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A Systems view of Nanoscience Education

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The National Nanotechnology Initiative (NNI) Strategic Plan¹ states the following: “*The ability to image, measure, model, and manipulate matter on the nanoscale is leading to new technologies that will impact virtually every sector of our economy and our daily lives.*” At the federal level, the NNI has four main goals, goal 3 of which is relevant to building strong educational resources:

- Goal 1. Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology.
- Goal 2. Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit.
- Goal 3. *Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology.*
- Goal 4. Support responsible development of nanotechnology.

The authors of this note, with support from NSF and their institutions (The Boeing Corporation’s Learning Training and Development (LTD) Engineering Group, The National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT), SRI International’s Center for Technology and Learning (CTL) and Foothill College) conducted a preliminary due-diligence study of course offerings at the community college/lower division undergraduate level to assess the availability and goals of course offerings. The results were combined with the results of three prior survey activities: (1) NCLT workshops conducted by Denise Drane and others; (2) Boeing workshops conducted by Vivian Dang; (3) Foothills College industry survey conducted by Robert Cormia. A secondary analysis was conducted through content research of course syllabi, course outlines of records, and complete program descriptions available on the internet.

This white paper reports on what was learned from the analysis. The analysis allowed us to survey the landscape of nanoeducation and to point to what is missing. We look at *nanoeducation* at the undergraduate level as a system rather than as individual courses or even program offerings. Our objectives are twofold. First, to focus attention to the areas we found lacking and propose solutions. Second, to argue that the infrastructure that the Federal agencies fund for nanoscience research needs to be extended to 7-16 nanoscience education since education is critical to achieving nanotechnology’s societal goals.

¹ National Science and Technology Council. *National Nanotechnology Initiative, Strategic Plan*. December 2004.

We will argue that the educational aspect of the nanoscience infrastructure should provide coherent education and training resources for students, teachers, and the incumbent workforce. This might include problem-based learning experiences in nanoscience application areas, possibly including access to equipment. Education and training should also support the use of the latest learning sciences advances, such as immersive learning technologies, to enhance the science learning opportunities of the students workforce.

NEW WAYS OF LEARNING

Many studies have shown that the traditional instructional methods are inefficient and could benefit from more research-based ways of appropriating advances in technology. In the National Research Council publication *How People Learn*, John Bransford and his colleagues document interesting idiosyncrasies regarding the current teaching methods and their negative effect on knowledge acquisition and transfer. *How People Learn* describes knowledge gained from the application of learning science research to the practices of education. Specifically, the five areas that changed in our conceptions of learning involve the use of memory, the structure of knowledge, better understanding of problem solving and reasoning, metacognitive processes and self-regulatory capabilities and the importance of cultural experience and community participation.

This very brief section should remind the reader that the current methods of science instruction are not ready for either the integration of nanotechnology material or the use of more effective pedagogies related to knowledge transfer. The baseline curriculum model of sequential courses is somewhat inflexible and is not optimal for integrating an interdisciplinary field like nanotechnology. In the background of our discussion of the nanoscience education system is the premise that new pedagogies, including technology-based modeling and simulations, problem-solving practices, and interactively assessing student learning, will make a profound impact on how well nanotechnology courses will transfer expertise and prepare students for the world of practice.

Although this paper discusses nanoscience education, we want to highlight the importance of *basic* science (physics, chemistry, and biology). Nanoscience-specific education rests upon a foundation of these disciplines, whose K-12 curricula may need to adapt to enable deeper learning of modern science. See for example the Atlas of Scientific Literacy (AAAS, 2000) and work on the “physics first” curriculum—basically, atomic and molecular science as the foundation for the study of physics, chemistry, and biology (Lederman, 2000; Tinker, 2000.) A report on major learning goals for the integration of nanoscience concepts and key science concepts that will promote an understanding of nanoscience in high school is being prepared by the authors, and will address this point in great detail (Stevens, et al. 2007).

SCHEMATIC VIEW OF THE NANOEDUCATION SYSTEM

Our analysis indicates that course offerings, including industry and academic outreach workshops, are determined primarily by institutional mission. Not surprisingly, students who do not follow a traditional four year university education with an appropriate technical and research orientation are confronted with a patchwork quilt of experiences:

- In Community Colleges, students learn primarily non-generalizable specifics of a topical area.
- In Universities, students learn primarily topics of research interest for the academic faculty.
- Through education outreach, students and practitioners learn at best fragmentary portions of the field.
- In industrial training, practitioners learn selected topics of near-term relevance.

Students who enter university or four year college with a good preparation in science, and who are likely to continue to higher degrees, are offered a coherent program of studies. But to provide students lacking either such preparation or such degree expectations with a possible coherent nanoscience and nanotechnology education path, attention should be paid to integrating the goals highlighted below. The same needs exist for students and practitioners who want to upgrade their skills, and for the private sector organizations where such students will work.

- For University Academic education, to make visible clear, specific learning goals of courses and programs, so that learners will be able to assess knowledge and skills missing
- For Community Colleges, to acquire and provide more complete awareness or access to cutting edge science
- For Industry programs, access to high value, adaptable materials, oriented towards different application areas
- For Educational Outreach programs, an integrative context to guide the applications of learning.

Our analysis points to a gap between industry needs and education as it pertains to nanotechnology. As we indicated before, students who enter university or four year college with a good preparation in science, and who are likely to continue to higher degrees, are offered a coherent program of studies. The gap we mention is evident when students who are not on track for nanoscience are asked for practical applications of their education within industry. Most engineering students have a solid grasp of theory but cannot effectively apply this theory to the industrial setting; most science majors may have a grasp of the basics of their scientific discipline, but lack the interdisciplinary and design knowledge needed. An immersive laboratory experience that is well integrated with more formal learning would provide students with knowledge and skills that can be easily transferred to the workplace.

We identified two general strategies that could provide for these needs in an efficient manner, and are an extension of the existing network of nanoscience and technology researchers: (a) support for a network of nanoscience education practitioners and researchers, associated with the NNIN but focused on a more general learner population and including experts of the use of technology in learning science pedagogy, and (b) a masters-level program, designed by both academic and industry experts, that uses problem-based learning methods to provide students with experience in applying general principles to specific sub-areas of nanoscience.

These needs and strategies are structural, not idiosyncratic and limited to the nanoscience areas, since they arise from the inherent goals and limitations of the organizations that provide the education and training. Thus, it is unlikely that all will be solved by independent researchers, educators, industries, or developers. The more effective and sustainable solutions require networked communities that coordinate activities, and could arise locally from education centers that serve regional needs, accumulate expertise and network local providers.

DUE DILIGENCE STUDY SYNOPSIS

Understanding national and state level needs in regards to nanotechnology education for an educated workforce has led to industry and academic interest in partnering towards the common goal. With this interest in mind, the due diligence study mentioned earlier was conducted to obtain more compelling knowledge and understanding of the objectives of current courses, workshops, facilities, and certificate programs. This study attempted to reveal where needs are being met and where further work is needed. Its results could help direct current and future efforts charged with providing a stronger nanotechnology education for academia and the workforce.

Course Analysis

More than 400 courses were identified from several universities that fit into the categories of materials science, polymers and composites, fabrication, and characterization. Larger engineering programs, i.e., ones that offered degrees in materials engineering, usually included three to five courses related to basic materials science, fabrication, and characterization, often including introductions to polymers, semiconductors, and basic characterization techniques. Additionally, over 100 individual courses were identified relating to nanotechnology and nanostructured materials.

Competency Analysis (COR'S)

The competency analysis was based upon the Knowledge, Skills, and Abilities (KSA) model. We define *ability* as the product of knowledge and a skill, in the context of work (to prevent the confusion with innate abilities, we will use the word “*capability*” in the remainder of this document). The notion of *competency* arises when a capability that arises from abstract (formal) knowledge and a work skill adds benefits from a large experience (practice) base. Thus, a capability practiced in the context of work over a period of time is defined as a competency. At this point, the practitioner can apply his knowledge and skills to solve new and unforeseen problems.

Academic Competency Needs

Both the analysis of courses and the interviews with faculty suggested that it is difficult to produce core competencies in engineering and design related to material properties in four-year engineering programs. Advanced graduate work, often in a single focused application, provides a much better opportunity for building these competencies. Courses concentrating on nanoscale applications of materials science and engineering were found infrequently. A majority of the nanoscience related courses were graduate level courses. Only the most select universities participating in nanoscience research provided nanoscience courses that were accessible to undergraduate students.

An increasingly large number of ‘hands-on’ workshops are being offered in materials characterization, but we found that they tend to be very general in approach, even when they have a materials focus. These workshops do supply valuable skills-oriented learning for workers employed in engineering fields using advanced materials. Without a solid foundation in engineering, and recent ‘On the Job Training’ (OJT) in materials science, these workshops probably would not be effective in providing the advanced skills desired by aerospace and other high tech industries.

Industry Competency Needs

Recent results of industry surveys administered at the Boeing Company clearly showed that aerospace engineers are involved in the design, engineering, manufacturing, and characterization of high-performance polymers and composite materials. The web-based survey of 40 engineers from across the Boeing enterprise, as well as over 20 nanotechnology companies from around the United States, suggested that several key areas of competency defined the knowledge, skills, and capabilities of these engineers: materials science, materials characterization, polymer and composite material fabrication and characterization, and manufacturing process engineering. In each of these categories, several key competencies were either gained or enhanced through on the job training.

SUMMARY AND RECOMMENDATIONS.

The four broad needs in our admittedly preliminary study are:

- Community Colleges need access to the *interdisciplinarity, design orientation and modeling approaches* of modern science
- Universities need to make visible and clear the *specific learning goals* of their courses and correlate them with the *interdisciplinary skill, knowledge and capabilities* that industry uses.
- There are no appropriate assessment methods to gauge student understanding of the new and often counter-intuitive concepts that are the bases of useable nanotechnology knowledge.
- There are no efficient mechanisms for developing competencies or assessing skills

The most significant gap found, in our view, is the following:

- Universities provide students with *general* knowledge while industry needs that knowledge *applied to specific contexts*. These contexts cover in general a broad range of application areas that cut across industries. There is a need for mechanisms such as practical courses and laboratories that provide university graduates with the experience of applying *general* knowledge to *specific contexts*—what educators call problem-based learning.

Filling this last gap requires long-term collaborations among academic and industrial practitioners. We could start by identifying a few cross-cutting nanoscience areas where such applications-oriented problem-based learning can occur. The areas of emphasis of the NNI could serve as a focus for selecting the applications so that they respond to more than local industry needs.

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Literature

American Association for the Advancement of Science (2001 and 2007). Atlas of Science Literacy. Washington, DC: American Association for the Advancement of Science.

Bransford, John D. *How People Learn: Brain, Mind, Experience, and School*. The National Academy of Sciences. 1999.

Bransford, John D. *Preparing People for Rapidly Changing Environments*. Journal of Engineering Education. Guest Editorial. January 2007.

Cowan, K. and Gogotsi, Y. *The Drexel/UPenn IGERT: Creating a new model for graduate education in nanotechnology*. The Journal of Materials Education. Volume 26. 2004.

Department of Defense. *Defense Nanotechnology Research and Development Programs*. May 08, 2006.

Fonash, Stephen J. et. al. *Education and Training Approach for the Future Nanotechnology Workforce*. IEEE. 2006.

Hardcastle, Alan. *Manufacturing in Washington State 1990-2002: Trends and Implications for the Industry and State*. Washington State University. December 24, 2002.

- Lakhtakia, Akhlesh. *Priming pre-university education for nanotechnology*. Current Science. Vol. 90. No. 1. January 10, 2006.
- Lederman, L. (2001) Revolution in Science Education: Put Physics First! Physics Today, September issue.
- Merzbacher, Celia. *Nanotechnology and Competitiveness*. 2006 Micro Nano Breakthrough Conference. July 25, 2006.
- National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. The National Academies Press. Washington DC. 2004
- National Science Foundation. Societal Implications of Nanoscience and Nanotechnology. NSET Workshop Report. March 2001.
- National Science and Technology Council. *National Nanotechnology Initiative, Strategic Plan*. December 2004.
- Roco, Mikhail C. and Bainbridge, William Sims. *Nanotechnology: Societal Implications – Maximizing Benefit for Humanity*. Report of the National Nanotechnology Initiative Workshop. December 03, 2003.
- Stevens, S., Shank, P., Sutherland, L., & Krajcik, J. (2007). Big Ideas in Nanoscience. Unpublished document, University of Michigan, <http://www.hice.org/projects/nano/index.html>.
- Tinker, R. (2000). Atomic-scale models: The key to science education reform. *The Concord consortium*, 4, (1), Winter. Retrieved August 18, 2005, from <http://www.concord.org/newsletter/2000winter/atomic-scale.html>.
- Tinker, Robert et. al. *Nanoscience and the New Secondary Science Curriculum*. The Concord Consortium. November 05, 2006.
- Washington Nanotechnology Initiative. *Preparing Washington's Companies to Excel in the Next Technology Transformation*. January 2005.