DELIVERY OF A NANOTECHNOLOGY COURSE IN A HETEROGENEOUS ENGINEERING ENVIRONMENT

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Abstract *¾ There is currently little nanotechnology provision of a broad nature in undergraduate engineering degrees. This lack of provision should be addressed so as to assure future human resource availability as the sector grows. We have developed a broad introductory nanotechnology course suitable for senior undergraduate cohorts consisting of two or more engineering disciplines. We give here details of how we handle and even exploit the heterogeneous nature of the cohort to enhance learning. We also detail the course aims, learning outcomes, content and assessment.*

Index Terms ¾ Nanotechnology, undergraduate, design, manufacture, testing.

INTRODUCTION

The science that underpins nanotechnology such as quantum chemistry, solid state physics, surface science and molecular biology has long been taught at the undergraduate (UG) level, even if it has not always been labelled as such. Conversely, most nanotechnology provision in higher education is at the postgraduate level. A survey undertaken by use [1] indicates that there are currently only a handful of *broad-based* nanotechnology courses in the world [2-5] and only a single UG degree, which is offered by Flinders University in Australia [6] (see [7] for launch in 2003).

The almost complete absence of nanotechnology provision at the UG level begs the question as to whether it is appropriate or not to offer it at this level. We believe there are at least two good reasons for doing so. Perhaps the most compelling argument can be made by comparing the microelectronics industry, which has employed millions of graduate engineers since its establishment in 1951, with the potentially much larger nanotechnology industry of the future. However, a more immediate reason for providing an opportunity to study nanotechnology at the UG level is to motivate undergraduates to go onto relevant postgraduate courses, thereby ensuring sufficient human resource for the rapidly growing research and development efforts in the field. It is this reason that principally motivates the course described here. However, it is also hoped that it will pave the way to a more comprehensive treatment of nanotechnology in the undergraduate engineering degrees at the University of Edinburgh and, indeed, elsewhere.

The course described here is to be offered in the first instance as an option to senior chemical and mechanical engineering undergraduates, with its offering being extended to the other engineering disciplines at Edinburgh in subsequent years. The students undertaking the course will be taught as a single cohort by staff from across the engineering disciplines. Delivering the course to such a heterogeneous cohort fits very much with the multidisciplinary nature of the subject. However, the fact that students of each discipline will present with different knowledge sets makes its delivery a challenge. We describe here details of the course and how we have sought to not only reduce the impact of the different knowledge sets but, in fact, exploit these differences to enhance learning.

COURSE DETAILS

Addressing the cohort heterogeneity issue

Nanotechnology is often discussed in terms of classes of technology – bionanotechnology, nanoporous materials, nanocomposites, nanomechanics, molecular engineering, NEMS and nanoelectronics for example – and much of the current higher education provision is organized along these lines [1]. This approach tends to reinforce discipline boundaries and is, therefore, not a good basis for a course that is to be undertaken by a cohort consisting of more than one engineering discipline. As illustrated in Figure 1, we intend instead to use the activities common to *all* engineers – design, manufacture and testing – as the basis for the course described here.

Adopting this approach does not, of course, obviate the fact that each engineering discipline is, at least in part, founded on principles and knowledge that are not common to the others. One way of dealing with this is to formally fill the knowledge gaps as part of the lecture course. Limited contact hours and excessive assimilation times makes this impracticable however. Instead, we will fill the gaps as necessary (*i.e.* the science learnt is strictly limited to that

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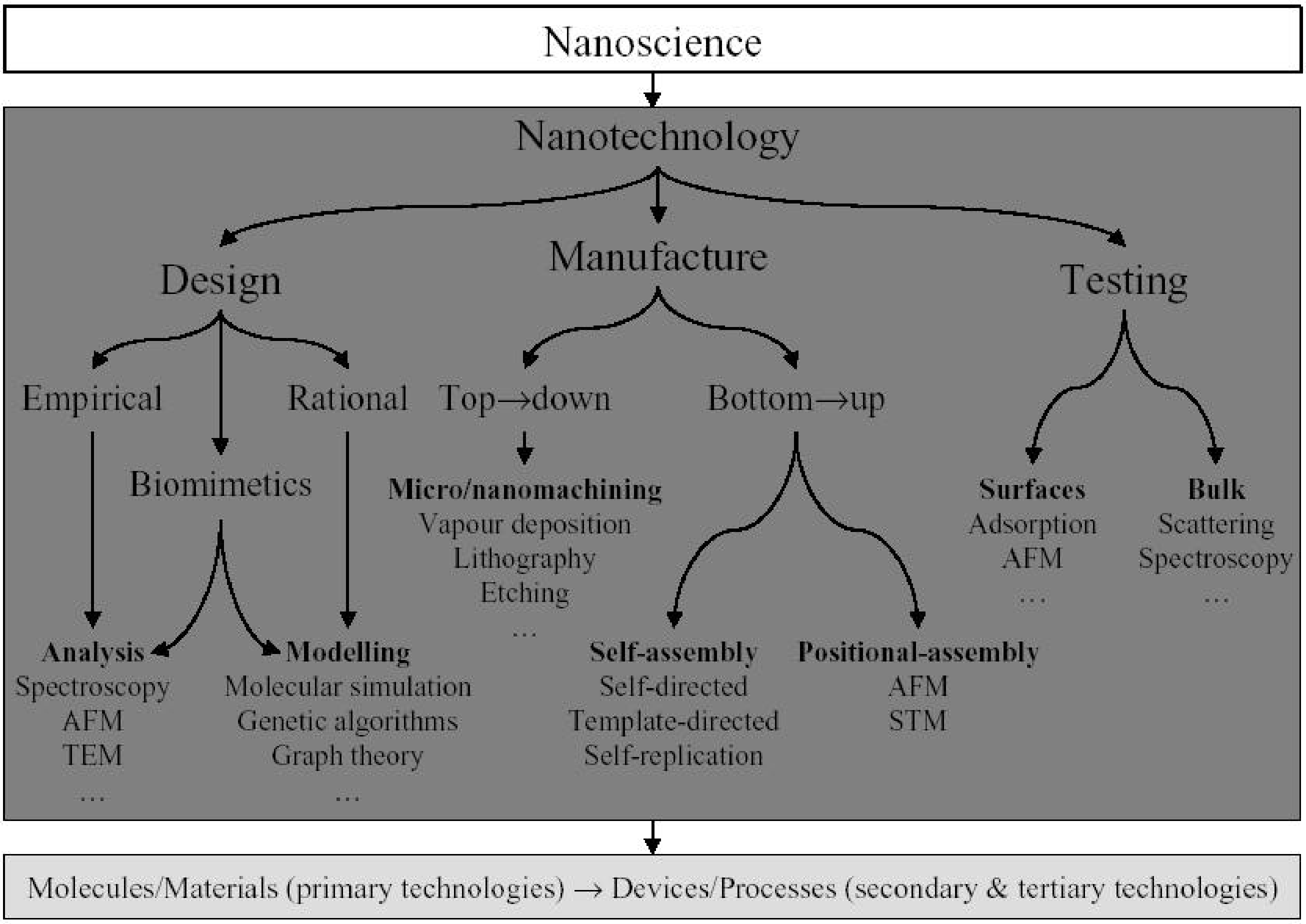

FIGURE. 1.
AN ENGINEERING VIEW OF NANOTECHNOLOGY. THE COURSE FOCUSES ON THE DARK GREY BOX (THE LISTS OF TOPICS GIVEN ARE EXAMPLES ONLY AND NOT EXHAUSTIVE). SPECIFIC NANOTECHNOLOGIES (LIGHT GREY BOX) WILL BE USED THROUGHOUT COURSE TO DEMONSTRATE CONCEPTS.

which is required) by fostering, through assessment, group-based independent learning using heterogeneous groups. This approach exploits the class heterogeneity and the fact that the knowledge gaps for each discipline are different but, on average, similar in extent.

Course Aims

As the student will be largely unfamiliar with nanotechnology, the main aim of the course is to provide a comprehensive introduction to the subject so as to provide a basis for further independent study.

In order to provide some depth in the time available, a second aim of the course is to explore in greater detail one aspect of nanotechnology of the student's choice through self-directed learning. The student will, in consultation with the course organizers, decide which aspect of nanotechnology to explore in greater detail.

Learning Outcomes

On completion of the course, the student should be able to:

- discuss what is nanotechnology and why we should be concerned with it as engineers;
- discuss in general terms a number of current and potential applications of nanotechnology and the underpinning science;
- review specific aspects of nanotechnology to a depth commensurate with their discipline; and
- apply both prior and newly acquired understanding and analysis methods in the nanotechnology context.

Assessment

The first two outcomes will be assessed by asking the students to work in predefined heterogeneous groups in order to build understanding relevant to three specific topics supplied by the course staff, and to then *individually* prepare and submit ~1000 word papers on each topic. The student will then be tested orally on their submissions to ensure they understand, at least to a reasonable extent, the work they have submitted.

The last two outcomes will be assessed by asking the student to prepare and submit an individual in-depth review of an aspect of nanotechnology. It is expected that the student will consult extensively the scientific literature and include consideration of relevant methods of analysis. The review should be ~4000 words excluding figures and analysis. So as to enhance the efficiency of the learning process, the student shall also present the main findings of their review to the rest of the cohort in a 5-minute oral presentation at the end of the course.

Course content and structure

The course runs for 13 weeks total and involves 20 one-hour lectures, 5 hours of "laboratory work" and, on average, a further 55 hours of "other study", which includes self-directed learning and completion of assessments.

The first lecture focuses on a broad discussion of what is nanotechnology and, to a lesser extent, nanoscience. The history of nanotechnology is first considered so as to identify key persons in its development and, more importantly, to demonstrate that nanotechnology means different things to different people. The lecture is concluded with our own, rather broad, definition, namely: nanotechnology is concerned with the exploitation of nanoscale entities and the effects arising from nanoscale-related phenomena in order to develop materials and associated secondary and tertiary technologies that may be usefully employed to advance society whilst making a profit for those engaged in its invention, development and delivery. In line with Drexler [8], this definition makes it clear that nanotechnology is about engineering rather than science. However, unlike Drexler, it does not restrict consideration to bottom-up manufacture (*i.e.* molecular engineering) but, instead, adopts the pragmatic view typical of engineers that it does not matter how a technology is achieved provided it is done in a way that is safe and morally, economically and environmentally sound. It also recognises that size in and of itself is not the key issue in nanotechnology but, rather, the "non-classical" effects that arise from working at the nanoscale.

The second to fourth lectures seek to explain why we should be concerned with nanotechnology at all. This is done by discussing some of the non-classical behaviours that arise when working at the nanoscale level and what we can achieve when these behaviours and the size of nanoscale entities are exploited. The latter are illustrated through the discussion of real and conjectured nanotechnologies. Systems that will be considered include reaction in nanodroplets, bubbles and particles (*e.g.* [9]), adsorption in nanoporous solids (*e.g.* [10]), self-assembly of molecules, nanoparticles and other nano-entities (*e.g.* [11]), nanotribology (*e.g.* [12]) and quantum dots (*e.g.* [13]).

The next five lectures will be concerned with analytical methods for characterization and testing of nanotechnology. These have been broken up into two broad groups: (1) those methods that probe the surface such as, for example, adsorption, STM, AFM and SEM; and (2) those methods that probe the bulk including, for example, NMR, TEM, FTIR, and radiation scattering. The large number of methods that are available to the nanotechnologist means only the basics (*e.g.* principle of operation; what they can determine) will be delivered for the vast majority of the methods. However, a small number of key methods such as AFM, STM and SEM will be considered in detail. The student will be encouraged to learn more about all the methods through assessment-mediated self-directed learning.

The next five lectures are concerned with manufacturing techniques. The first two of these lectures focus on top-down strategies such as etching, micromachining, lithography, vapour deposition and microcontact printing and concludes with a discussion of the limitations of the top-down approach. The final three lectures focus on bottom-up strategies of self-assembly and positional assembly. Once again, real examples from the literature and our laboratories are used to demonstrate each approach.

The final six lectures are concerned with design of nanotechnology. Three main approaches to the design process are discussed: (1) empirical, which relies on heuristics and relatively crude analysis, and is dominated by trial and error and experiment [14]; (2) biomimetics, which reduces trial and error by "borrowing" from nature (*e.g.* [15, 16]); and (3) rational design approaches that rely on simulation methodologies combined with prior experience, which may include that coming from biomimetics, so as to reduce the role of trial and error and experiment (*e.g.* [17, 18]). Real examples from the literature and our laboratories will be used to demonstrate each approach.

In addition to the lectures, the student will undertake five hours of "laboratory work". The first, which is two hours in length, will be concerned with nanofabrication using self-assembly and testing using AFM. The second session, also of two hours length, will involve the use of molecular simulation to predict molecular structures. The final demonstration will involve a one hour tour of the microfabrication facilities at in the Scottish Microelectronics Centre at the University of Edinburgh [19].

THE FUTURE

The proposed course will be delivered for the first time to final year chemical and mechanical engineering undergraduates in the 2002/2003 academic year. Following evaluation, which will be presented in a future publication, it is anticipated that the course will be made available the following academic year to the final year undergraduates of the other engineering disciplines at Edinburgh. The course will also be enhanced at that time to integrate aspects of innovation, synthesis and economics.

In the longer term, it is our hope that this course will lay the foundations for the development of a more comprehensive set of nanotechnology-related courses that will form the basis of nanotechnology "streams" in the various engineering degrees offered at Edinburgh.

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