Contextual Chemistry and Physics Teaching in an Undergraduate Nanotechnology Degree

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ABSTRACT

Curtin University established a Bachelor of Science(Nanotechnology) degree in 2002 as a joint program between the departments of Applied Chemistry and Applied Physics. This paper describes the structure of the degree and the approaches taken in the development of a stream of nanotechnology units aimed at enhancing the teaching of fundamental concepts in Physics and Chemistry within a Nanotechnology context. Student perceptions of the value of these nanotechnology units are also discussed.

Keywords: *Science Education, Nanotechnology*

INTRODUCTION

There is growing concern about declining enrolments in tertiary Chemistry and Physics courses throughout Australia. The trend of decreasing student numbers in the so-called enabling sciences has been well documented and reflects a corresponding decrease in the number of students electing to take the science subjects at high-school level.[1] The problem is not limited to Australia, as similar trends have been reported worldwide.[2] There is no consensus however, on the reasons for this trend, and few educational researchers have tackled the question, but perceptions of a diminished relevance of science subjects to students' career aspirations, and a decrease in general public interest in the physical sciences are often cited as reasons for the decline.[3]

A generation ago, at the height of the "space race", physical sciences were seen as fields of endeavour with exciting opportunities for the future, but they are now perceived as disciplines with nowhere left to go. As scientists, we know that this isn't true, but for much of the general public, the disciplines of physics and chemistry are seen as fields that are past their prime. This may be due to the fact that new developments in technology tend to catch the public eye far more readily than the underlying science that makes the technology possible.

The emergence of nanotechnology has presented an opportunity for science educators to tap into an area which is generating renewed interest in science among young people and is receiving regular coverage by the popular science media. Nanotechnology provides a vehicle for presenting the traditional physical science disciplines within the context of exciting developments that offer a wide range of practical applications, and provide broad scope to present students with ways to apply fundamental chemistry and physics in a practical setting. It is for this reason that many universities are looking to integrate nanotechnology into their courses, or to develop new courses in nanotechnology as a means of improving enrolments and retention rates in the physical science disciplines.

Curtin University of Technology began offering its Bachelor of Science (Nanotechnology) degree in 2002 and at the time only a handful of Australian universities were offering such degrees. There are now twelve Australian universities offering undergraduate degrees in nanotechnology or nanoscience,[4] and this growth seems to reflects a general awareness that, in order to attract students to study physical sciences, universities need to provide courses that will stimulate the students interest and present the fundamental science content in ways that relate to up-to-date developments in technology.[5]

This paper aims to provide a general description of the approach taken at Curtin University of Technology in developing an undergraduate course in Nanotechnology, with a focus on the particular issues driving the development of contextual nanotechnology units in this course.

COURSE STRUCTURE AT CURTIN

The field of nanotechnology is very broad, encompassing aspects of various traditional scientific disciplines, including chemistry, biology, physics, materials science and engineering, but unified by the common theme of working with materials and phenomena on the nanometer scale. This presents a problem in the design of an undergraduate degree in nanotechnology; students need sound training and knowledge in the underlying disciplines, but it is impossible to thoroughly cover such a broad knowledge base within the confines of a standard undergraduate course. Most Australian universities that offer nanotechnology courses, have dealt with this by focussing on areas of strength in their teaching and research capabilities to provide degrees centred around one or two of the relevant scientific disciplines. The BSc(Nanotechnology) offered by Curtin University of Technology is a case in point. The Curtin degree is run jointly by the departments of Applied Chemistry and Applied Physics and aims to provide graduates with a ‘double qualification’ in Chemistry and Physics. An important aspect of the course from its commencement in 2002 was the commitment to ensure that graduates completed enough high-level units in each discipline to be eligible for membership of both the Royal Australian Chemical Institute and the Australian Institute of Physics.

The Curtin course draws upon units offered by the Physics and Chemistry departments to provide a path of equivalent level to Chemistry and Physics majors. At first year level, students complete chemistry, physics and mathematics units. At second and third year levels the chemistry content is comprised of Inorganic and Physical Chemistry units, while the Physics content is essentially Solid-State and Materials Physics although Quantum and Statistical Physics is also included.

In order to ensure that an advanced level of study can be achieved in both disciplines, the course is a four-year course with an embedded Honours program. At fourth year level the Honours program is available to students who achieve the required grades throughout the first three years of the degree. The difference between the Honours and non-Honours streams is only in the amount of research-based study in year four. All students do research projects, but the Honours program includes a higher proportion of research-based work, with half of the final year’s assessment being based on a year-long research project.

NANOTECHNOLOGY CONTENT

Although the course is centred around Chemistry and Physics content, teaching of these fundamental disciplines is complemented by a series of nanotechnology units running through the

Table 1 : *Nanotechnology units in the BSc(Nanotechnology) degree at Curtin*

Unit Title	*Credits**	*Lecture Hrs/week*	*Lab Hrs/week*
1st Year			
Nanotechnology 101	**12.5**	**2**	**0**
2nd Year			
Nanotechnology 201	**25**	**2**	**2**
3rd Year			
Nanochemistry 301	**25**	**2**	**4**
Nanochemistry 302	**25**	**2**	**4**
4th Year			
Nanocharacterisation 401	**25**	**2**	**2**
Nanotech Honours Dissertation 401	**50**	**0**	**~ 12**
Nanotech Honours Dissertation 402	**50**	**0**	**~ 12**

* A full-time enrolment is comprised of 100 credits per semester.

course at all year levels. The purpose of these units is to place the Chemistry and Physics content into the context of applications in nanotechnology. An outline of the nanotechnology units in the Curtin university course is presented in Table 1.

First Year

The first year nanotechnology unit aims to provide a general introduction to nanotechnology, by covering important developments in science that have led to the rise of nanotechnology as an exciting research field. Important characterisation techniques such as electron microscopy, atomic force microscopy and X-ray diffraction are covered in a very simple way in order to help students understand the challenges of studying nanoscale systems. Students are introduced to some of the major concepts in the debate about the future directions of nanotechnology; the Drexlerian vision of mechanosynthesis; the pros and cons of top-down and bottom-up fabrication methods and supramolecular self-assembly.

When this course began many students who came into the course had an unrealistic idea of what nanotechnology could achieve; their views had been shaped by hype and science fiction, and this unit served to correct some their misconceptions. In recent years however, we have found that first-year students are much better informed about nanotechnology, so we now feel that the main objective of this unit is to inspire students about the field of nanotechnology and to give them a clear perspective on the ways in which chemistry and physics are applied in nanotechnology.

Most of the classes in this unit include group discussion sessions, in which students work in groups to address a series of guiding questions presented in a worksheet. The worksheets are made available to students via a web-based interface at the start of the course, and each worksheet has an associated list of reading material that is also provided online. Examples of discussion topics include subjects such as “Nanobes: Fact or Fiction”; “The Space Elevator: Can it work ?” and “Does Nanotechnology have Politics ?”. The discussions provide an opportunity to explore the wider implications of nanotechnology in society, but each is also linked to a lecture topic that introduces a scientific aspect of nanotechnology, i.e. the discussion about nanobacteria links with a lecture on electron microscopy; the space elevator discussion links with a lecture about buckballs and carbon nanotubes and the nanopolitics discussion links with a lecture about the uses of nanoparticles.

Second Year

The second year nanotechnology unit has two content modules: Carbon Technologies and Analytical Chemistry. The Carbon Technologies module aims to build on the very basic introduction to fullerenes and nanotubes that was provided in the first year unit, at second year level. The material covered in this module includes synthesis, chemistry and physical properties of fullerenes and nanotubes, and the module provides an opportunity to place in context some of the principles being taught in concurrent chemistry and physics units, and thus to reinforce learning of these principles. For example, knowledge about hybridisation of *s* and *p* orbitals can be reinforced by considering the bonding in fullerenes, and band theory of conductivity can be enhanced by studying the conductive properties of carbon nanotubes.

The presence of an analytical chemistry module in a nanotechnology unit might seem a little incongruous at first, but the reasons for its inclusion in the unit are twofold. Firstly, some basic understanding of analytical chemistry principles and techniques was considered important in a course that aimed to provide a full qualification in chemistry, and other chemistry units included in the nanotechnology course did not cover analytical chemistry. Secondly, analytical chemistry was seen as a topic in which the importance of miniaturization could be introduced to the students through discussion of microfluidics, flow analytical systems and “lab-on-a chip” technology.

The laboratory component for this unit is aimed at providing key skills in analytical chemistry such as correct sampling procedures, preparation of standards and method validation. At present the unit draws on pre-existing laboratory classes from the standard chemistry course, but new experiments are being developed to place the analytical chemistry skills within a nanotechnology context. Planned lab classes include topics such as UV/Vis analysis of C_{60}/C_{70} mixtures and AAS determination of residual Ni catalyst content in as-prepared carbon nanotubes.

Third Year

At third-year level, the nanotechnology component begins to place more of an emphasis on skills and competencies than in previous years, and thus the two Nanochemistry units have a significant laboratory component as part of their assessment. These two units are comprised of content modules that focus on chemistry topics of special relevance to nanotechnology: surface and colloid chemistry; polymer chemistry; nanoparticles; computational chemistry and supramolecular self-assembly. The third year laboratory classes aim to provide students with the skills that they will need to work in a research environment. Good maintenance of laboratory notebooks is emphasised and lab books showing accurate recording of data and risk assessment for all procedures are collected and assessed at the end of semester.

Typical laboratory exercises encourage the students to engage in independent enquiry and to use the scientific literature to assist in their experimental work. As an example, we run an experiment in which students prepare Mn-doped ZnS nanoparticles and then measure their quantum yield. Students compare the quantum yield of the as-prepared nanoparticles with those coated with surfactant of their choice, and they are encouraged to use literature sources to put their results into context and to explain their observations. Laboratory reports are laid out in accordance with a journal-style template.

Fourth Year

Nanocharacterisation is the "capstone" unit of the nanotechnology course and it aims to give the students some understanding and practical experience with some advanced characterisation techniques that are used in nanotechnology. The coursework is divided into modules, of which Scanning Probe Microscopy is a core component. Other modules have been provided in specialty areas by research staff or visitors and have included topics such as small-angle X-ray scattering, magnetic characterisation and molecular biophysics. The practical component of the unit involves a supervised series of workshop sessions that give the students some hands-on experience with atomic force microscopes and the transmission electron microscope. For these workshops, carbon nanotubes are used as the samples for characterisation, and the main aim is for students to measure the diameter of the tubes.

All fourth-year students carry out research projects throughout the year, and by running the nanocharacterisation unit in first semester, we ensure that students who need to use these techniques in their research projects receive a significant component of their training as a core part of the course. Thus many of the students are able to produce high quality results in their research projects, as they do not need to spend extra time being trained to use equipment at the start of the year.

STUDENT PERCEPTIONS

In mid 2006 third- and fourth-year students in the Nanotechnology degree were surveyed by e-mail to gauge their attitudes to various aspects of the degree, and in particular, their feelings about the nanotechnology units within the course. The survey invited open-ended responses to general questions such as "What do you think is the best thing about the Bachelor of Science(Nanotechnology) degree?" and "What do you think can be improved in the Bachelor of Science(Nanotechnology) degree?"

The results of the survey supported our belief that students would value the practical experience provided by the nanocharacterisation unit and that they would find the contextual nanotechnology units stimulating. The top two responses to the question of "What do you think is the best thing about the Bachelor of Science (Nanotechnology) degree?" were " Practical experience on instruments" and "Nanotechnology units". These responses or similar variations were given by 12 out of the 20 students who responded to the survey. Other significant responses were "Broad coverage of Physics and Chemistry" and "Practical work in research projects".

The results of the survey suggest that the students have responded well to situations in which the concepts they have learned in their Physics and Chemistry units are put into a nanotechnology context. However, it should be noted that the value of the nanotechnology units in the course may extend beyond the direct educational benefits. For students in the nanotechnology degree, these units provide an opportunity for interaction with their peers as one group, while other units in their degree will always include students enrolled in other courses. Thus we believe that these units play an important role in giving the students a sense of cohesion and identity within the wider sphere of general science undergraduates.

CONCLUSIONS

The Bachelor of Science (Nanotechnology) degree at Curtin University of Technology has been successful in attracting students to study physical science disciplines at a time when student numbers in many traditional chemistry and physics courses are in decline. An important consideration in any undergraduate course in nanotechnology is the need to ensure an adequate level of education in traditional science disciplines, and to balance this need with the demands of the very broad and ever-expanding field that nanotechnology has become.

Curtin's course aims to produce graduates with a 'double qualification' in Physics and Chemistry and to provide students with a significant level of practical experience in the use of advanced technologies. Through the development of a suite of nanotechnology units in each year of the degree, the principles taught in Chemistry and Physics units are reinforced within the context of Nanotechnology applications, and the student feedback on these units has been very positive.

The Curtin degree aims to produce graduates with a sound background in physical sciences, suitable for research careers in areas related to nanotechnology. Nanotechnology contextual units have been an integral part of the educational framework developed to achieve this, and our experience to date has indicated that these units have been very successful.

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