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CONTEXTUALISING NANOTECHNOLOGY IN CHEMISTRY EDUCATION

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Abstract

This paper will give an example of a pedagogical approach taken in integrating nanotechnology into a chemistry degree course. In recent years nanotechnology has widely become part of the course content for undergraduate chemistry and physics degree curriculum. How contextualised the delivery of the subject matter may vary. The role of contextualisation of nanotechnology in the delivery of the content is the main focus of this paper, as to date in Ireland and many other countries nanotechnology has not been integrated into many chemistry degree courses but is slowly becoming the case. An evaluative methodology of the pedagogical approach for two introductory nanotechnology courses has been chosen for this study. Pre and post-course testing at a 4th year level and 2nd year level have been carried out and the feedback summarised. The role of visualisation and contextualisation (linking research and industrial applications to the area) will be discussed in relation to learning and teaching nanotechnology. The benefits of using nanochemistry and nanotechnology can be highlighted and this may be linked to an examination of existing applications in everyday life. It is hoped that this paper will stimulate some ideas for academics who may find themselves faced with teaching nanotechnology in the near future.

Keywords: nanotechnology, contextualisation, visualisation, student-based learning

Introduction

Nanotechnology encompasses a variety of subjects such as chemistry, physics, materials science, engineering, biology, and medicine. This ever evolving area is rapidly growing in industry and research and this phenomenon has been realised by third level institutions internationally at an undergraduate and postgraduate level. The need for teaching strategies for the integration of nanotechnology into the curriculum has been recognised in engineering education (Lee, 2005) and in science education due to its multidisciplinary nature. Our challenge as academics is to provide an interdisciplinary approach to teaching nanotechnology and methodologies have been suggested. '*The fundamental objective of nanotechnology is to model, simulate, design and manufacture nanostructures and nanodevices with extraordinary properties and assemble them economically into a working system with revolutionary functional abilities. In order for undergraduate students to face the challenges presented by nanotechnology, the following educational goals should be applied:*

- *Provide understanding, characterisation and measurements of nanostructure properties.*
- *Provide ability for synthesis, processing and manufacturing of nanocomponents and nanosystems.*
- *Provide ability for design, analysis and simulation of nanostructures and nanodevices.*
- *Prepare students to conduct research and development of economically feasible and innovative applications of nanodevices in all spheres of our daily life.*'

(Uddin and Chowdury, 2001).

The focus of this paper will be to demonstrate nanotechnology as an enabling technology in our daily life.

In recent years the traditional chemistry degree programmes in our Institute have included a section of a module dedicated to nanotechnology. In addition, in September 2006, the first enrolment on our new interdisciplinary B.Sc. in Science with Nanotechnology took place. The nanotechnology introductory courses that will be discussed in this paper are not supported by laboratories but this may evolve in the future. Though the courses are short lecture courses they are useful platforms for developing pedagogical strategies for the new more vocational type nanotechnology degree course in our Institute.

The attraction to both students and staff learning and teaching nanotechnology is that it is a new subject that does not have any preconceptions on how it was taught in the past. (Barnett, 2000) The nanotechnology course can be designed with new pedagogical approaches depending on the programmes it is aimed at. Planning the methodology in which this subject will be taught is key to delivering such a perceived conceptually difficult topic.

> *"Planning for learning means that designing the forms of instruction which support learning becomes as important as preparing the content of programmes"*(Dearing, 1997).

Some nanotechnology courses are aimed at physical sciences, engineering and life sciences students. (Chen, 2006) There were two groups surveyed in this paper, the first are 2nd year, of a four year degree in Forensic and Environmental Analysis (***Case study A***) with a class size of 34, facilitated by Dr H. Hayden over 12 lecture hours. The second group, facilitated by Dr C. O'Connor over 6 lecture hours was the 4th year, of a four year degree in Chemical Sciences (***Case study B***) with a class size of 18. Currently the curriculum allows for introductory nanotechnology to be presented at this stage of each programme as part of the inorganic chemistry module but this is subject to change in the future when the courses are reviewed. Both courses are examined at the end of the module by a closed book summative exam.

One example of a pedagogical approach is a team-taught nanotechnology course by a chemist, a mechanical engineer and a physicist (Maleki, 2004). The team mentioned have incorporated the use of web-book modules for teaching nanotechnology in introductory physics, chemistry, and engineering courses. The pedagogical strategy that has been incorporated in the learning and teaching of this introductory nanotechnology course is a 'blended approach' incorporating; (I) Contextualisation, (II) Visualisation, and (III) Student centred-learning which are recognised as good practice in learning and teaching chemistry.

Background

(I) Contextualisation

In order to show students the relevance of nanotechnology within their chemistry curriculum a good place to start is by defining nanoscience and nanotechnology;

> ***"Nanoscience is the study of very small things at the nanometer scale."***

It may be pointed out that this is the scale of large molecules, molecular chains and proteins.

"Nanotechnology comprises of the technological developments on the nanometer scale."

Nanotechnology includes the techniques used to create structures at a size scale below 100 nm, including those used for fabrication of tiny devices in new generations of electronics and computer chips.

The main emphasis of the pedagogical approach has been to focus on contextualising nanotechnology so that the purpose and requirement is apparent. *'The employment of more 'real-life' examples has been identified as a recommendation for the teaching of chemistry following a review of the science curriculum in schools in the UK'* (Belt et al., 2005). The popularity of context-related teaching methodologies in second level has been recognised (Holman and Pilling, 2004; Burton et al., 1995) and this context based teaching does not in the most part continue into the third level Institutes.

A summary of the topics covered in the introductory nanotechnology lectures presented to the undergraduate students are as follows:

(i) The History of Nanotechnology,

(ii) What is a Nanomaterial?

(iii) Why Nanotechnology?

(iv) Buckminsterfullerene,

(v) Nanotubes and Nanowires,

(vi) Quantum Dots,

(vii) Where will Nanotechnology make an Impact?

(viii) Molecular Self Assembly,

(ix) Sol Gel Technology,

(x) Nanoanalytical Techniques (AFM, STM, etc.).

The topics were contextualised by lending current and potential uses. The history of nanotechnology is useful for showing the various milestones from R. Feynman's "Plenty of room at the bottom" in 1959 to the scanning tunnelling microscope (STM) in 1981, the atomic force microscope (AFM) in 1986 and the discovery of carbon nanotubes in 1991. From 2000 onwards nanotechnology initiatives have been launched worldwide. Other topics that are introduced are summarised in Table 1. Each topic that is introduced is constructively aligned with its current or potential applications.

Table 1: Nanomaterials: properties and applications.

Nanomaterial	Properties	Current and Potential Uses in Industry and Medicine
Buckminsterfullerene, C_{60}, 'Buckyball'	▪ Extremely stable, can withstand high temperatures and pressures. ▪ May react with other species while maintaining the spherical geometry. ▪ Ability to entrap other smaller species by doping fullerenes, they can be electrically insulating, conducting	▪ Lubricants, ▪ Polymers, ▪ Toners, ▪ Pigments, ▪ Drug delivery systems.
Nanotubes	▪ Extremely light, strong and flexible, ▪ Can act like conductors, semiconductors or insulators ▪ Electrons move without losing energy inside the nanotubes, which makes them ideal connectors for electrical devices.	▪ Microelectronics - microcircuits, cell phones, computers ▪ Conductive plastic auto body panels ▪ Polymers and coatings ▪ Nanotube resistors ▪ Artificial joint and bone replacement materials ▪ Drug delivery systems ▪ Biosensors ▪ Hearing Aids
Nanowires	▪ Ultra fine glass strands that can be used to guide light, diameter approx 50 nm ▪ Incredibly strong, flexible and smooth ▪ Metallic and magnetic	▪ photonic devices, ▪ optical sensors, ▪ Selective, specific molecular monitoring e.g. detection of cancer
Quantum Dots	▪ Nanoscale objects (1-10 nm) ▪ Contain tiny amounts of free electrons	▪ Used to track DNA molecules in cells ▪ Efficient alternatives to

	▪ Semiconductor crystals that absorb and emit photons of light at specific light waves, from visible colours into infrared. ▪ Dot size determines which colour is absorbed.	conventional lighting sources ▪ Biosensors used to detect agents of biological warfare.

In terms of where the impact of nanotechnology is envisaged in the future the subject matter was discussed under three main headings:

1. Electronics and photonics*:* molecular electronics, miniaturisation of electronics, molecular wires, spintronics, quantum computing, photonic bandgap materials, single photon sources, sensors and detectors.

2. Materials: harder, more corrosion resistant (outdoor piping), hydrophobic coatings/-self cleaning surfaces (kitchen and bathroom surfaces, windows e.g. Pilkington Activ® glass), scratch proof paint (car paint), dirt/bacteria repellent (anti-MRSA coatings, anti microbial paints in hospitals), transparency modulated windows (buildings and cars).

3. Contribution to Society and Health: Biocompatible prostheses, diagnostics, drug delivery, biomedical research tools (labelling, nanotools applied to biomedicine i.e. artificial retina, hearing aids), biotechnology applied to nanoscience and technology (biomimetics).

In terms of the biomedical applications, the emerging applications of nanomaterials in sunscreen and cosmetics as many commercially available products advertise their nanotechnology enhanced protection against the sun or ageing. The role and applications of dendrimer technology as an enabling technology in the area of adhesives and coatings, chemical sensors, medical diagnostics, drug-delivery systems, high-performance polymers, catalysts, building blocks of supermolecules, separation agents was introduced and current examples of PAMAM dendrimers from the literature for example were discussed.

An area that may be useful for initiating contextualisation is to focus on the relevant careers applicable to graduates with an appreciation for nanoscale events. Industries such as semi-conductor, electronic, pharmaceutical, medical device, automotive, food and agriculture are some examples. In this course the current research carried out within the Institute was highlighted, giving project titles to show the diversity of applications that nanotechnology embraces. Nanophysics and Surfaces Group, Physics of Molecular Materials Group, Material Synthesis and Applications Group and the Centre for Research in Engineering Surface Technology are all research groups locally that would work on nanotechnology projects. The DVDs 'Nano: the Next Dimension' and 'Nanotechnology' give further insight into the applications and European research in the area of Nanotechnology, (European Commission, 2003).

(II) Visualisation

"*The essence of nanotechnology is the ability to work at the atomic, molecular and supramolecular levels, in the length scale of about 1 to 100 nm range, in order to create, manipulate and use materials, devices and systems with fundamentally new properties and functions because of their small structures. It includes understanding of phenomena and processes at the nanoscale, and integration of nanostructures along larger scales*" (Roco, 2002). Visualisation of these nanoscale structures and how they are incorporated in macro level applications is the key to bridging the gap from macro to nano. In this study real life examples, molecular models as depicted in Figure 1 and animated DVDs ('Nanotechnology' and 'Nano: the Next Dimension') showing real scientists were employed as visualisation tools. In particular in the later of the two DVDs mentioned the animation of a scanning tunnelling microscope etching a pattern on a surface at the atomic level was very useful to convey the tunnelling effect. Many visuals are also available through a wide range of relevant websites as listed at end of paper. Research has shown how the internet can be a valuable tool in visualisation of nanotechnological materials (Ong, 2000).

Figure 1: Molecular model of a Nanotube and C_{60}.

(III) Student-centred learning

Student-centred learning has been described as flexible learning (Taylor, 2000), experiential learning (Burnard, 1999) and self-directed learning (Gibbs, 1992), hence student-centred learning can mean different things to different people (O'Neill and Mc Mahon, 2005). Lea et al. (2003) summarises some of the student-centred literature as follows;

'the reliance on active rather than passive learning'

'an emphasis on deep learning and understanding'

'an interdependence between teacher and learner' ‘and a reflexive approach to the teaching and learning process’

Harden and Crosby (2000) distinguish the teacher-centred strategies as the focus on the teacher transmitting knowledge, from the expert to the novice, whereas student-centred learning focuses on the students’ learning. In the context of this paper the student-centred learning is similar to that described by O’Neill and Mc Mahon (2005) for the four main strategies employed by the University of Glasgow which are;

(i) To make students more active in acquiring knowledge and skills.

(ii) To make students more aware of what they are doing and why they are doing it.

(iii) To focus on interaction i.e. use of discussion groups.

(iv) To focus on transferable skills.

The nanotechnology course has been delivered to encourage the *‘students to construct their own meaning by talking, listening, writing, reading, and reflecting on content, ideas, issues and concerns’* (Meyers and Jones, 1993). The effectiveness of student-centred learning has been recognised within our School (Mc Donnell et al., 2007) and it is hoped that this will be built upon in future module designs. The transferable skills gained through student-centred learning are invaluable to the graduate such as; research skills, problem solving and scientific communication skills.

Method

To establish a starting point with both groups of students, pre-course surveys were carried out to ascertain any prior knowledge of ‘nanotechnology’.

Pre-course survey

Prior to the delivery of the course both groups were given a short pre-course anonymous survey on hard copy containing the following questions:

1. What does the word nanotechnology mean to you?
2. Give two examples of chemistry and nanotechnology.
3. What are the areas of research in nanotechnology?
4. What are the applications in the real world of nanotechnology?

The students were requested to grade their prior knowledge of nanotechnology on a scale of 0 (never heard of it) to 10 (I have done projects in the area before).

The results of the pre-course survey showed that 80% of the 2nd year class (***Case study A***) had little or no prior knowledge of the nanotechnology subject area. The negative response to the familiarity with the subject matter is depicted in Figure 2. The students are on a Forensic and Environmental Analysis course so the majority of their coursework would have been focussed on general chemistry and analytical analysis.

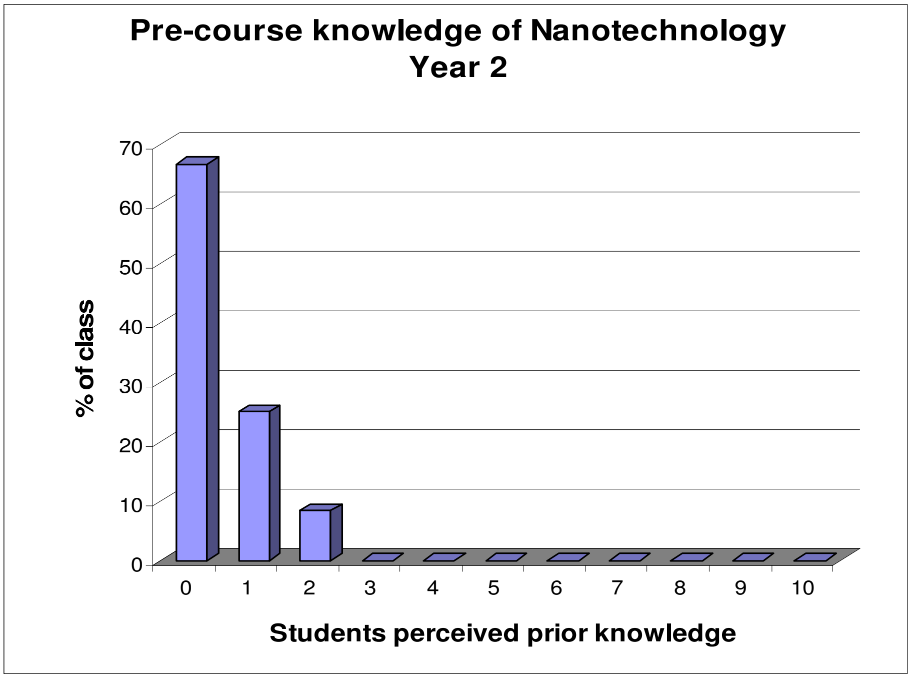

Figure 2: Profile of students' perceived prior knowledge of Nanotechnology at 2nd year. Scale of 0 (never heard of it) to 10 (I have done projects in the area before)

The results of the pre-course survey for (***Case study B***) showed that approximately 63% of the 4th year class had little or no prior knowledge of the concept of nanotechnology. As before the students were requested to grade their prior knowledge of nanotechnology on a scale of 0 (never heard of it) to 10 (I have done projects in the area before) and the graph in Figure 3 depicts the distribution of results. The difference in the spread of results illustrates that the students do not have substantial prior knowledge of the field before the lecture course. The 4th year students have been slightly more exposed to the subject matter in comparison to the second years and this may be attributed to students having carried out individual project work in the subject area in their third year or as summer research assistants in the college.

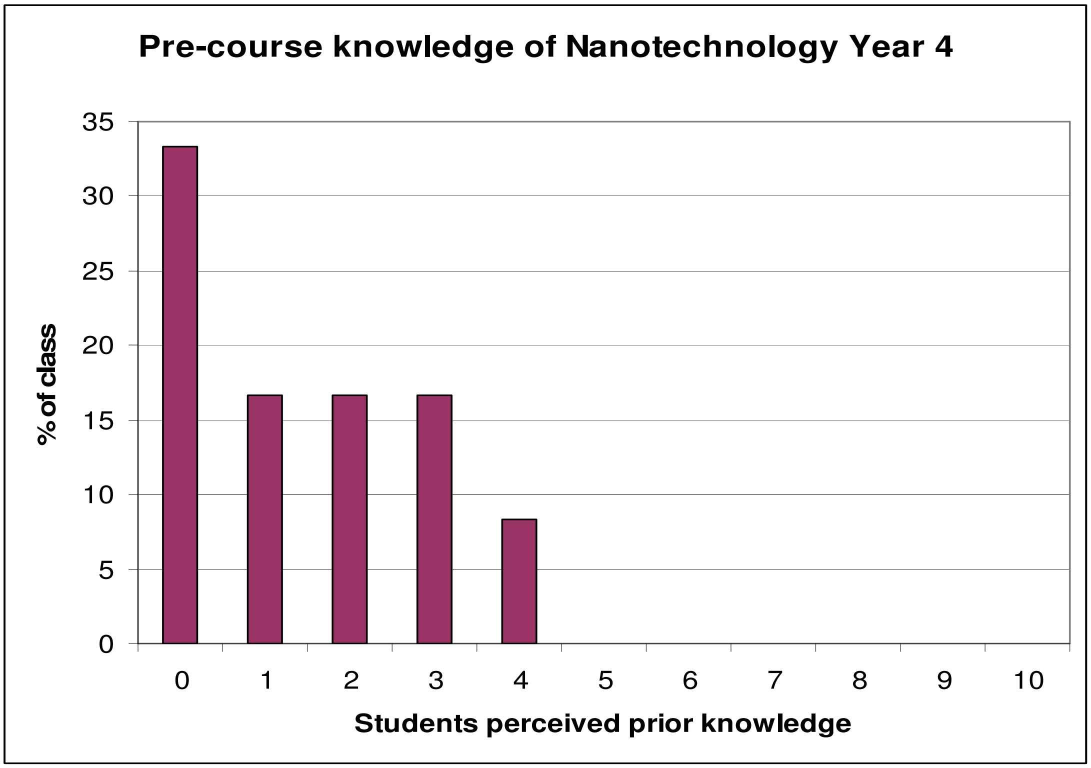

Figure 3: Profile of students' perceived prior knowledge of Nanotechnology at year 4. Scale of 0 (never heard of it) to 10 (I have done projects in the area before)

Course delivery

As mentioned previously the two groups surveyed in this paper are 2nd year, of a four year degree in Forensic and Environmental Analysis (***Case study A***) with a class size of 34, and 4th year, of a four year degree in Chemical Sciences (***Case study B***) with a class size of 18. The delivery of the nanotechnology course for both groups is a 'blended' approach summarised as follows;

Case Study A: Lectures, DVDs with structured question sheets, Discussion Groups, Project: The Publics Perception of Nanotechnology.

Case Study B: Lectures, DVDs with structured question sheets, Discussion Groups, Reflection Question Sheets.

In case study A (the 2nd year course) the students are given formal lectures from the facilitator supported by the nanotechnology DVDs with structured question sheets. The question sheets were designed by the facilitators to encourage engagement and reflection on the material covered in the DVDs.

Examples from the DVD question sheets are:

- *Where does the word Nano come from?*
- *What do you understand by the phrase 'top down' versus 'bottom up'?*
- *Give some real life applications of intelligent materials.*
- *What contributions to society, health and challenges were mentioned?*
- *Give examples of the application of nanoparticles enhancing product efficiency.*
- *Scanning Tunnelling Microscope is based on the Tunnel effect. What is the tunnel effect?*
- *How can an STM etch patterns for electronics circuits?*

The self-directed activity in case study A is a project on the 'public perception of nanotechnology'. The students are put in groups of 3 and asked to design questionnaires, carry out surveys with their friends, families and other students, and must present their findings as a group PowerPoint presentation to their class. They must suggest ways of overcoming misconceptions of nanotechnology they have met in surveying the public.

'*By introducing concepts such as nanomedicine, nanochemistry and nanotechnology devices and how they impact on human health and the environment, students can build on prior knowledge and construct an understanding of the significance of developments on the nanoscale*' (Wu, 2004).

There is a difference between the two case studies in regard to the student-centred learning activities and this was due to the time constraints in the nanotechnology 4th year course which is delivered over 6 lecture hours. In case study B the students received formal lectures from the facilitator supported by the same nanotechnology DVDs with accompanying structured question sheets as employed in case study A. In this case study the student-centred approach was focussed on reflective and discussion based activities rather than a group project. The students were given a series of questions at the end of each class to prompt reflection on what they had learned and to promote learning through discussion for at least 10 minutes at the end of each class. The formal lecture class is based on interactive gapped lecture notes prompting the students to expand on their notes. The students were given time to answer their own question sheets and after they had jotted down their thoughts they were asked to discuss them as a group with the lecturer as the facilitator of the discussion.

Examples of reflective questions are;

'What are the main benefits of working on the nanoscale?'

'Where do you think nanotechnology will make a large impact?'

'Outline the applications of dendrimers in nanotechnology.'

'What does the term self assembly mean?'

The two case studies differ on how they are assessed as case study A has nanotechnology assessed as 50 % of the formal summative assessment inorganic chemistry module paper. Case study B is an optional question worth 25 % of the formal summative assessment inorganic chemistry module paper. 80% - 100 % of the class have answered the optional nanotechnology question each year since it has been put on the paper.

The role of nanotechnology in everyday life was highlighted by contextualising the benefits of nanotechnology. Real life examples of everyday value-added to commercial items such as the innovative self-cleaning surfaces and light carbon fibres in tennis rackets and bikes were incorporated into the content as mentioned are in section (I). In order to evaluate the course delivery post course surveys were carried out on the two groups on an anonymous basis. The questionnaires were designed by the facilitators to prompt Yes/No answers with room for further comments or suggestions. The percentages presented in the feedback and in Table's 2 and 3 are based on Yes/ No responses given by the students. The post-course survey focused on pedagogical aspects such as *Contextualisation, Visualisation, Student-centred learning* and *Engagement*. Each of the learning and teaching mechanisms will be dealt with individually as feedback from the evaluations.

Results of Evaluations

The results of the evaluations have been split into Case Study A (2^{nd} year student group) and Case Study B (4^{th} year student group).

Case Study A

Feedback on contextualisation

The students found using examples of nanoproducts in everyday life e.g. ZnO in sun cream and the manufacture of CPU (Computer Processor Unit) chips by Intel with gaps of 90 nm, made the subject more relevant. The comments from the case study A surveys stated that;

(i) it is better to use examples as it helps aid understanding,

(ii) it is more interesting to study something if you can visualise uses for it, and

(iii) the DVDs were useful for discovering research in the area across Europe.

100% of the students felt that the examples of research, real life applications and industry were appropriate to the content of the nanotechnology course as reflected in Table 2. The particular applied areas of nanotechnology are depicted in Figure 4, the biomedical applications (nanodrugs) are of main interest as opposed to nanoelectronics, nanotubes and nanoparticle coatings.

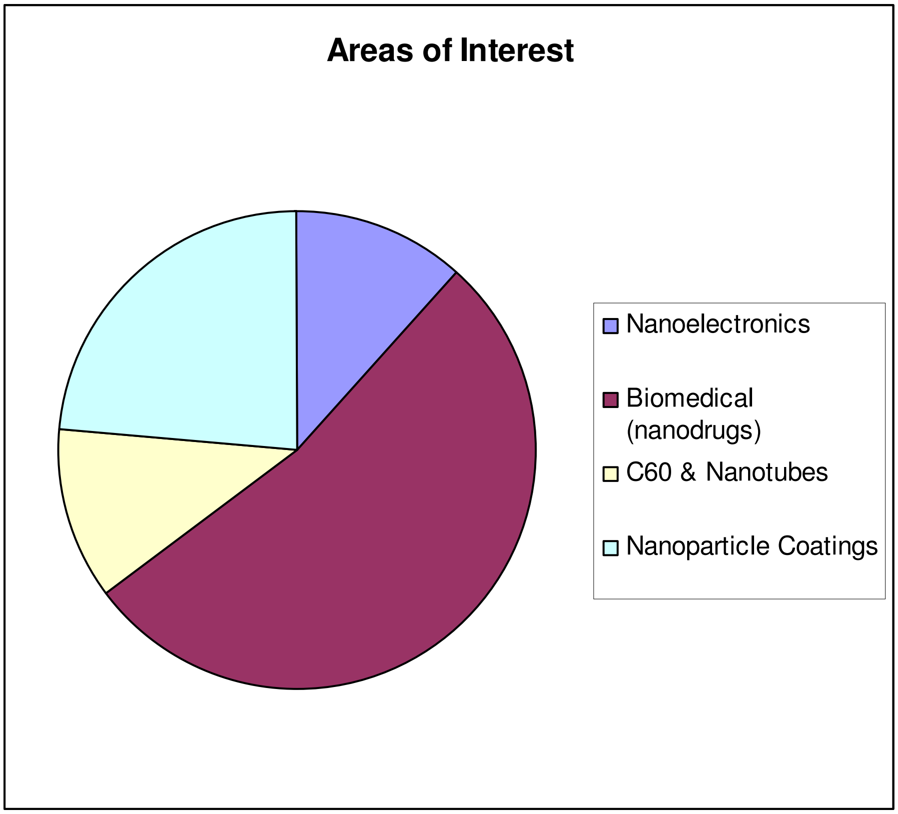

Figure 4: Case study A students' areas of interest in the applications of nanotechnology.

Feedback on visualisation

The students found molecular models of nanotubes, C_{60} and the DVD animations very useful in linking the macro scale to the nano scale. The students commented that they would remember the lectures on nanotubes and C_{60} because they could physically touch and see a molecular model of them while discussing the topics. It was mentioned that the DVD animations gave a better scope of the scale involved. They felt that seeing the animation in 3-D made the concept a lot easier to follow. 100% of the students as shown in Table 2 agreed that molecular models and DVD animations make it easier to visualise the subject matter. The ability to see how nanotechnology was researched across Europe in both academic and industrial centres was a great advantage.

Feedback on student-centred learning

When the students were asked if they could make links from their nanotechnology course to other modules on the programme their response was interesting as shown in Table 2. 62% felt they could, mainly in the areas of ‘physical, inorganic and organic chemistry’ were the modules mentioned. When asked if they would be comfortable speaking about Nanotechnology in the future in an interview situation, 69% replied that they would be confident. When asked if they would be interested in researching in the area of nanotechnology in the future, 62% said they would. On completion of the nanotechnology course 85% felt that they had a greater awareness of nanotechnology research locally in the Institute.

Students' perceptions of nanotechnology

As mentioned earlier the 2nd year students completed a project on the public perception of nanotechnology and they were surprised to find a lot of negative information in the public domain. Feedback ranged from book reviews on the danger of nanoscience e.g. a review of ‘Prey’ by Michael Crichton on nanobots attempting to destroy the world, which is reviewed as being current real science, to an organisation campaigning against it; ETC (Erosion, Technology and Concentration) group formed to fight GM (Genetic Modified) food and are now focusing on the dangers of nanotechnology. Their mission statement on nanotechnology includes “*the ETC group believes that a moratorium should be placed on research involving molecular self-assembly and self-replication*” (ETC Group, 2006). The students concluded that programs should be in place to educate the public on false perceptions, but also more stringent testing of nanomaterials are needed to examine their toxicological effects. By getting students to research the public perceptions of nanotechnology they have come to the realisation that nanotechnology could become the next big scientific scare story unless a clear programme of information backed with scientific data can be initiated.

Engagement

To determine if the students found the course and course material engaging; they were asked to comment on whether the nanotechnology course was interesting on an anonymous basis. The 2nd year students were in general very positive as they felt that there is so much potential in the area of nanotechnology. They commented that it was interesting to find out what nanotechnology is and what it is working towards. The questions asked on the evaluation questionnaires and the percentage positive responses are illustrated in Table 2. As the course is relatively new it was interesting to see the pace and level at which the course was delivered was also amenable to the students.

Table 2: Case study A student post-course questionnaire response.

Survey Questions	Positive response
Could you link nanotechnology to other parts of the curriculum?	62%
Would you be comfortable generally speaking about this area in the future e.g. at an interview?	69%
Would you be interested in carrying out research in the area?	62%
Are you aware of research in this area at DIT?	85%
Was the material delivered at an appropriate level?	100%
Were the handouts easy to follow?	100%
Were the DVD question sheets useful to recap?	100%
Were the examples of research, real life applications and industry appropriate?	100%
Do molecular models and DVD animations make it easier to visualise the subject?	100%

Case Study B

Feedback on contextualisation

The 4th year students recognised the benefits of contextualising the subject area. Figure 5 illustrates the student's particular areas of interest in the applications of nanotechnology. It is no surprise that the biomedical and electronics areas are of interest to the students as these are areas that would concern them more than the applications of nanotechnology in areas such as the innovative surfaces and coatings industry.

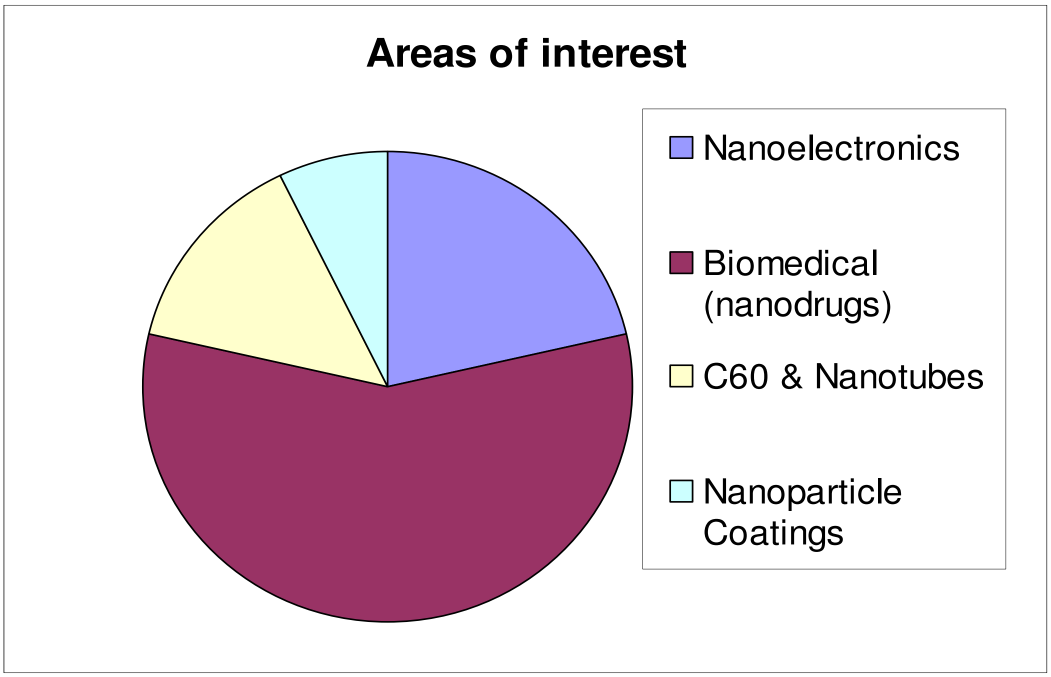

Figure 5: Case study B students' areas of interest in the applications of nanotechnology.

Feedback on visualisation

100% of the students remarked that the use of the molecular models of nanotubes, C_{60} and the DVD animations proved very useful in linking the macro scale to the nano scale. They particularly enjoyed the visuals of self assembly and the Scanning Tunnelling Microscope (STM) which were shown on the DVDs. They enjoyed listening to the world renowned scientists in their own classroom environment.

Feedback on student-centred learning

The nanotechnology course was an introduction to the concept and as part of the learning the 4^{th}

year students were given a series of questions at the end of each class to get them to reflect on what they had learned and to promote learning through discussion for 10 minutes or more at the end of each class. Some of the student comments on the use of the revision sheets are as follows:

"Summarises what is covered in class and is very useful for revision"

"Enhances clarity of lecture before the session ends"

"Main points are highlighted and this helped jog the memory"

"They were useful as you had to at least half pay attention!"

Students' perceptions of nanotechnology course

When the students were asked if they could make links from their nanotechnology course to other parts of the programme their response was that 100% of the class could make links. Some of the student comments are as follows;

"Yes, the tunnelling microscope to quantum mechanics"

"Physical chemistry – electrochemistry, surface chemistry"

"Metal structure bonding and self assembly"

When asked if they would be comfortable speaking about Nanotechnology in the future, 80% of them said they would be confident. They felt they would be able to define what nanotechnology is and would know enough to let an interviewer know they have an idea of the topic. The perceived confidence in the subject matter can be attributed to the weekly discussions with the 4th

year students at the end of class which may have built their confidence. It also may be assigned to the maturity of the final year of degree group.

When asked if they would be interested in researching in the area of nanotechnology in the future, 80% said yes. On completion of the nanotechnology course 69% of the students in this group felt that they had a greater awareness of nanotechnology research in our Institute. Table 3 gives an overview of the responses given in relation to the evaluation questions.

Table 3: Case study B student post-course questionnaire response

Survey Questions	Positive response
Could you link nanotechnology to other parts of the curriculum?	100%
Would you be comfortable generally speaking about this area in the future e.g. at an interview?	80%
Would you be interested in carrying out research in the area?	80%
Are you aware of research in this area at DIT?	69%
Was the material delivered at an appropriate level?	100%
Were the handouts easy to follow?	100%
Were the question sheets useful to recap at the end of class?	92%
Were the examples of research, real life applications and industry appropriate?	100%
Do molecular models and DVD animations make it easier to visualise the subject?	100%

Engagement

The 4th year students were extremely enthusiastic as they felt that nanotechnology is becoming an advancing area of chemistry with very practical applications. They liked the broad base of applications that is encompassed by nanotechnology and expressed that it is *'cutting edge science'*. It was also mentioned that the biomedical applications (as shown earlier in Figure 4) and how it proposes to benefit people in the future were very interesting. 100% of the students felt the course was delivered at an appropriate level and pace. 92% of the students felt that the end of class revision sheets and group discussions were useful. The minority felt uncomfortable discussing their thoughts in front of their peers.

Conclusion

The main findings of this study are that students from both case study A and case study B initially had 80 % and 64 % respectively self perceived prior knowledge of nanotechnology before the courses were delivered. We are sure with time this will not be the case as there is ever increasing media coverage on this topic.

Both case studies received formal lectures supported by the same DVD's and question sheets. The students are very interested in learning about nanotechnology and enjoy its futuristic concepts. Incorporation of contextualisation is the key to facilitating understanding of the concepts using examples from research, industry and commercially available products. Students identified that nanotechnology is an enabling technology and when surveyed the biomedical applications were of most interest to them. The subject matter heightens the enthusiasm of the students as a similar approach has been taken by the academics involved in delivering other modules on the programme to the same group. Contextualised areas of interest seem to be similar although case study A students are slightly more interested in nanoparticle coatings than case study B and in both cases the main interest was in the use of nanotechnology in biomedical applications (nanodrugs).

Enhancing visualisation through the use of 3-D models and DVD animations helped students think on the nanometre scale. Both case studies enjoyed the use of the nanotube and C_{60} molecular models and the use of the two DVDs mentioned in the paper. One of the DVDs is aimed at younger students than undergraduates but the graphics and animations was appreciated by the undergraduate students and assisted their understanding of the concepts in nanotechnology.

The two case studies differed in terms of the year/ stage of the programme in which they were delivered, the contact hours for formal lectures and also the student-centred activities assigned to each case study. Case study A had time to carry out a self-directed group project into the public perceptions of nanotechnology. The students found a lot of negativity in the public domain and presented their findings along with suggestions of how the misconceptions of nanotechnology may be overcome such as information sessions on current research in nanotoxicology. Case study B student-centred activity was focused on end-of class revision sheets followed by group discussions. It was hoped that the revision sheets with group discussions facilitated by the lecturer would promote metacognitive skills and assist students in making links to other subjects in their programme. 100 % of the class could make links from the nanotechnology course to other modules and mentioned specific areas.

80% of case study B said they would feel comfortable talking about nanotechnology in the future in contrast to 62% of case study A. This may be attributed to the maturity of the final year students. Case study B showed a greater interest in carrying out research in the area of nanotechnology, whereas a more reserved 62% of case study A expressed the same interest. Overall, a greater awareness of current research within the Institute in nanotechnology was achieved for both groups. It is hoped that this will be built upon in the form of undergraduate projects and essays. Our next goal is to develop undergraduate nanotechnology focussed experimental laboratories, preferably based on case studies. “Current research topics are ideal case studies for our undergraduates” (Spinks, 2006).

On reflection of the student feedback, linking the ‘macro world’ to the ‘nano world’ may be achieved through models, animation/film and contextualisation in everyday life. The concepts are fascinating when described by scientists such as Prof Jean Marie Lehn and Prof Harry Kroto on DVD. Students find nanotechnology an exciting ‘new’ subject that links other core elements of their curriculum together.

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