Nanotechnology Education

A Hearing by the Subcommittee on Research and Science Education,
House Committee on Science and Technology

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Testimony presented by

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Preamble

I have been invited to testify before the sub-committee on the current state of education in nanotechnology within *undergraduate* serving institutions and to offer my opinion concerning ways in which this education can be enhanced at such institutions. This is a particularly important subject at the present time as nanotechnology is without doubt a major global focus where a competitive advantage will be accrued by those nations having a workforce which is broadly educated in nanotechnology. Through research, the US currently has a competitive advantage, but maintaining this advantage will depend on the development of a well-educated workforce that is able to exploit the various research thrusts by realizing commercial products from ideas. In the following, I assess briefly the current status of undergraduate education in nanotechnology and discuss ways of enhancing this by answering the questions posed to me by the Chairman of the Subcommittee, Congressman Baird.

Current Status: Nanotechnology in Undergraduate Education

As a result of the vigorous focus on nanotechnology, underscored by the National Nanotechnology Initiative (NNI), there has been a development of courses and degree programs that involve nanotechnology. The vast majority of these activities are aimed at graduate education, where programs involving MS and PhD degrees in the subject have been established, and courses are included in the offerings in various science and engineering programs. The degree to which nanotechnology has been included in undergraduate education is much less than that at the graduate level, and has involved efforts such as NSF's *Research Experience for Undergraduates* programs at a number of institutions. For example, according to the NNI, there are five graduate degree programs and two associate degree programs (provided in conjunction with research universities) focused explicitly on nanotechnology, but no BS programs are listed. The reason for this lies in the fact that progress in nanotechnology is the result of execution of vigorous research programs. These are almost exclusively undertaken in our nation's major research universities, and hence the immediate fallout regarding education involves graduate programs in these institutions.

Barriers to Undergraduate Nanotechnology Education

In addition to the concentration of activity in nanotechnology being in the research programs of our universities, there are two other major problems that need to be addressed in order to realize curricula that will serve as an attraction to students such that a significant workforce may be developed. Firstly, in general the equipment required for such curricula, for processing, characterization and property assessment of nanomaterials and nanodevices, is currently expensive to acquire and is complicated to operate. For example, it would be necessary for much of this equipment to be operated by an expert, which would increase an instructional budget significantly. Equally important is the cost of maintaining such equipment, again imposing a financial burden on the establishment of an undergraduate program.

The second problem involves, on the part of faculty at a large number of our nation's academic institutions, the lack of experience and knowledge required to develop an undergraduate program involving nanotechnology, especially regarding the operation and maintenance of equipment for either demonstrations in lectures and/or laboratory classes, which are essential in any undergraduate program. In general, the equipment required to develop attractive undergraduate laboratory classes on nanotechnology, including instruments that produce nanomaterials, characterize them and measure their properties, are found in research laboratories and are often rather sophisticated and complex. This lack of familiarity inhibits faculty from fully developing effective and attractive courses in the subject.

It is my understanding that the proposed bill, H.R. 2436, aims to obviate these barriers to permit effective and attractive courses to be developed.

Answers to specific questions:

In the following, I have taken the liberty of reversing the order of questions 2 and 3, because the answer to the second question draws on the answer to the third. I have indicated the original order of the questions.

Question 1: *Please describe current nanotechnology education efforts at the undergraduate level. As new fields emerge in science, how do university science departments merge them into the current undergraduate curriculum?*

I have made reference above to the current state of inclusion of nanotechnology in undergraduate studies, where the main efforts to include nanotechnology in curricula are taking place at the graduate level. Regarding the merging of new fields into undergraduate curricula, generally faculty at major research universities, especially those with research components involving a new technology, will add in an *ad-hoc* manner, content to their existing classes and develop new classes that focus on the given new technology. Such developments will take place at a slower pace at other tier 1 and tier 2 and 3 colleges. As an example, consider the inclusion in undergraduate curricula of a different, but important, novel technological area, namely computational materials science (i.e., the modeling and simulation of the behavior and performance of materials). Having declared this a thrust area of our department at Ohio State, and hiring three new faculty members in this area, a highly successful undergraduate course has been developed. This was not attempted prior to the employment of these faculty members with the appropriate research expertise mainly because the existing faculty did not have the requisite knowledge and familiarity with the subject.

Of course, as a given technology matures, and its body of literature broadens, it is possible for faculty with little initial familiarity with the subject matter to develop undergraduate course material by drawing on this body of literature. However, in the context of the currently proposed House Bill, aimed in part, "to maximize the benefits of nanotechnology to individuals in the United States", it is important to develop the course material at an early stage of the development of this technology and hence indeed maximize potential benefits.

Question 2 (originally question 3): *What types of nanotechnology equipment could be used for educational benefit at the undergraduate level?*

Generally, there are three types of equipment required for study of nanomaterials and/or nanodevices, which are for processing materials and devices, for their characterization, and for measuring their properties. In principle, undergraduate courses on nanotechnology would benefit from the provision of all three types of instrumentation. However, in the following, I will argue that because of constraints of budget, a focus should be maintained on materials characterization, as indicated in the proposed House Bill.

Regarding processing equipment required to produce nanomaterials and nanodevices, this tends to be of a specialist nature and not necessarily commercially available. Where it is available for purchase, it tends to be rather costly, requiring an expert for operation and significant maintenance expense. In addition, the study of a range of nanomaterials and nanodevices would require the acquisition of a number of pieces of processing equipment since a given instrument is usually focused on the processing of a given material type (e.g., a magnetron sputtering device used for deposition of nanoscaled multilayered materials would not be used to grow carbon nanotubes). These issues also apply to equipment required to measure properties and performance of nanomaterials and nanodevices. For example, there is a wide range of properties that in a comprehensive study would be the subject of measurement, i.e., optical, electrical, magnetic, and mechanical, and each of these would require specific instrumentation to make the requisite measurements.

Equipment for characterization offers a number of significant advantages regarding the provision of attractive undergraduate courses in nanotechnology. Regarding the issues raised above, concerning the need for a number of different instruments to process a wide variety of materials, or to measure a broad range of properties, a single instrument for characterization can make observations of a wide variety of materials types. Perhaps most importantly, is the ability to *see* the products of nanotechnology. This ability to *observe* micro- and nano-structures is a key to attracting students to physical sciences and engineering, and, of course, nano-technology. To serve as examples, please refer to the two figures. Figure 1(a) shows an image of an advanced titanium alloy that is used in aerospace applications. It appears to be a simple shiny piece of metal, grey in color. However, when imaged in the scanning electron microscope (figure 1(b)), its rich microstructure is revealed, and it is these nanoscaled features that govern the properties and performance of these alloys. For reference, a human hair is approximately 40μm in diameter. The second example involves the imaging of the eye of a fly in the scanning electron microscope, figure 2(a). Increased magnification reveals finer scaled structure, see figure 2(b). It is the observation of these regarding the development of attractive undergraduate courses.

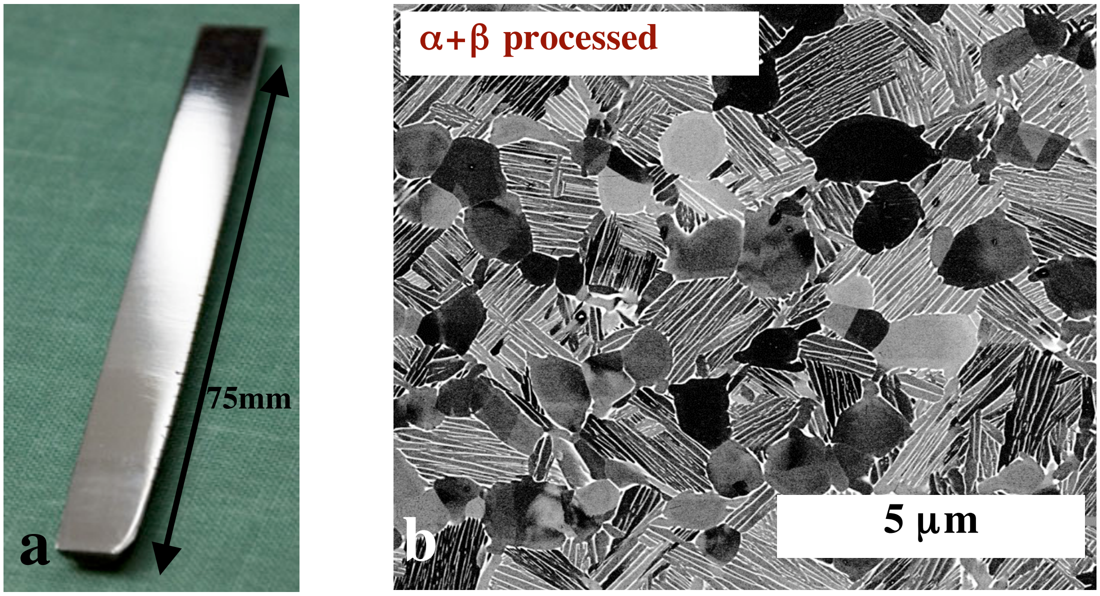

Fig. 1. (a) An image of an advanced titanium alloy captured with a digital camera. (b) The same material observed in a scanning electron microscope revealing microstructural features.

To reveal these nano-scaled features requires the use of equipment with the appropriate resolving power. A number of instrument types may be used, but a most appropriate machine for use in undergraduate education is the scanning electron microscope, largely because of its simplicity of use. This is particularly the case for recently developed table-top scanning electron microscopes, where the operating system and procedures have been very much simplified, and the costs of ownership and maintenance have been significantly reduced. It is because of the impact of effective materials characterization of nanomaterials and nanodevices on attracting students, and the more recent developments regarding ease of use and reduced costs that, in my opinion, materials characterization can be the basis for the development of very effective undergraduate courses in nanotechnology.

Question 3 (originally question 2): *How would a grant program, like the one proposed by H.R. 2436, be used by undergraduate serving programs? At the college level, does the opportunity to work with new technology draw in students who might otherwise have been uninterested in science? Do hands-on experiences offer a unique learning opportunity that is difficult to replicate in a lecture?*

The proposed grant program would be used in two ways to impact undergraduate programs. Firstly, a part of the funding would be used to develop undergraduate educational modules that would include versions for both teachers and students. These modules would be lecture-based courses where experiments involving materials characterization (following my conclusion above) would be included, and also laboratory courses that would be instrument intensive. These developed materials would then be available for use by other tier 1,2 and 3 institutions. Secondly, the funds provided by a grant could be used to acquire a table-top scanning electron microscope, augmented by the provision of PC-based scanning electron microscope simulators, for use in the combination lecture/laboratory modules and the laboratory classes themselves. It is worth noting that at present, university faculty have almost no access to funding to assist in the development of undergraduate courses that would be coupled with in-class experiments, as proposed here, and to acquire the necessary hardware. The proposed House Bill H.R. 2436 would fill an important gap.

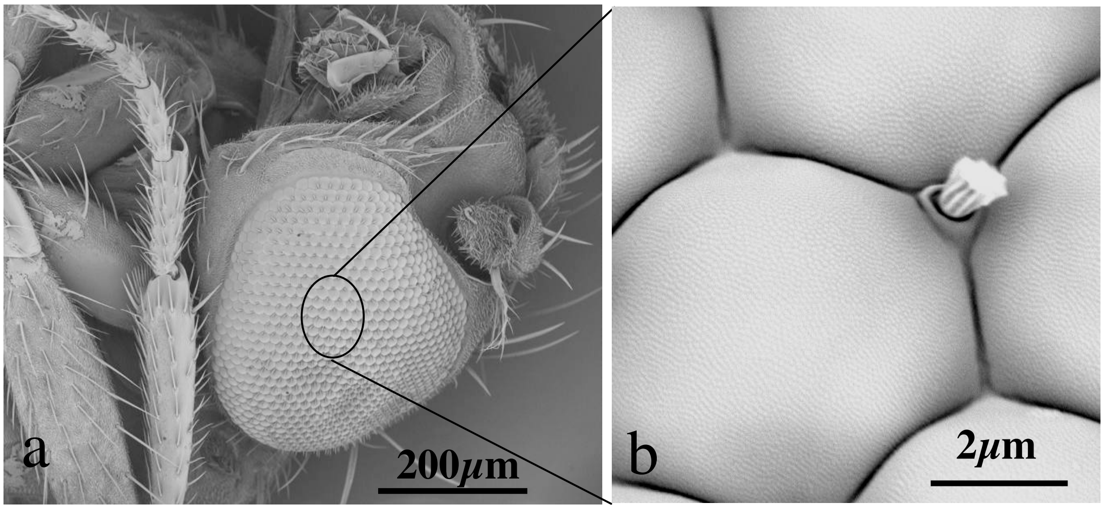

Fig. 2. (a) A scanning electron microscope image of an eye of a fly. (b) Magnified image revealing refined structural details of the eye.

Without doubt, the opportunity to work with new technology acts as a tremendous draw for undecided students. But students tend to be rather clever and have usually done their homework regarding the impact that studying new technologies will have on their careers (particularly regarding employment!), and will make their choices accordingly. Nanotechnology is not only new, but its economic implications are not missed by the students. Promoting attractive undergraduate courses in nanotechnology will lead to increased numbers of students studying science and technology and will provide for a suitably trained workforce.

Our experiences with the provision of laboratory classes in undergraduate curricula are in concert with the notion that hands-on experiences are essential. But, it is important to point out that lecture courses are efficient methods of covering much basic groundwork in a given subject for a significant number of students. However, such courses can be very significantly enhanced by combining lectures with hands-on experiences as I have noted above.