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Educational Needs for Personnel in Nanotechnology: Core Competencies for Technicians

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Nanotechnology is a relatively new and growing area that is developing into applications involving a wide variety of processes and products. While scientists and engineers are able to provide the basis for these applications, future progress will require the education of technicians to develop, maintain and and operate equipment, and to translate process development into production. This paper presents the results of a survey of nanotechnology professionals focused on the competencies these technicians will need to have to adequately function as technicians in the nanotechnology area. With these competencies understood, educational providers will have sufficient information for the development of needed curricula, both basic and applied. Current curriculum sources are discussed and several sources are provided. The results of this study indicate that a broad base of education is needed, while specific applications may require training in specific knowledge and processes technologies.

Keywords:

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1. INTRODUCTION

Personnel working in nanotechnology, like other scientists, engineers and technicians, require a fundamental set of understandings and abilities. These include knowledge of basic workplace skills, skills in applications of chemistry and physics, and specific abilities related to research, development and device production. The goal of this competency study is to lay the groundwork for an understanding of the needs of the technical personnel who will work in the nanotechnology area as it develops. This will provide guidance for educators who design programs and curricula as the field grows in terms of the scope of its technological relevance, and as it expands in terms of its reach within out society, as discussed by Roco (2003).

At present, many personnel working in the nanotech area are scientists or engineers who have been educated in science or engineering and who have learned techniques needed for nanotechnology product development in industry or in a university laboratory. However, as the nanotech area grows and applications increase, it will be necessary to broaden the scope of personnel with capabilities to carry out basic processes utilized in nanotechnology research, development and production. Specifically, there will be a need for technicians to carry out both basic and advanced processes related to everything from photolithography to thin film deposition and self-assembly of particles, as well as production of products. The focus of this study is on technicians, although many of the skills needed apply equally to future scientists and engineers.

2. BACKGROUND AND DATA COLLECTION

Core competencies are skills needed by individuals or organizations to successfully deliver value to the customer. In the case of technological employees, core competencies relate to the specific set of skills needed by the employee to successfully carry out their jobs, be they in manufacturing, design, communications or administration. The background and use of competency studies has been outlined by several authors (Campbell and Luchs, 1997; Sanghi, 2007). Manufacturing skill standards have been developed by several organizations (Manufacturing Skill Standards Council, 2006; Manufacturing Technology Advisory Group, 1999), and more specific studies of core competencies have been compiled in several technology areas, including studies of materials technologies by the authors (Mott, 2007) and of marine technologies (National Resource Center for Materials Technology Education, 2012). Because of the specific technological needs of many of today's specialized fields, it is important that focused consideration of competencies be developed

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in each field to assist educators with education in those areas.

To develop a broad understanding of the technical needs of the nanotechnology area, the authors first conducted a competency survey of professionals working in nanotechnology in industry and university. An initial report on the data collected was published on the Internet in December 2010 (National Resource Center for Materials Technology Education, 2010). This paper is based on these survey results, along with additional input and validation developed during 2012 through discussions with colleagues working in various aspects of nanotechnology. This validation was undertaken to ensure that the trends found in the original data provided the appropriate base for educational development in this growing and rapidly expanding field.

This survey was undertaken based on requests from colleges wanting to develop educational programs in nanotechnology for technicians and other technical personnel. The survey was managed by the National Resource Center for Materials Technology Education and utilized processes based on the literature and on the authors' experience in their earlier surveys of technician needs (National Resource Center for Materials Technology Education, 2012).

For consistency, data were gathered in broad "Competency Concentrations," which are general areas of abilities, shown in the following tables in **bold**. These competency concentrations were then divided into "Performance Indicators," which focus on what technicians must be able to do in specific situations. Ratings shown relate to each specific performance indicator and are averaged over all respondents for that indicator using the scale 1 = vital, 2 = relatively important, 3 = desirable, and 4 = relatively unimportant.

Survey responses were requested from 198 professionals in the U. S. and abroad utilizing a listing developed of those contributing to the literature in 2009. Responses were received from 38 individuals, 32 of which were currently operating in the United States. This corresponds to a 19 percent response, a rate that may be consistent a reasonable rate of response for valid data (American Association for Public Opinion Research, 2008). From the respondent data in Table I, the distribution of respondents is seen to vary considerably by size of program, product area and area of work. For this reason, it is concluded that the breadth of applications used, job responsibilities and areas of interest of the respondents provide a good cross section of the industry at present. Since this area and its applications are growing rapidly, these results can only be considered as a starting point for educational programs in nanotechnology. As noted below, additional data was obtained to ensure the general validity of these data.

Table I. Information on survey respondents.

	% respondents
1. Size of research program at your location (38 respondents)	
Small, under 50 employees	53
Medium, 50 to 500 employees	32
Large, over 500 employees	18
2. Your primary work emphasis (30 respondents)[a]	
Post-secondary faculty or student	40
Researcher in industry or university	40
Supervisor in device manufacturing	13
Supervisor in product R and D	10
Supervisor in process R and D	7
Other	27
3. Your product area (24 respondents)[a]	
Materials research	50
Electronic devices	8
Medical research	29
Photonics	21
Medical devices	17
MEMS	17
Surface engineering	13
Other	58
4. Length of service in this field (36 respondents)	
Less than 5 years	22
Between 5 and 10 years	17
More than 10 years	61

[a]Multiple responses allowed.

3. KNOWLEDGE NEEDED BY TECHNICIANS IN APPLIED CHEMISTRY AND PHYSICS

To develop a base line on the education needed by a technician to function in a nanotechnology career, the study focuses initially on basic science. A series of questions were asked regarding specific basic knowledge areas in applications of physics and chemistry. This section of the survey was rated by 29 or more of the respondents. Ratings from all respondents were averaged to provide the ratings shown in the tables that follow. Eighty-five percent of the responses were in the range 1 to 2.5 and are reported and discussed here.

Applied chemistry topics that received ratings that averaged between 1.0 and 2.5 in the survey are shown in Table II. The results indicate the vital nature of handling and understanding chemicals and of chemical safety. Also needed is the ability to read and understand basic chemical nomenclature, along with an ability to apply the scientific method in the lab and related situations. Other areas of note include being able to compare organic versus inorganic chemicals and preparing etching solutions.

Table III shows similar data for applied physical science performance indicators. Results indicate the importance of applying appropriate units, correct use of weight versus mass, demonstrating an understanding of metrology and a wide variety of areas focused on processing and materials behavior.

Table II. Applied chemistry performance indicators showing average ratings for each indicator.

	Rating
Apply Safe and Environmentally Appropriate Methods to Chemical Handling	
Demonstrate safe handling of acids, bases, flam. liquids, cryo-fluids and compressed gasses	1.1
Apply safely the information available in Material Safety Data Sheets	1.4
Apply knowledge of chemistry and environmental safety including waste disposal and recycling	1.3
Classify flammability hazards of solvents such as flash point and explosive potential	1.5
Demonstrate understanding of interactions of science and technology with society	2.4
Demonstrate Knowledge of Chemistry Fundamentals	
Read basic chemical compound abbreviations, e.g., HCl as hydrochloric acid	1.2
Demonstrate knowledge of chemical symbols and the periodic table of the elements	1.6
Demonstrate understanding of chemical concentrations and what they mean	1.4
Explain the importance of material compatibility	1.7
Apply the scientific method in a laboratory and in a variety of technical situations	1.5
Describe the fundamental nature of liquids, solids and gasses	2.0
Describe and compare the nature of organic and inorganic chemicals	2.4
Prepare an etching solution	2.4

Note. Rating Scale: 1 = vital; 2 = relatively important; 3 = desirable; 4 = relatively unimportant.

4. COMPETENCIES IN SPECIFIC PROCESSING AND OPERATIONS AREAS

In rating the importance of specific processes and operations, respondents were asked to provide an overall rating of important for each of 20 process, synthesis and analysis methods. These ratings are shown in Table IV. With a rating below 2.5, eighteen of the methods were considered to be important, with the most important being photolithography, thin film deposition and optical and laser analysis. It should be expected, however, that the priority for specific processes or techniques will relate to the specific applications of a particular organization, operation or company, and that other methods not on the list will be highly important in specific cases; this may be the explanation for a smaller numbers of respondents in this section.

Survey respondents also indicated what the technician needed to know about the specific process system in Table IV. "Operate the system," indicated for 8 of the systems listed, includes a full understanding of the system in question, along with maintenance, troubleshooting and operation. Undoubtedly, a different set of respondents would perhaps indicate a different list for "operate the system." Each industry has its own focus, as was noted in comments received from respondents. Technicians may also be expected to be able to enter data into an SPC system and to respond to the corrected action noted, as well as conduct failure analysis studies. In all cases, safety is essential and it is often necessary for a technician to interact positively with suppliers and/or other technical assistance. All of these considerations will be important in a technician education program.

Table III. Applied physical science performance indicators showing average ratings for each indicator.

	Rating
Apply Basic Concepts of Physics	
Apply correctly appropriate units for physical quantities	1.2
Use correctly the concepts of weight and mass	1.6
Apply concepts of heat, temperature, thermal conductivity, specific heat	2.0
Apply principles of force, moments and static equilibrium	2.1
Explain electrical properties of conductors, insulators and semiconductors	2.1
Describe concepts of electromagnetic waves, X-rays, UV, radio waves and visible light	2.2
Use concepts of thermal expansion and differential thermal expansion	2.4
Apply concepts of digital and analog electronics	2.4
Apply concepts of light and optics as applied to physical measurements	2.4
Describe Effects of Processing and Manufacturing Variables on Material Properties	
Explain effects of operator, machine and material error on properties and products	2.0
Describe how changes in material processing affect material properties	2.0
Explain how defects affect properties of nanostructure systems	2.1
Describe how defects in surface preparation affect preoperties and products	2.1
Demonstrate Ability to Utilize Equipment and Measurement Techniques	
Understand Metrology and its uses	1.6
Operate and troubleshoot vacuum systems	1.9
Describe gas flow systems	1.9
Troubleshoot process equipment	1.9
Show Ability to Operate Characterization Systems	
Perform quality control and SPC analysis	2.2
Operate testing methods	2.4
Demonstrate Ability to Enhance Product or Process Quality	
Develop means to enhance product quality	2.3
Analyze manufacturing processes for quality improvement	2.4
Identify Fundamental Aspects of Materials used in Nanotechnology	
Explain causes for differing material behavior	2.0
Discuss the general structure and properties of materials	2.0
Explain applications of surface effects in materials	2.0
Compare thermal, physical and mechanical properties of materials	2.1
Identify the general nature of ceramics and glasses	2.2
Explain the structure of polymers and their uses	2.4

Note. Rating Scale: 1 = vital; 2 = relatively important; 3 = desirable; 4 = relatively unimportant.

RESEARCH ARTICLE

RESEARCH ARTICLE

Table IV. Process capability requirements average importance ratings and knowledge needed for each topic.

Processes and techniques	Importance rating	Principal knowledge needed
Materials and Device Processing	(26 responses)	
Photolithography	1.8	Operate the system
X-ray lithography	2.8	Define what it is
SPM-based lithography	2.7	Define what it is
E-beam lithography	2.7	Explain its use
Nanomanipulation	2.6	Define what it is
Plasma etching	2.1	Define what it is
Wet chemical etching	2.0	Operate the system
Nanoscale Materials Synthesis	(25 responses)	
Thin film deposition	1.8	Operate the system
Electro-deposition	2.2	Explain its use
PVD/evaporation	2.3	Operate or explain system
Chemical vapor deposition	2.2	Explain its use
Self assembly of particles	2.4	Define what it is
Analysis Methods	(22 responses)	
Optical and laser analysis	2.1	Operate the system
X-ray diffraction	2.3	Define what it is
Optical and electron spectroscopy	2.0	Operate the system
Surface analysis methods	2.1	Operate the system
Electron microscopy	1.9	Operate the system
Scanning probe microscopy	2.2	Define what it is
Gas adsorption	2.8	Define what it is
Device failure analysis	2.6	Explain its use

Note. Rating Scale: 1 = vital; 2 = relatively important; 3 = desirable; 4 = relatively unimportant.

5. ADDITIONAL INPUT AND VALIDATION

Additional input, obtained since the survey was completed, has assisted the authors in ensuring that the survey data is valid. It has also added additional depth of understanding of educational needs for technicians working in this area. This additional input was obtained in early 2012 through discussions with 12 professionals working in the nanotechnology area. These included academic researchers, technician instructors, technicians, small startup entrepreneurs and large corporation engineers. In general, this group considered the results of the survey to be relevant and applicable to technician education for nanotechnology.

The validation group appreciated the focus on basic areas of chemistry and physics, and added further focus to the results of the survey. Chemical synthesis and processing, along with sample preparation, can be essential areas for education. Abilities ranging from the utilization of statistical process control, to an understanding the importance of MSDS sheets, especially for nano-sized particles, were emphasized. On the practical end, hands-on abilities are well appreciated in a technician, along with an ability to understand and assist in a full process line in addition to isolated equipment. It was also noted that since the applications of nanotechnology are quite multi-disciplinary, an even broader education could be desirable in some cases.

The focus on equipment was foremost in the minds of this group. Technicians must "own" the equipment, being able to understand its operation and use, and be able to maintain and operate it. The type of equipment will vary with application, depending very much on the specific focus of work and also depending on whether the equipment is used in R&D, product development or production. For example, some were involved in research that involved AFM and SPM, and felt that these should be as highly rated in terms of equipment operation as the others in Table IV. This reinforces the earlier observation that the focus on process capability can and will vary widely with application and focus.

Scaling up applications of nanotechnology R and D will require the development of different types of equipment than is currently available, as has been recognized by the U.S. National Science Foundation' program on Scalable Nanomanufacturing (www.nsf.gov/pubs/2012/nsf12544/nsf12544.htm) and other research organizations (www.internano.org; www.sinam.org). This may require yet additional types of training for the technicians who will operate in such nanomanufacturing environments as they are developed.

Technicians come from many sources, including associate degree programs at community colleges, technology programs at high schools, the military and even from those with BA degrees. Large organizations often have specific, rigorous training programs, whereas small companies and startups must rely on on-the-job training. Many suggested that an associate's degree is a big advantage that shows students hot to learn and understand technical subjects. Overall, the broader the background with an ability to learn provides a technician with the initial capability to succeed.

As this relates to education, the principle point, reemphasized by this group of professionals, is that education is paramount. The intimate interactive relationship between structure, properties and processing is as valid in nanotechnology as in materials science and other areas, and must be well understood, since changes in one parameter can affect change in other parameters. Some of those changes can be predicted but at very small dimensions, perhaps not. Every scientist, engineer and technician needs to be aware of the structure/properties /processing principle and must be prepared to apply it to each situation.

6. DISCUSSION

For an educator developing courses and curricula for technicians focused on the nanotechnology area, this survey identifies the needed capabilities—to understand basic chemical and physical science areas and to be able to operate specific systems, processes and analytical techniques. The knowledge needed in chemistry and physical science, as illustrated in Tables II and III are generally included in introductory courses in those areas. Developing understanding of the workings of specific processes and specific operating skills pose a more difficult problem. Here, the ability to understand instructions and equipment specifications is an important start. General familiarity and experience with equipment maintenance and operation will also help. Companies have relied on training received in the military and/or in other industries for this general knowledge of equipment and processes; there is no reason, however, that colleges and other educational providers cannot develop the same type of insight in their students. For specific processes or facilities, however, colleges may need to rely on on-the-job training or in some cases, educational programs in related microtechnology and semiconductor processing technology areas.

In addition to the specialized education discussed here, it is also important that basic educational needs be addressed. The technician must be able to read and understand instructions and be proficient in use of units, computer programs and basic mathematics. Other abilities relate to hands-on skills, teamwork, professionalism and an understanding of safe laboratory practice. Generally, these types of skills are rated more highly than specific technical skills, as noted in in general technician competency studies (Mott et al., 2007), and must be addressed in any technician education program.

For the educator, a variety of curricula and specific course modules are available. Some are available in journal articles, such as in Al-Haik (2010). Others are available from various projects that publish their content on the Internet. Curricula and educational modules related to nanotechnology are included in a collection of sources published by the National Resource Center for Materials Technology Education (2012). To date, eighteen different sources of modules are listed in this compilation, from basic to advanced and from basic materials science to nanotechnology. Examples related to nanotechnology education are given below, with the URLs noted being valid as of July 1, 2012.

MatEd Modules, 44 modules covering most areas and levels, available at http://www.materialseducation.org/educators/mated-modules/

Manufacturing modules covering basic manufacturing technology areas http://www.mtag-wa.org/curriculum/

MATEC modules on semiconductor technology http://matec.org/ps/library3/process_I.shtml

Microsystems Resources, 44 beginning and advanced modules, available at http://SCME-NM.org

Nano4me, a wide variety of nanotechnology modules http://www.nano4me.org

Nano-Link Resources covering fundamentals and activities in nanotech www.nano-link.org

NISE Networks, with many informal activities and applications of nanotech www.nisenet.org/catalog

The full listing of modules and sources is available at www.materialseducation.org

7. CONCLUSIONS

A wide variety of need have been identified in this study, and several sources of curricula have been identified for the instructor. Neither the needs nor the sources are complete, but are intended only as a starting point for curriculum development. As the nanotechnology field advances in the point of widespread production of products, technicians with the skills discussed here will be needed in increasing numbers. With this growth, further diversification of applications may be expected, such that further studies of need may be helpful to educators in this area. This may best be considered within the future development of new materials technologies (Stoebe et al., 2012). Overall, the principle focus for nanotech technician education, as with technician education in general, must always start with the basics then proceed to essential science understanding, then to the specific process skills needed for each individual product.

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RESEARCH ARTICLE

References and Notes

Al-Haik, M., Luhrs, C., Leseman, Z., & Taha, M. R. (2010). Introducing nanotechnology to mechanical and civil engineering students through materials science courses. *J. Nano Educ. 2,* 13–26.

American Association for Public Opinion Research (2008). Response rate—An overview. Retrieved from http://www.aapor.org/Response_Rates_An_Overview1.htm, June 30, 2012.

Campbell, Andrew & Luchs, Kathleen Sommers. (1997). *Core competency-based strategy*. Toronto, Ontario: International Thompson Business Press.

Manufacturing Skill Standards Council. (2006). *High-performance manufacturing: Portable production skills*. Columbus, OH: McGraw-Hill.

Manufacturing Technology Advisory Group. (1999). EALR's and competencies. Retrieved from http://www.mtag-wa.org/competencies/.

Mott, R. L., Stoebe, T. G., Simoneau, R., & Cossette, I. (2007). Core competency needs in materials technology. *J. Materials Education 29*, 259–268.

National Resource Center for Materials Technology Education. (2010). Core competencies for technicians working in nanotechnology. Retrieved from http://www.materialseducation.org/educators/competencies/ July 1, 2012.

National Resource Center for Materials Technology Education. (2012). Retrieved from the "Education" tab under www.materialseducation.org, June 30, 2012.

Roco, M. C. (2003). Broader societal issues of nanotechnology. *Journal of Nanoparticle Research 5*, 181–189.

Sanghi, S. (2007). *Handbook of competency mapping*. Thousand Oaks, CA: Sage Pubications.

Stoebe, T., Cox, F., & Cossette, I. (2012). Future outlook for materials technology education. *Journal of Engineering Technology* In press.

NSF program on Scalable nanomanufacturing. http://www.nsf.gov/pubs/2012/nsf12544/nsf12544.htm.

InterNano Resources for Nanomanufacturing. http://www.internano.org/.

SINAM, Center for Scalable and Integrated Nanomanufacturing. http://www.sinam.org/.

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RESEARCH ARTICLE