific – that a scientist must possess in the current work environment.

Secondly, students undertake a series of Problem-Based Learning (PBL) tutorials examining various scientific commercialisation issues, such as corporate culture, intellectual property, etc [2][13]. PBL tutorials involve the presentation of scenarios to students in a series of steps called triggers. As a group guided by a tutorial leader, students debate, discuss and argue points related to the case presented. In so doing, they first identify the important issues and then, with some research between the tutorials, answer some of their own questions. This is a very effective way of presenting material to students and they tend to engage more deeply in their learning from this approach than they would in the classic lecture-only approach. The tutorial learning is strengthened by a series of lectures from people who are experts in the various fields. Further, a subset of students is then given an *argument* to contest. This might be a debate, presentation to an enquiry or court case where students have to argue a particular position. The intention is that this starts to develop students' abilities to present rational arguments based on the facts they find.

Thirdly and finally, students again work in groups on a project that is based on a scientific idea, but has become a commercial success. Some projects include the laser and global positioning system. Students are asked first to understand the scientific basis of the product and then try to learn something about the steps from scientific discovery to commercialisation. Again, oral and written reports are required from each group.

OTHER NANO TOPICS

There is a dedicated nanotechnology topic in both second and third year for each stream. As nanotechnology is a new science, these topics are quite difficult to put together and much of the material is drawn from current literature. The most important aspect of the lecture component of these topics is that they draw on students' exposure to basic science to help explain new and exciting applications in nanotechnology. For example, when teaching electronic transport in confined nanostructures, understanding of concepts such as quantum mechanical tunnelling and band theory of solids is vital. Again, this reinforces the relevance and importance of these basic sciences and helps to sustain students' engagement with the broader ideas and concepts in science.

Each of these topics also has a laboratory associated with it. The fact that a new topic was created, and hence no existing practicals, was a real bonus, despite the fact that this meant a large amount of extra work was required. New practicals were designed, with many based on very recent literature [14-16]. Some laboratories include kinetics using STM, imaging of self-assembled monolayers using STM, various syntheses and measurements of nanoparticle properties, porous Si experiments, construction and characterisation of a solar cell, etc.

The theme of these practicals is to again use basic science (often from a couple of different areas) to understand new and exciting applications. In the third year laboratories, the practicals are related to other key areas like electrochemistry, kinetics, measurement of quantised conductance and optics. These are areas in which students have previously completed courses and this theme is developed further to show the basic science underpinning these new and exciting applications. Students are exposed to techniques such as a QCM and a Langmuir Blodgett trough with an emphasis on using existing techniques in new ways. For the biosensors stream, this includes new techniques to detect old favourites (ie glucose biosensors).

Some of the laboratories are dedicated to just one stream or the other, while about two-thirds of the practicals are designed to stretch across both streams. In the final part of the third year topics, students are asked to design an experimental programme based on earlier experiments. This starts to develop the basic scientific skills that will be core to students' future careers.

ECON 3011: Science-Based Enterprises

ECON 3011 is the final topic that students take in the stream of non-science topics. It attempts to tie all of the previous ideas into one topic where students are given a case study of a new nanotechnology company and must make critical comments as they would in any other business case. The intention is that students undertaking this topic appreciate that the skills developed could well be ones they will use in their careers as scientists, especially in a small company.

Honours

The final year of the degree is divided into two parts. The first is based on coursework: both scientific and non-scientific. The scientific courses are fourth year basic science courses, while the non-scientific courses involve the production of a business plan based on an idea produced by a small group of students. The second part of the honours year is a research project. The student will spend about five months working as a research student in one of the laboratories at Flinders or elsewhere on a project of current interest. At the end of the research project, students again must present an oral seminar and a written thesis. This combined effort of research (science) and business activities will draw together and call on students' experiences and knowledge gained over the previous three years [3]. Further, it presents them with the exact situation they may encounter after they finish their degree and prepares them to handle those situations.

CONCLUSION

The Bachelor of Science in Nanotechnology degree at Flinders University and has proven very successful. Interest in the physical sciences by very capable students has been affirmed by the numbers who have decided to undertake the degree. The new topics that are part of the degree have been successful and provided students with the opportunity to discuss issues, both scientific and non-scientific, which will be important to both their careers and the future of nanotechnology in Australia.

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