Overview of Education and Workforce Development in Nanotechnology

Introduction

Nanotechnology is a scientific and engineering enabler that cuts across many applications. As such, it offers numerous opportunities for advancing the economic value and impact of new U.S. technologies in diverse business sectors. The global market value for products incorporating nanotechnology was about $30 billion in 2000 (Roco, 2011). That increased to $731 billion in 2012, and the global value of nano-enabled products, nano-intermediates, and nanomaterials is forecasted to reach $4.4 trillion by 2018 (Lux Research, 2014). As the market expands, the number of jobs needing different skill levels in nanotechnology will increase. Thus it is essential that a sufficient supply of qualified workers be developed to fill that need. To train students that can enter such a workforce as technicians, an increasing number of education programs have been established in community or technical colleges around the country (National Nanotechnology Initiative, 2013). This overview describes how nanotechnology can be taught in different types of programs at these colleges, and how a suite of basic skill set standards have been established to provide teaching guidelines as well as a basis for uniformity in the qualifications of program graduates.

Types of Education Programs

In recent years, a large number of programs that focus on nanotechnology education at the undergraduate level have been established in the United States. Many of these programs were set up with the assistance of federal and state funding, and have a main objective of producing graduates from two-year colleges that can enter the nanotechnology workforce as technicians or engineering assistants. Since nanotechnology education has traditionally been geared towards advanced degrees, this emphasis on the entry-level worker addresses the need to develop a balanced workforce that encompasses the entire skill spectrum.

These education programs typically offer a two-year associate degree or a certificate of completion majoring in nanotechnology. The students are required to successfully complete a core set of courses that cover various key aspects of nanotechnology. The certificate option takes less time to complete and is usually taken by students that already have some college education or are in the workplace, and are seeking to learn new skills or update their current ones.
There are also programs at two-year colleges that offer associate degrees with more established majors such as Electronics or Engineering Technology, and programs at four-year colleges that offer baccalaureate degrees in traditional science, technology, engineering, and mathematics (STEM) fields. Students in these programs take only courses focused on certain aspects of nanotechnology (e.g., device processing or material characterization). This approach sometimes offers a college a higher enrollment for these courses, since typically there are a larger number of students with established STEM majors.

Finally, there are programs at two-year colleges that offer only an introductory course in nanotechnology or just add select nanotechnology topics to existing STEM courses. In most cases, such a scope is dictated by one or more of the following conditions: (1) the program is just starting up; (2) funding for the program is limited; and (3) the nanotechnology industry in the college’s area has not developed to the point that a steady supply of technicians is needed.

Within the different approaches described above, there are also variations in curriculums that have been made by colleges to better match up with local and regional industry needs. Given the diversity in scope and location for the various education programs across the country, it is beneficial to colleges, students, and industry to establish a foundational set of standards for use in the education of the U.S. nanotechnology workforce as defined in this overview. This provides a basis for uniformity in the qualifications of graduates from these educational programs. Details on these standards are given in the next section of this overview.

**Standards for Education and Workforce Development**

During the last few years, a standards development team has been working with ASTM International (ASTM, [http://www.astm.org](http://www.astm.org)) to establish a suite of standards for use in the education and development of the U.S. nanotechnology workforce. The team is comprised of staff members from national and regional centers funded by the Advanced Technological Education (ATE) program of the National Science Foundation (NSF), and focused on the creation and support of nanotechnology education programs. These centers include the Nanotechnology Applications and Career Knowledge (NACK) National Support Center ([http://www.nano4me.org](http://www.nano4me.org)), Seattle’s Hub for Industry-driven Nanotechnology Education (SHINE, [http://www.seattlenano.org](http://www.seattlenano.org)), and the Nano-Link Center for Nanotechnology Education ([http://www.nano-link.org](http://www.nano-link.org)).
The aforementioned team began the standards development process by defining a set of key subjects and technology areas relevant to nanotechnology, and then establishing a set of basic skills or knowledge considered as being important within each subject or area. The components for each skill and knowledge are selected from inputs provided by nanotechnology educators and industry professionals, then grouped into individual documents for specific subjects or technology areas. Each document, formatted in the template for an ASTM standard, is reviewed by industry representatives affiliated with the ATE Centers and by other subject matter experts including educators teaching nanotechnology. After any revisions necessitated by this review, the formal process to establish a standard is initiated.

A document is first registered in ASTM Technical Committee E56 on Nanotechnology (http://www.astm.org/COMMITTEE/E56.htm), under Subcommittee E56.07 on Education and Workforce Development (http://www.astm.org/COMMIT/SUBCOMMIT/E5607.htm), as a work item. An ASTM Collaboration Area may be established to facilitate on-line discussion and further revision of the work item. At the appropriate time, the E56.07 Chair will initiate and conduct a subcommittee ballot on the work item. The ASTM standards development process is unique in that, if there are one or more negative votes on a ballot, the comments must be addressed and the standard must be re-balloted if any technical changes were made. Once the work item has been successfully balloted at the subcommittee level a full E56 committee ballot is initiated and conducted, and the procedure is repeated until all negative votes have again been addressed satisfactory. This process aids in the refinement of the document, and ensures an industry-accepted consensus view is achieved before a standard is approved and published by ASTM. Additional details about the process can be found in the Regulations Governing ASTM Technical Committees (http://www.astm.org/Regulations.html#s10).

The standards development team has thus far identified a set of key subjects and technology areas relevant to nanotechnology that can be grouped into six standards; four of these have already been published by ASTM (see below). The remaining two proposed standards are under development, and are expected to be approved and published by the end of 2016 or in early 2017.

* **ASTM E2296** Standard Guide for Workforce Education in Nanotechnology Health and Safety
* ASTM E3001 Standard Practice for Workforce Education in Nanotechnology Characterization
* ASTM E3034 Standard Guide for Workforce Education in Nanotechnology Pattern Generation
* ASTM E3059 Standard Guide for Workforce Education in Nanotechnology Infrastructure
* ASTM E3071 Standard Guide for Nanotechnology Workforce Education in Materials Synthesis and Processing
* WK56677 Proposed Standard Guide for Nanotechnology Workforce Education in Material Properties and Effects of Size

Each standard contains a list of key topics relevant to the subject matter that is the focus of the standard. Within each topic, important components of that topic are also provided. For example, ASTM E3034 lists significant methods for pattern generation relevant to the education of a workforce in nanotechnology. Significant sub-topics specific to each method are also included. It is understood that additional topics or sub-topics may be added on an as-needed basis or during the periodic revision of a standard in order to remain current with this ever-evolving technology.

To provide a comprehensive education of the subject matter covered by a specific standard, it is recommended that all topics and sub-topics be included in the relevant courses. The only exception at this time is in the area of characterization (ASTM E3001). Given the large number of characterization methods applicable to nanotechnology and the time constraints associated with a course in an undergraduate program, that standard only specifies a certain number of methods be selected and taught.

Colleges with nanotechnology education programs can make use of these standards in a number of ways. For those offering a degree or certificate of completion majoring in nanotechnology, the recommendation is to require students to complete courses on subjects and technology areas covered by all six standards. This will ensure broad coverage of the key fundamentals in nanotechnology. For the sake of flexibility, detailed design of the curriculum is handled by the educators in each program so that different levels of emphasis can be placed on
various topics to address local or regional industry emphasis. Programs can also teach additional topics within each subject or technology area as needed.

Other colleges can offer courses that cover only topics in one or more of the six standards (e.g., a course on characterization or infrastructure for nanotechnology). Select topics can also be picked and added into existing STEM courses (e.g., properties and behaviors of nanomaterials in a chemistry course). This last case can serve as an initial step to developing a course that eventually conforms to the specific standard.

**Future Developments**

**Updates and New Standards.** At this time, the six education standards described above provide guidance for covering the foundational knowledge deemed necessary by the nanotechnology industry for its workforce education and development programs. However, given the evolving nature of nanotechnology and the associated business needs, the standards will be updated as necessary, in addition to ASTM’s mandatory five-year review requirement. Further, additional education standards will be developed to cover other aspects of nanotechnology as needed.

**Stackable Personnel Certificates.** The logical next step after the suite of education standards has been established would be the development of performance-based assessments whereby successful participants can earn, through ASTM, industry-endorsed stackable credentials in nanotechnology. To this end, ASTM will team with the NACK Support Center and its partners to develop a set of six stackable Personnel Certificates that correspond to the six education standards. A certificate can be obtained by successfully passing an exam developed specifically for the assessment of the relevant knowledge and skills.

These Personnel Certificates will provide employers with a basis for evaluating skills and qualifications of current and future employees. The Certificates allow individuals from anywhere who have taken nanotechnology workforce skill-set courses or have gained the relevant knowledge through work to be judged equally. The certificate holders will also be able to differentiate themselves from others in their profession and advance their careers.

ASTM and the NACK Network will convene a Technical Advisory Committee (TAC) to establish the Personnel Certification Program structure, exam questions, and efforts to disseminate information about the Program. Members of the TAC will include representatives from academia, government and industry. The targeted timeframe for the widespread availability
of all six exams is Spring 2018. Participants can earn from one to six individual certificates in any sequence.

References


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