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A Profile of Nanotechnology Degree Programs in the United States

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This report is the third in a three-part workforce assessment study series that explores the emerging effects of nanotechnology on the demand for, and educational preparation of, skilled workers. The series was designed to build policy-relevant knowledge of the labor market dynamics of nanotechnology-enabled industries and to foster better alignment of nanotechnology education with the skill needs of employers.

The first report, The Workforce Needs of Companies Engaged in Nanotechnology Research in Arizona, used interviews, focus groups, and an on-line questionnaire to profile a single labor market - identifying the skill needs of high-tech companies in Arizona and the types of nanotechnology educational programs being developed at post-secondary institutions in the region. In the second report, The Workforce Needs of Biotechnology and Pharmaceutical Companies in New Jersey That Use Nanotechnology, researchers used interviews of representatives from pharmaceutical and biotechnology companies to understand nanotechnology employer needs in New Jersey. This third report examines the emerging development of nanotechnology degree programs.

REPORT SUMMARY

Research suggests that new degree programs are one way that postsecondary institutions respond to perceived labor shortages in areas of emerging technology (Stephan et al., 2007). This study offers a "snapshot" profile of nanotechnology degree programs in the United States. While not the most common, or even necessarily the most effective form of nanotechnology postsecondary education, nanotechnology degree programs represent institution-level change, presumably to address new knowledge and employment needs posed by nanotechnology.

Nanotechnology degree programs are defined here as associate's, bachelor's, master's and doctoral degrees that use the term "nano" in the formal degree title. To ensure the most complete coverage possible, researchers did not include certificates, minors, tracks, or concentrations in nanotechnology. Researchers used structured Internet searches, expert recommendations, and existing degree program lists, several of which are funded by the National Science Foundation, to identify degree programs (See Figure 1 below). The study also involved the analysis of institutional data, 15 interviews with faculty associated with active degree programs, and reviews of program-related Websites. Researchers also conducted a total of 14 interviews with faculty from inactive or ineligible programs during the course of the study to better understand the obstacles to establishing degree programs in nanotechnology.

Figure 1. Comparison of nanotechnology degree programs, by list source

Nanotechnology Degree Program Lists	# Nanotechnology Degree Programs*
This Research	**49**
The Penn State University Center for Nanotechnology Education and Utilization	33
National Nanotechnology Initiative (NNI)	14
National Center for Learning and Teaching Nanoscale Science and Engineering (NCLT)	13
Small Times Survey 2007	9

** Only programs meeting the definition established for this study were counted above.*

FINDINGS

Seven findings emerged from the study, as follows:

Finding 1: **The total number of formal nanotechnology degree programs in the United States is small, with associate's degrees being the most prevalent, followed by doctoral degrees**.

Researchers identified 49 degree programs with the term "nano" in the degree title at 38 postsecondary institutions in the U.S. Thirty-two (65%) of these programs are associate's degree programs, more than half of which (18) are in Pennsylvania. One program exists at the bachelor's level, eight at the master's level, and eight at the doctoral level.

Finding 2: **Nanotechnology degree programs are not concentrated in areas of high nanotechnology publication activity, but rather, clustered in response to federal and state investments.**

While the majority of graduate-level degree programs are housed at research institutions, researchers found no correlation between the location of nanotechnology degree programs and metro areas with high levels of nanotechnology publication and patent activity, which are important indicators of innovation. Eleven of the sixteen graduate programs identified were offered by institutions that perform high or very high levels of research according to the Carnegie Classification system.[1] Only 2 of the 38 institutions, however, were in one of the top 10 "nanodistricts", metropolitan areas with the highest rates of nanotechnology publication and patent activity (Shapira and Youtie, 2008).

Instead, programs are clustered in areas where state and/or federal investments promoted their growth. In the cases of Pennsylvania and New York, needs of current employers and economic development goals drove the creation of statewide nanotechnology initiatives, which in turn supported the development of degree programs. In the Midwest, the National Science Foundation supported the development of **NANO-LINK**, a set of six associate's degree programs linked across five states.

[1] The Carnegie classification system is a coding system developed by the Carnegie Commission on Higher Education to assist researchers and policy analysts to categorize schools by key characteristics. For more information see: http://www.carnegiefoundation.org/classifications/

Finding 3: **Workforce and economic development are key motivators for the creation of associate's degree programs in nanotechnology, while reasons for creating other types of degrees are more diverse.**

All ten associate's degree program faculty interviewed cited workforce development and business attraction as key reasons for creating their programs. For example, the Pennsylvania Nanofabrication Manufacturing Technology Network, which links 18 nanotechnology degrees across 16 institutions to a capstone semester at Pennsylvania State University, began as a result of employers asking state workforce and economic development officials for help in training nanotechnology technicians. According to administrators, the program is also designed to attract more nanotechnology-enabled manufacturers to the state.

At the bachelor's level and above, motivations for creating degree programs were more variable. Some, such as The College of Nanoscale Science and Engineering at the University at Albany, State University of New York, were created as part of state or local initiatives to support and grow nanotechnology businesses. However, other programs cited a desire to attract more students and faculty interest in formally linking nanotechnology education across disciplines.

Finding 4: **Employer involvement in degree programs is inconsistent.**

Employer involvement in nanotechnology degree programs varies across programs, even among those with a workforce development mission. While all associate's degree programs contacted reported some level of employer involvement, the degree and type of involvement varied from initial consultation about program design, to ongoing involvement in curriculum development, internships, funding assistance and job placement. At higher levels of education, where motivations for program development are more variable, employer involvement of any kind was less common. The major exception to this is at the College of Nanoscale Science and Engineering in New York, where six graduate degree programs involve high levels of industry partnership.

Finding 5: **A shortage of qualified faculty, limited consensus on learning needs, and other factors contribute to varied approaches to the interdisciplinary aspects of nanotechnology education in degree programs.**

All programs contacted use pre-existing courses from different disciplines – an approach known as "synthetic interdisciplinarity" (Lattucca 2001). Several, however, involved faculty from multiple disciplines to create new course content

that emphasized the common elements linking various disciplines, known as a "transdisciplinary" approach (Lattucca 2001).

Especially at the associate's level, the lack of transdisciplinary courses was linked to difficulties finding qualified faculty. This issue is often addressed through partnerships with four-year universities, where students have access to more transdisciplinary coursework, as well as advanced lab equipment. Program purpose, faculty perceptions of needed knowledge, and structural barriers, such as faculty reward structures and accreditation requirements also appear to contribute to differences in program approaches to interdisciplinarity. Some faculty worried that overemphasis on interdisciplinary education would dilute core, discipline-based knowledge.

Finding 6: **Partnerships among related programs were common, especially across institutions.**

Graduate degree programs reported informal ties to nanotechnology research centers at the same institution, while partnerships across institutions at all levels were both common and formal. The NSF-funded **Pennsylvania Nanofabrication Manufacturing Technology Network** and **NANO-LINK** programs developed partnerships both among several community colleges and between these schools and universities. Locally-driven partnerships have also developed in other areas on a smaller scale. Inter-institutional partnerships, as mentioned above, include capstone semesters and lab rotations offered at four-year institutions for associate's-level students, as well as formal articulation agreements that allow students to transition from an associate's degree in nanotechnology to a bachelor's degree in a traditional discipline, often with a nanotechnology or nanoscience focus.

Finding 7: **Little is known about the employment outcomes of nanotechnology degree program graduates.**

Few students have completed the nanotechnology degree programs contacted. Further, few programs have systems in place to track graduate outcomes. Anecdotal reports indicated that students either went on to higher levels of education or found relevant nanotechnology positions at competitive salaries. Overall, however, very little information was available about student outcomes.

CONCLUSIONS

Several conclusions are important for policymakers to consider. These include:

The development of nanotechnology degree programs reflects the emerging nature of the technology itself.

While much has been written about the potential of nanotechnology to transform industries and education, only early signs of transformation are evident in both today. Stephan et al. (2007) found that most nanotechnology postsecondary education is occurring informally in university lab environments, not within formal degree programs. Research with employers also suggests that employers train many nanotechnology workers on the job (Van Horn and Fichtner, 2008; Van Horn et al., 2009). This research, which reveals few formal programs and variations in focus and content among them, demonstrates that, like the technology itself, educational approaches to nanotechnology are still emerging.

Not surprisingly, the value of formal degree programs for meeting employer needs is unclear.

Because many nanotechnology degree programs are new, little is known about the success of graduates in the labor market. Recent studies have revealed limited demand for skilled nanotechnology workers (Stephan et al. 2007) and many employers do not yet see value in a nanotechnology specific degree (Van Horn and Fichtner 2008; Van Horn, Fichtner, and Cleary 2009). Plus, the fact that degree programs are not associated with publication and patent activity suggests that, at least as currently structured, they may not play a significant role in the innovation process.

Employer involvement in many associate's degree programs, however, may indicate an emerging need for technician-level skill development in nanotechnology. Further, just as few employers saw value in an information technology degree in 1972, limited demand for workers with a nanotechnology degree may reflect employers' limited understanding of the future skill implications of an emerging technology. As a result, nanotechnology degrees may prove to be more valuable in the marketplace as the technology itself matures.

POLICY IMPLICATIONS AND FUTURE RESEARCH OPPORTUNITIES

The research has implications for current policies that support the development of educational approaches to nanotechnology and suggests areas for further research. Based on the results of this study, policymakers at the National Science Foundation should consider the following:

- Continue support for experimental approaches to nanotechnology postsecondary education until proven models emerge,
- Encourage employer involvement in curriculum development, the creation of more transdisciplinary content, and continued partnership development,
- Support further research on postsecondary degree program processes and outcomes, as well as those for other types of nanotechnology education.

FULL REPORT

INTRODUCTION

Experts predict moderate to strong growth in the emerging field of nanotechnology, especially after 2010 (Hullman, 2006; M.C. Roco, 2003). While the current international recession may slow the pace of demand, Hullman argues that it could eventually become as pervasive as information and communication technologies.

As demand for products that incorporate nanotechnology rises, American colleges and universities will come under increasing pressure from employers and policymakers to prepare a skilled, nano-literate workforce. Many scientists, employers, and educators agree that nanotechnology requires interdisciplinary skills and knowledge – knowledge that may transcend traditional disciplinary boundaries (Van Horn & Fichtner, 2008; Van Horn et al., 2009; Wansom et al., 2008).

While there is no consensus yet on the best form or method to teach future nanotechnology workers, colleges and universities are developing a variety of courses, certificates, minors and degree majors that focus on nanotechnology (Stephan et al., 2007; Wansom et al., 2008). Currently, most nanotechnology education occurs informally in university labs, as well as through elective courses (Stephan et al., 2007). This study sheds light on one of the newest, most visible, and most formal incarnations of nanotechnology education at the post-secondary level in the United States - nanotechnology degree programs.

The purpose of this study is to build new policy-relevant knowledge about nanotechnology degree programs at colleges and universities in the United States. It identifies existing programs, as well as the institutions and departments that house them, and describes key program characteristics and trends across programs. This work adds to the sparse knowledge that has been developed regarding the ways that American colleges and universities are adapting to the education and workforce preparation challenges nanotechnology presents.

The report will address the following research questions:

- At what education levels do degree programs tend to occur?

- Which types of institutions are implementing degree programs?
- Where are programs located? To what extent are programs clustered in areas with state, regional, or local nanotechnology initiatives or high nanotechnology publication activity?
- How are programs structured to deal with the interdisciplinary aspects of nanotechnology?
- What is the role of employers in these programs?
- What factors were important in the development of these programs?
- What partnerships exist among nanotechnology degree programs and other education and research programs in nanotechnology and related fields?
- What is known about the employment and education outcomes of students?

While little is known about the most effective form of nanotechnology education given the emerging nature of the field, formal nanotechnology degree programs are nonetheless important to study. Degree programs represent institution-level change to accommodate nanotechnology, as well as a public statement on the part of the institution that this is an important new area of knowledge. The process through which a degree program is added is lengthy and time-consuming, requiring commitment on the part of faculty, administrators, and staff. Nanotechnology degree programs are also somewhat more comparable across institutions than other forms of nanotechnology education.

Limitations of the study include the fact that it covers only a small portion of nanotechnology education practices in the U.S. It does not address other forms of nanotechnology education at the post-secondary level, nor does it cover educational practices at other levels of education, which some scholars believe are necessary components to preparing a skilled nanotechnology workforce for the future (M. C. Roco, 2003; Wansom et al., 2008). In addition, while many steps were taken to ensure adequate coverage of all current degree programs, the difficulties and cost involved in surveying all higher education institutions and

departments make it difficult to know if this list represents a comprehensive review of all degree programs.

As new research on effective pedagogy, program structure, and course content associated with nanotechnology workforce education emerges, the value of the degree program models discussed in this report will become more apparent. In the meantime, this research provides policymakers and educators with important information about the number and types of nanotechnology degrees currently in place in the U.S., as well as key trends associated with their development. The study also adds to the sparse literature available on the ways that colleges and universities are responding to the educational challenges posed by nanotechnology and the demand for skilled nanotechnology workers.

LITERATURE REVIEW

This section discusses areas of the scholarly literature that informed the development and implementation of this study. In includes a review of studies that discuss the emerging demand for a skilled nanotechnology workforce, implications of nanotechnology for U.S. higher education, and the current state of knowledge regarding the educational approaches to nanotechnology being developed at U.S. postsecondary institutions.

Demand for Nanotechnology Workers

An often quoted estimate promulgated by the National Science Foundation projects that 2 million nanotechnology workers will be needed worldwide by 2015, including 800,000 to 900,000 in the U.S. alone (M. C. Roco & Bainbridge, 2001). While the current international recession may slow the pace of demand, Hullman (2006) notes that a range of studies agree that growth is likely to surge after 2010.

Today, however, demand for skilled nanotechnology workers appears limited. A study of job postings from several prominent sources conducted by Stephan et al. (2007) indicated that demand for nanotechnology workers with a bachelor's degree or above was in the range of hundreds of workers nationwide in 2005. While this represented annual growth rates of up to 43% per year over a three year period (2002-2005), the overall market is still small. Positions were spread across academic, government and non-profit organizations, as well as private firms. Yet, the study found that most advertisements were placed by large, established firms as opposed to small companies. This may be a function of the cost of placing ads, but it could also represent limited nanotechnology work among small or emerging firms.

Stephan's findings are consistent with case studies performed as part of the larger NSF-funded CNS-ASU workforce assessment project that funded this research. An analysis of the hiring needs of firms using nanotechnology in Arizona found limited employer demand for highly skilled nanotechnology workers (Van Horn & Fichtner, 2008). Limited case studies of pharmaceutical and biotechnology firms in New Jersey revealed that even large firms are hiring very few nanotechnology workers and are unsure of their future hiring needs in this regard (Van Horn et al., 2009).

Overall, it is difficult to predict the rate at which the demand for nanotechnology workers will grow. As noted in Hullman's work, a review of market analysis studies shows consensus regarding the potential for growth, but significant variation in the pace and timing of this growth, especially prior to 2010.

Implications of Nanotechnology for Higher Education in the United States

Several studies have explored the types of skills and knowledge that employers require of nanotechnology workers. While specifics vary by industry and application, employers and academics agree that nanotechnology requires a significant amount of interdisciplinary knowledge across multiple science and engineering areas (M. C. Roco, 2003; Van Horn & Fichtner, 2008; Van Horn et al., 2009; Wansom et al., 2008). This will require colleges and universities to develop students who have the breadth and depth of scientific knowledge needed to enable both research-based and commercial advancements in nanotechnology.

In 2006 and 2007, the National Center for Learning and Teaching Nanoscale Science and Engineering, which is funded by the National Science Foundation, supported several workshops to identify "big ideas" and key goals for nanotechnology-related education. These workshops identified nine broad knowledge and skill areas important to nanotechnology education including: size and scale; surface-to-volume ratio, surface-dominated behavior; self-assembly; quantum mechanics; size-dependent properties, tools/instruments and characterizations; models and simulations; and societal impact (Wansom et al., 2008). Much has been written on the ethical, legal and social implications of nanotechnology and the importance of teaching students about these (Kjolberg & Wickson, 2007; Mnyuswalla, Daar, & Singer, 2003; M. C. Roco & Bainbridge, 2001; M. C. Roco, 2003; M. C. Roco, 2003).

This study did not include an examination of these knowledge elements and whether they were present in nanotechnology degree programs. However, as employers and experts agree that interdisciplinary education is necessary to achieve these knowledge objectives (Van Horn & Fichtner, 2008; Van Horn et al., 2009; Wansom et al., 2008), this study looks broadly at how educational institutions approached the issue of interdisciplinarity within their degree programs.

Lattuca (2001) provides a useful framework for understanding university approaches to interdisciplinarity. She identified three key types of interdisciplinary education. The first, and weakest, form is called *informed disciplinarity*, which involves education based in a core discipline that includes additional information about another area of knowledge. Lattuca describes the second form, *Synthetic interdisciplinarity,* as a side-by-side presentation of concepts from various disciplines. Finally, *transdisciplinarity* stresses underlying connections among disciplines. It appears to be this third form that some visionary experts in the field of nanotechnology espouse (M. C. Roco, 2003; Wansom et al., 2008). However, not all faculty and employers appear to agree that this level of interdiscipliarity is required or preferable (Stephan et al., 2007; Van Horn & Fichtner, 2008; Van Horn et al., 2009; Vogel & Campbell, 2002).

While there is some emerging agreement among employers and science experts on the broad types of skills and knowledge future nanotechnology workers need to have, there is no consensus on how best to structure undergraduate and graduate teaching and research activities to promote that learning. The debate about the extent of interdisciplinary knowledge students need and the best ways to structure teaching is still active.

Educational Responses to Nanotechnology in American Colleges and Universities

How are U.S. colleges and universities responding to the challenge of producing students who are prepared to help American businesses and research centers realize the potential of nanotechnology? While nanotechnology is relatively new in the private sector, academics have been advancing knowledge about nanotechnology for decades. As early as 1959, Richard Feynman gave a classic talk to the American Physical Society at the California Institute of Technology (Caltech) entitled, "There's Plenty of Room at the Bottom," where he described the manipulation of matter down to the atomic level. (Feynman, 1960 – engineering and science reference) The invention of the scanning tunneling microscope in 1981, which allows researchers a clear view of atomic surfaces, and the atomic force microscope in 1986, which allows viewing at the sub-atomic nanoscale, provided important tools for the advancement of nanotechnology research.

Academic departments ranging from physics to materials science have, over time, developed both formal and informal ways to teach students about nanotechnology.

While very little is known about nanotechnology education in colleges and universities, Stephan et al. (2007) found that most nanotechnology education occurs informally in laboratories. Other nanotechnology education practices range from modified course content to new classes, as well as certificate programs, minors, concentrations and tracks within degree programs, and some formal major degree programs (Stephan et al., 2007; Wansom et al., 2008). Wansom et. al found wide variations in the content and structure of coursework in degree programs and minors across several postsecondary institutions.

Stephan et al. and others identified several potential barriers to establishing formal nanotechnology degree programs including the fact that they need to span several disciplines, which requires inter-departmental cooperation. Other key barriers included the lack of faculty with the interdisciplinary background needed to teach effectively and the often daunting degree requirements for nanotechnology which may add on to coursework in core disciplines (Stephan et al., 2007). Other difficulties included the concerns among faculty about the curricula of nanotechnology degree programs being more "general" than is needed to give students depth of knowledge in core disciplines, as well as a concern that the field is too nascent to warrant its own degree programs (Vogel & Campbell, 2002). Wansom et. al (2008) also found that degree programs centered on particular disciplines faced the challenge of having few faculty members properly trained in the interdisciplinary aspects needed to teach all necessary nanotechnology concepts. These authors also noted that accreditation bodies and structural barriers within universities limited the ability of programs to span multiple disciplines well.

METHODS AND DATA

This section describes the methods and data sources that researchers used to define and identify nanotechnology degree programs, and to identify salient characteristics of programs and the institutions that offer them.

Defining Nanotechnology Degree Programs

For the purposes of this study, researchers defined nanotechnology degree programs to be postsecondary degree programs at the associate's, bachelor's, master's, or doctoral level that contained the term "nano" in the formal degree title. This definition excludes degree minors, tracks, and other types of sub-specializations. In addition, it does not include other types of post-secondary credentials, such as graduate and professional certificates, nor does it include stand-alone nanotechnology courses or modules, or informal research-based nanotechnology education performed at colleges and universities.

This narrow definition of nanotechnology degree programs was chosen for several reasons. First, as indicated in the introduction, establishing a major area of study in the form of a new formal degree program represents a significant institutional commitment to a new area of knowledge development. Adding a track or a minor to a pre-existing degree program is less significant in this regard. The use of the term "nano" in the formal degree title is assumed to reflect a serious intention by the institution and the program to establish a primary, rather than a secondary, focus on nanoscience and/or nanotechnology. Also, given the Web-based search methods available to identify programs (see below for more information), this definition enhanced the likelihood that this study would result in a comprehensive identification of degree programs in the United States. Finally, focusing on programs with the term "nano" in the title offered a degree of comparability among programs, especially given the wide range in the types of nanotechnology education provided at postsecondary institutions.

Identification of Nanotechnology Degree Programs

Researchers used multiple methods to identify nanotechnology degree programs. Due to difficulties identifying the correct contact persons across the

many institutions, departments and schools where nanotechnology degree programs occur, researchers could not reasonably conduct survey research with colleges and universities as a means of identifying programs.[2] Instead, researchers relied on several national databases and lists of nanotechnology degree programs, extensive structured Web-based searches, a review of the scholarly literature on nanotechnology education in the United States, and the recommendations of experts.

First, researchers used publicly available data on nanotechnology degree programs, including lists and databases maintained by the following organizations:

- The National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) through the NanoEd Resource Portal (http://www.nanoed.org/degree/degree_by_subject_list)
- The National Nanotechnology Initiative (http://www.nano.gov/html/edu/eduunder.html)
- The Penn State University Center for Nanotechnology Education and Utilization (http://www.nano4me.org/)
- The Small Times 2006 University Rankings Survey, as published in a May 2007 article on SmallTimes.com (http://www.smalltimes.com/display_article/292542/109/ARTCL/none/none/1/Educating-small-tech%E2%80%99s-revolutionaries/)

Second, researchers conducted structured Web-based searches for nanotechnology degree programs in the U.S. using various combinations of the following search terms.
- "Nanotechnology", "Nanoscience", "Nano";
- "degree", "education", "program";
- "associate's", "bachelor's", "master's ", "Ph.D.", "doctoral"; and
- "university", "community college", "college"

Researchers also conducted a review of the scholarly literature on nanotechnology education to identify nanotechnology degree programs cited in previous studies. A review of these studies is included in the introduction of this paper. Finally, researchers consulted nanotechnology education experts at a

[2] Initially, researchers attempted to survey major U.S. universities and community colleges by distributing an on-line survey instrument through several national associations, including the Council of Graduate Schools, the American Association of Universities, and the American Association of Community Colleges. However, these organizations did not agree to distribute the survey to their membership.

variety of institutions around the country to identify gaps in the list of degree programs compiled.

Several programs in existing degree program lists or identified in initial Web searches were excluded from the final list of active nanotechnology degree programs for one of the following reasons: 1) The program had been cancelled 2) The program was only a proposed, but not an approved and active program or 3) The program did not actually meet the criteria for a nanotechnology degree program established for this study.

Identifying Degree Program Characteristics

Researchers conducted more than 28 structured interviews with degree program faculty and administrators to understand key program elements and characteristics. Researchers also examined program-related Websites, including course requirements, program and course descriptions, news articles, and other documents describing the programs.

Though only active programs that met the criteria established for this study were counted in degree program totals, researchers conducted interviews with faculty from both active and inactive, cancelled or proposed programs in order to better understand the obstacles faculty and institutions face establishing nanotechnology degree programs. A total of 15 interviews with faculty from active, eligible degree programs were conducted, along with an additional 14 interviews with faculty from programs that were either cancelled, planned but not implemented, or deemed ineligible based on the criteria for a nanotechnology degree program established for this study.

Key information categories explored through structured interviews included:

- Factors that led to developing the program
- Key obstacles to establishing the program
- Employer involvement
- Program approach to interdisciplinary aspects of nanotechnology education
- Connections to nanotechnology research centers and other relevant academic programs within and outside of the institution
- Employment experiences of program graduates

In addition to interviews, researchers examined Websites related to each nanotechnology degree program, including those that contained program descriptions, news stories, and other information about the degree programs. Through these Websites, researchers supplemented the information obtained in interviews. Course data was not examined in this study, as this was considered to be outside the scope of this research and requires significant expertise to categorize effectively.

Identifying Institutional Characteristics

Researchers used publicly available data from the Integrated Postsecondary Education Data System (IPEDS) to identify several characteristics of postsecondary institutions that deliver nanotechnology degree programs. Data elements examined included location and Carnegie classification. The Carnegie classification system is a coding system developed by the Carnegie Commission on Higher Education to assist researchers and policy analysts to categorize schools by key characteristics. Originally developed in 1970, the system was modified in 2005. Carnegie classification data used in this report is based on the 2005 classification categories. For more information on the Carnegie classification system, see: http://www.carnegiefoundation.org/classifications/

In order to determine if nanotechnology degree programs were located in areas of high nanotechnology policy and publication activity, researchers cross-referenced the data on institution location with data on this activity from two sources. First, researchers used a 2003 report released by the National Nanotechnology Initiative documenting state, local and regional nanotechnology initiatives (National Nanotechnology Initiative Workshop, 2003). Second, researchers consulted a list of the top 10 "nanodistricts" in the U.S., metropolitan areas featuring high levels of nanotechnology publication activity, compiled by researchers at the School of Public Policy at the Georgia Institute of Technology (Shapira & Youtie, 2008). The data was created as part of a related research project also funded by the Center for Nanotechnology and Society, Arizona State University (CNS / ASU) under cooperative agreement #0531194 with the National Science Foundation.

Limitations

Every effort was made to identify and verify active nanotechnology degree programs in the United States using the methods described above. There is no way to ensure, however, that the list provided in this study is entirely comprehensive. In addition, the programs that have been identified may not exist beyond the timeframe of this study.

It is possible that nanotechnology degree programs that meet the criteria established in this study were not captured through other degree lists, Web-based searches and other sources used to identify programs. In addition, for programs where an interview was not completed, it is possible that the program is not categorized correctly, especially if information on the Internet regarding the program is out of date, incomplete, or inaccurate. As was mentioned above, several programs identified as formal nanotechnology degree programs by other lists, reports, and even program Websites did not accurately characterize the operating status and/or the nature of the program.

Given the number of programs identified that have been cancelled, as well as those that have been proposed but not yet implemented, it is evident that the number of nanotechnology degree programs is in flux and subject to change. While this is certainly the case with all types of degree programs, the creation and destruction of nanotechnology programs may be more pronounced than more established disciplines due to the emerging nature of nanotechnology and the uncertainty surrounding the best way to teach nanotechnology concepts.

RESULTS

The following sections describe key characteristics of nanotechnology degree programs in the United States and the postsecondary educational institutions that offer them. This section is divided into nine areas including prevalence of nanotechnology degree programs and nanotechnology degree granting institutions in the United States; degree type; institution type; geography, including the intersection of nanotechnology degree-granting institutions with areas that have state nanotechnology initiatives, and high levels of nanotechnology publication activity; factors involved in program development; key challenges and obstacles; employer involvement; partnerships with related programs; and student outcomes.

For the purposes of this study, nanotechnology degree programs are defined as major degree programs at all levels of postsecondary education that include the term "nano" in the formal degree name. This definition excludes certificate programs and degree minors, concentrations and tracks, as well as course clusters that do not comprise a degree program. So, a nanotechnology track within a Physics Ph.D. would not be counted, whereas an Associate's degree in nanofabrication would meet the definitional criteria.

Readers should note that the number of programs and institutions identified in this report is different than that which may be found in other inventories of nanotechnology degree programs. This is due to two factors. First, degree programs were defined somewhat narrowly in this study for purposes of comparability. Also, formal degree majors are the most difficult new programs to set up in most institutions, thus making them an indicator of institutional commitment to a new body of knowledge. As a result of this narrow definition, however, several programs and sets of that are counted by other sources are not included here. The table below provides a summary of the number of nanotechnology degree programs identified in this research compared to the number identified in other sources when the definition used in this study is applied. Overall, however, this study identifies more formal degree programs than other lists.

Figure 2. Comparison of nanotechnology degree programs, by list source

Nanotechnology Degree Program Lists	# Nanotechnology Degree Programs*
This Research	**49**
The Penn State University Center for Nanotechnology Education and Utilization	33
National Nanotechnology Initiative (NNI)	14
National Center for Learning and Teaching Nanoscale Science and Engineering (NCLT)	13
Small Times Survey 2007	9

** Only those programs that met the definition of a degree program established for this study were counted.*

The second reason why the identification of nanotechnology degree programs differs among various inventories is that several lists count planned programs or programs that began early stages of implementation but were cancelled or delayed in their opening. Upon completing interviews for this study, several programs included on others lists that met the technical criteria established for this study were found to not be currently functional due to lack of funding, lack of employer demand, or other factors. Because understanding the issues that contribute to program failure are important for policymakers to understand, interview results from non-functional programs are discussed in this section, but the programs themselves are not counted in the program and institution totals provided.

Prevalence of Nanotechnology Degree Programs and Nanotechnology Degree Granting Institutions in the United States

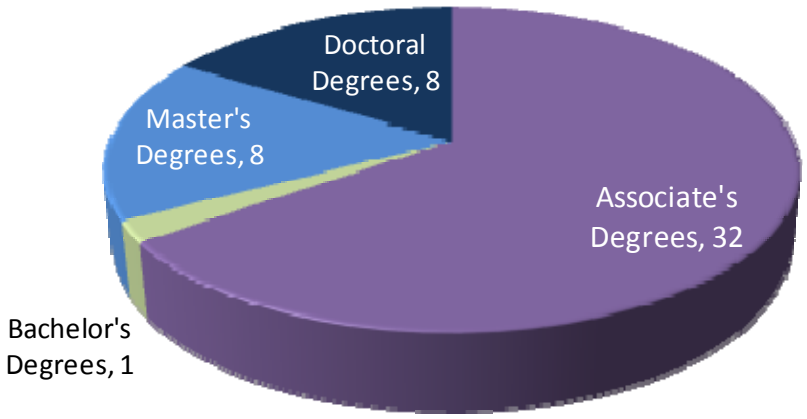
This study identified a total of 49 currently functioning degree programs that contain the term "nano" in the formal degree title. These degree programs are awarded by 38 institutions of higher education in the U.S. These numbers are small compared to the hundreds of thousands of degree programs offered at postsecondary educational institutions in the U.S. In fact, institutions that offer nanotechnology degree programs in the U.S. comprise less than 1% of all degree-

granting institutions in the country (Postsecondary Education Data System, *2008).*

Degree Types

The majority of nanotechnology degree programs identified in this study are associate's level programs. Thirty-two, or 65%, of the 49 programs are associate's degree programs (See Figure 3 below). All but two of these programs are Associate's of Applied Science degrees (30). The remainder (2) comprise Associate's of Science or Associates of Arts degree programs.

Figure 3. Nanotechnology degree programs, by degree level



N=49

The second highest number of degree programs is found at the graduate level, where 8 Ph.D. and eight masters' degree programs were found, each comprising 16% of all nanotechnology degrees identified. Only one nanotechnology degree program, or 2% of all identified programs, is currently available at the bachelor's degree level.

Degree names revealed a variety of concentrations among nanotechnology degree programs. As Figure 4 below indicates, 16 of the 32 associate's level degrees are in a nanofabrication area. Several degrees at various levels are focused broadly in nanoscale science and nanoscale engineering and related

technologies. Other degrees span fields ranging from nanobiotechnology to materials and molecular science.

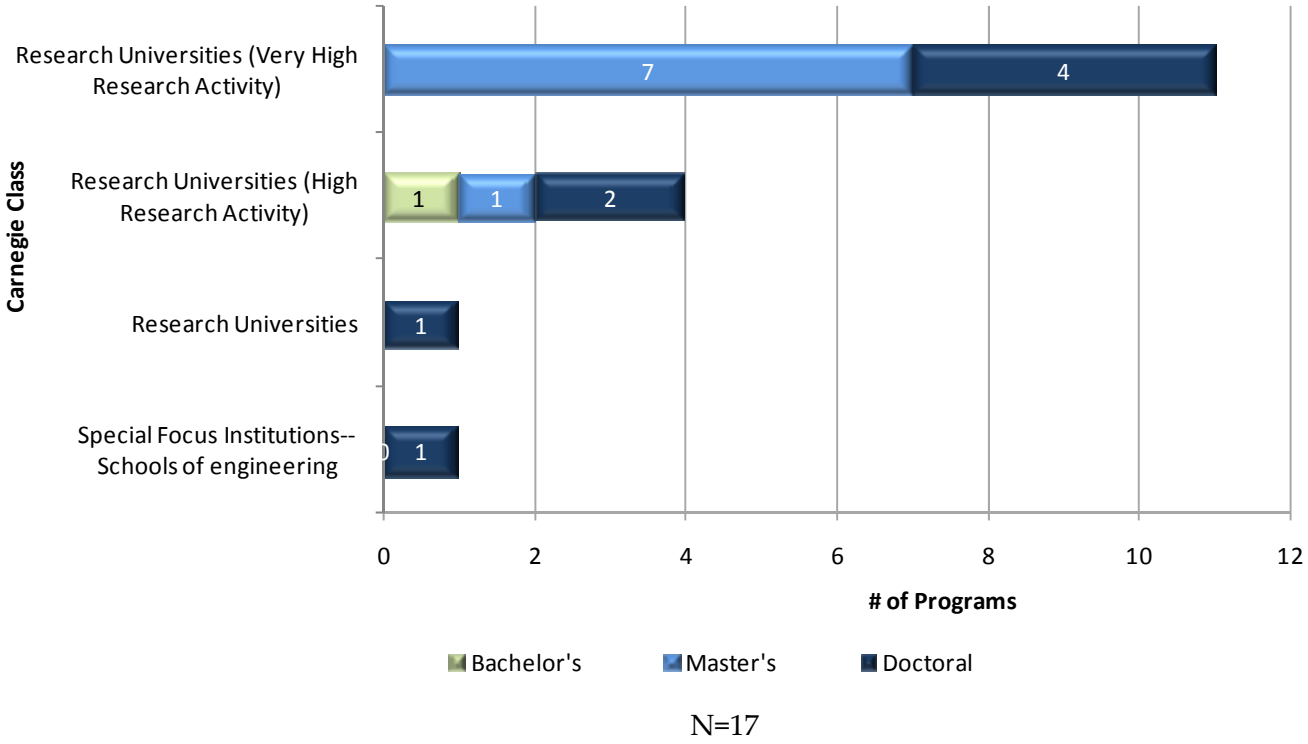
Figure 4. Nanotechnology degree names, by degree level and detailed type

Nanotechnology Degree Program Name	AAS	AS	AA	BS	MA	MS/ MBA	MS	PHD	Total
Bionanotechnology	1	-	-	-	-	-	-	-	1
Nanobiotechnology	1	-	-	-	-	-	-	-	1
Engineering Technologies Nanoscientific Instrumentation Technology	1	-	-	-	-	-	-	-	1
Materials and Nanotechnology	-	-	-	-	-	-	-	1	1
Micro/Nanotechnology and Micro/Nanoelectronics	-	-	-	-	-	-	-	1	1
Molecular Science and Nanotechnology	-	-	-	-	-	-	1	-	1
Nanofabrication	1	-	-	-	-	-	-	-	1
Nanofabrication Manufacturing Technology	9	-	-	-	-	-	-	-	9
Nanofabrication Technology	6	-	-	-	-	-	-	-	6
Nanoscale Engineering	-	-	-	-	-	1	1	1	3
Nanoscale Materials Technology	1	-	-	-	-	-	-	-	1
Nanoscale Physics Professional Master of Science	-	-	-	-	1	-	-	-	1
Nanoscale Science	-	-	-	-	-	1	1	2	4
Nanoscience & Nanoengineering	-	-	-	-	-	-	-	1	1
Nanoscience and Microsystems	-	-	-	-	-	-	1	1	2
Nanoscience Technology	4	-	1	-	-	-	-	-	5
Nanoscience Professional Master of Science						1			
Nanosystems Engineering	-	-	-	1	-	-	-	-	1
Nanotechnology	6	1	-	-	-	-	-	1	8
Total	30	1	1	1	1	3	4	8	49

Institution Types

Twenty of the thirty-eight postsecondary institutions offering nanotechnology degrees (56%) are classified within the Carnegie Classification system as public, two-year degree granting institutions. Another two (classified as "other" in the figure below) are community colleges that are not included in the Carnegie system. Together, these community and technical colleges offer 26 of the 32 nanotechnology associate's degrees found. The remaining six associate's degree programs are conferred by public bachelor's (4) and master's degree-granting institutions (2). Figure 5 below provides a summary of the institutions that offer nanotechnology degrees at the bachelor's level and above by their Carnegie classification status.

Figure 5. U.S. Postsecondary Institutions Offering Nanotechnology Degrees at the Bachelor's Level and Above, by Carnegie Classification



N=17

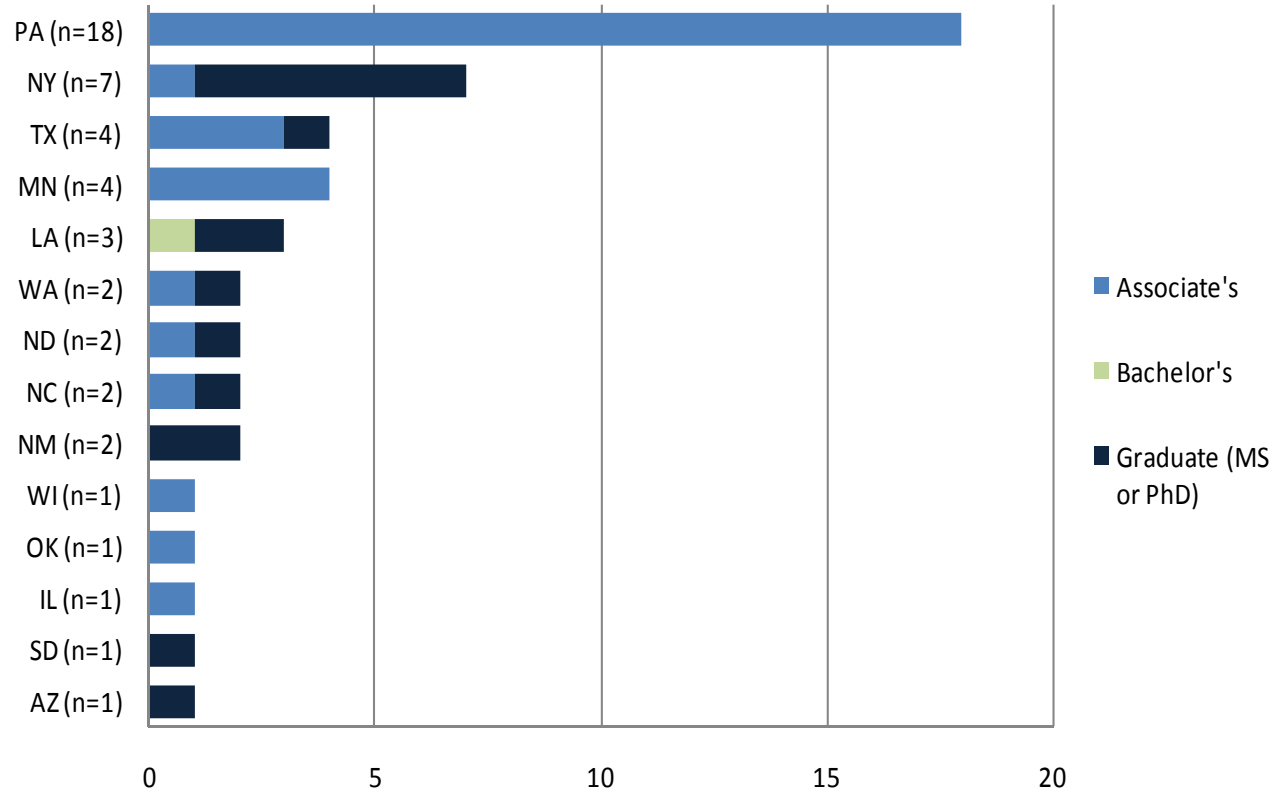
Source: Carnegie classifications from Integrated Postsecondary Education Data System (IPEDS), 2008, Carnegie Classification data, 2005 categories.

Most of the institutions offering graduate degrees in nanotechnology are classified as "very high" or "high" research institutions within the Carnegie classification system. The one bachelor's –level degree is offered by Louisiana Tech University, classified in the Carnegie system as a university that performs high levels of research. Seven of the eight master's degree programs and four of the eight Ph.D. programs are offered by institutions classified as "very high research" institutions. The remaining master's program and two Ph.D. degrees are offered by a "high research activity" institution, while one "research/doctoral" university and one special focus engineering school offer the remaining two Ph.D.'s.

Geography

Nanotechnology degree programs are highly concentrated in two states, including Pennsylvania and New York (See Figure 6 below). Pennsylvania, especially, is a unique case. The state is home to the **Pennsylvania Nanofabrication Manufacturing Technology Partnership (PNMTP)**, a network of postsecondary institutions throughout the state that offer degrees or courses related to nanofabrication. The network includes 16 institutions that offer 18 nanotechnology associate's degrees that met the criteria for this study. Pennsylvania State University's University Park campus, which does not offer a nanotechnology degree itself, provides an 18-credit capstone semester that is required for completion of the associate's degree at all network institutions.

Figure 6. Nanotechnology Degree Programs, by State



Source: Integrated Postsecondary Education Data System (IPEDS), 2008

By contrast, nanotechnology degree programs in New York are concentrated at the University of Albany's College of Nanoscale Science and Engineering, which offers all six nanotechnology degree programs in the state.

The four nanotechnology degree programs in Texas are spread across four separate institutions. A master's program is offered at Rice University, while the remaining three institutions include three community and technical colleges in different areas of the state. Minnesota's four programs are distributed among three community colleges. These colleges are part of a National Science Foundation educational partnership called **NANO-LINK**, that is similar in design to the model in Pennsylvania, but which links six associate's degree programs across five states. **NANO-LINK** programs include a capstone semester at the University of Minnesota. However, the university itself does not offer a formal nanotechnology degree that meets the criteria established for this research.

Louisiana has three programs, all located at Louisiana Tech University. The remaining 11 programs are distributed across 8 different states including Washington, North Dakota, North Carolina, Wisconsin, South Dakota, Oklahoma, New Mexico, and Illinois.

Presence of State, Regional, and Local Nanotechnology Initiatives

In 2003, the National Nanotechnology Initiative identified 19 state, regional, and local nanotechnology initiatives designed to promote economic growth in nanotechnology-enabled industries. Not every state or area that has such an initiative has a nanotechnology degree program established within its borders. However, many of the institutions that offer nanotechnology degrees are located in states or areas that have such an initiative in place.

All three states with the highest numbers of nanotechnology degree programs – Pennsylvania, New York, and Texas - have statewide nanotechnology initiatives in place designed to stimulate economic development through workforce education and other programs. Pennsylvania established the Pennsylvania Nanotechnology Initiative (PNI) to unite economic and workforce development efforts to promote growth in the nanotechnology sector. The state's business attraction website, NEWPA.com describes the program as, "a statewide strategy that currently combines the efforts of the Pennsylvania Department of Community and Economic Development (DCED), the Commonwealth's research universities, the Pennsylvania State System of Higher Education, over 125 companies, and economic development organizations. PNI is leveraging Pennsylvania's clusters of research, industry, and workforce development assets

to make Pennsylvania a global leader in nanotechnology research, commercialization and economic development activities." (NEWPA.com, 2009)

The New York State Foundation for Science, Technology, and Innovation established the Center for Advanced Technology in Nanomaterials and Nanoelectronics at the College of Nanoscale Science and Engineering at the University of Albany to be "a strategic partnership between premier research universities and the nanoelectronics, optoelectronics, telecommunications, defense, and nanobiotechnology industry clusters in New York State. The Center's mission is to provide industry with critical research and development, business assistance, workforce training, and economic outreach within a technically aggressive and financially competitive environment." (College of Nanoscale Science and Engineering Website, 2009)

The Texas Nanotechnology Initiative was begun in 2000 (Nanotechnology Initiative Workshop, 2003). Governor Rick Perry launched an industry cluster project in 2004 to focus state resources on promoting job growth in six core industry areas, including advanced technologies. Further, the state legislature launched the Emerging Technology Fund to promote the development of educational centers of excellence in key technology areas, including nanotechnology (Texasnano.org, 2009).

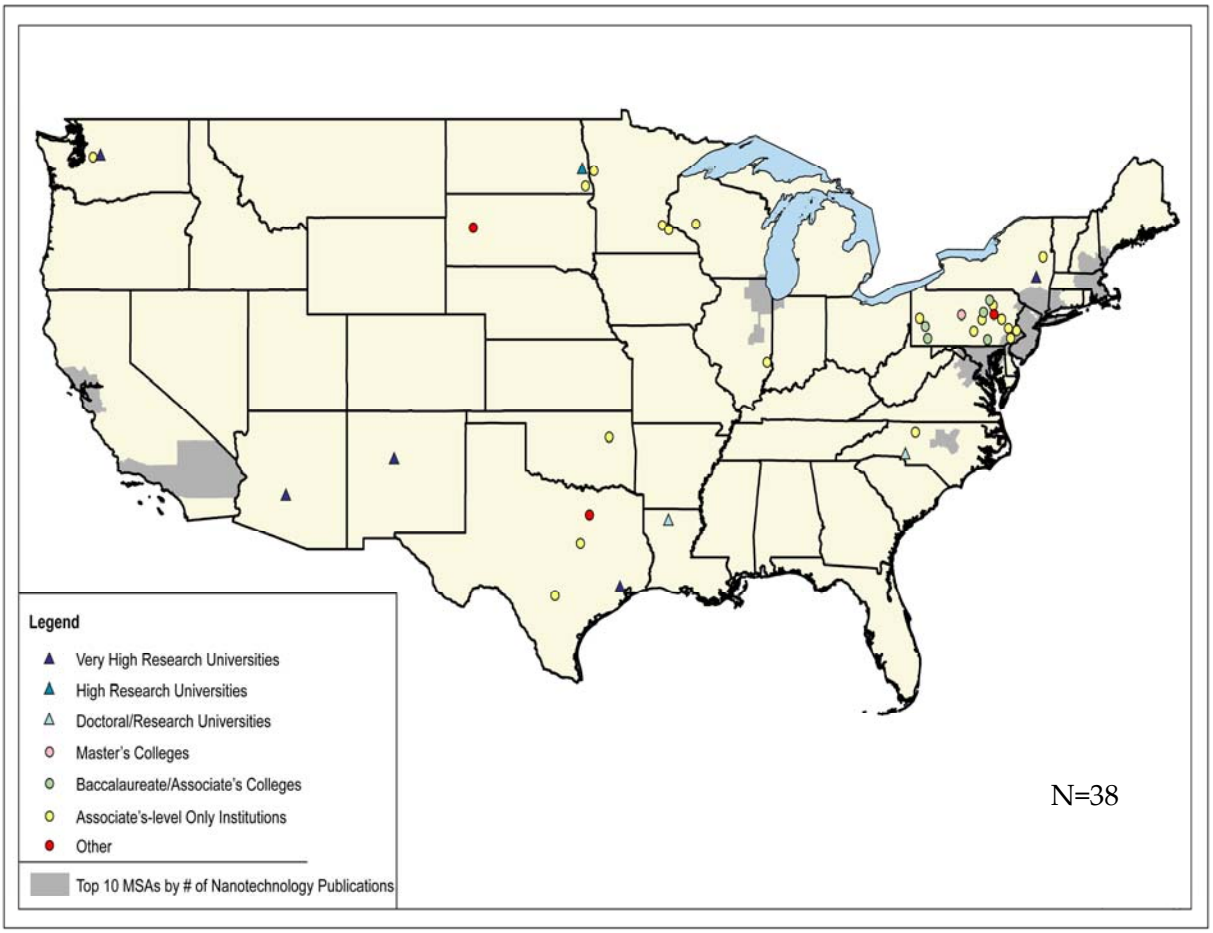
Presence of High Nanotechnology Publication Activity

There is little correlation between the location of degree programs and other types of nanotechnology activity. As Figure 7 below indicates, only 2 of the 38 institutions with active nanotechnology degree programs were located in one of the top 10 nanodistricts in the U.S. "Nanodistricts", as identified by Shapira and Youtie (2008) are U.S. metropolitan areas with the highest levels of nanotechnology publication activity. Researchers for this study compared the location of nanotechnology degree-granting institutions to the top 10 nanodistricts. The top 10 "nanodistricts" identified by Shapira and Youtie include:

1. New York–Newark–Bridgeport, NY–NJ–CT
2. San Jose–San Francisco–Oakland, CA
3. Boston–Worcester–Manchester, MA–RI–NH
4. Washington–Baltimore–Northern Virginia, DC–MD–VA–WV
5. Los Angeles–Long Beach–Riverside, CA
6. Chicago–Naperville–Michigan City, IL–IN–WI

7. Philadelphia–Camden–Vineland, PA–NJ–DE–MD
8. Raleigh–Durham–Cary, NC
9. Champaign–Urbana, IL
10. Santa Barbara–Santa Maria, CA

Figure 7. Nanotechnology Degree Programs and Top 10 Nanodistricts



The lack of correlation between areas of high nanotechnology publication activity and the location of degree programs is consistent with the results of a study by Stephan et al. (2007), which found that only three nanotechnology degree programs were located across 14 "laboratory" universities that had multiple research centers and laboratories dedicated to nanotechnology. According to that study, this trend stands in contrast to previous findings in the field of bioinformatics, where the presence of formal degree programs and laboratories were highly correlated. Overall, the study noted that federal

funding that prioritizes research and development over education in nanotechnology may contribute to this lack of connection.

Motivations for Program Development and Employer Involvement

Several themes appeared among nanotechnology degree programs regarding the factors that motivated initial program development. These include economic development, workforce development, student attraction, and faculty recognition of and/or interest in the interdisciplinary nature of nanotechnology. Several programs also noted that their nanotechnology degree programs grew out of programs in related fields that are incorporating nanotechnology, such as materials science, biotechnology, or semiconductor programs.

Motivations for nanotechnology degree program development and employer involvement vary by degree type. Among associate's degree programs, motivations were clearly related to workforce and economic development and direct employer involvement was common. However, among graduate programs, motivations for program development and employers involvement were more variable.

Nearly all associate's degree programs were designed to train nanotechnology technicians, according to interviews with program faculty and administrators. All of the associate's degree programs contacted reported some level of employer involvement. This involvement ranged from initial consultation with employers at the start of the programs with little to no further direct employer contact, to high levels of ongoing contact with employers. Among those colleges that reported high levels of employer involvement, activities included regular input into course curricula, donations of funding and equipment, provision of internship and/or post-program job placement opportunities for students.

Interestingly, several associate's degree programs mentioned that their degree programs were initially funded or organized by local universities and that these universities continued to be important partners. However, none of these partner universities offer formal degree programs at the undergraduate level or above. In both Pennsylvania and Minnesota, universities provided a "capstone semester" that was required for the completion of the associate's degree. Employers are generally involved in these capstone programs, and the universities support the practical training offered by the associate's degree granting institution by providing access to equipment, facilities, and the faculty

and classroom space for the more advanced education provided in the capstone courses. In other associate's degree programs, university partners were somewhat less involved, providing access to labs and equipment or complementary courses, or working with the community or technical college to ensure articulation between the nanotechnology associate's degree and a more traditional disciplinary degree at the undergraduate level.

Among graduate programs, student attraction and faculty motivation to establish interdisciplinary education in nanotechnology were common themes in program development and employer involvement was less common. The South Dakota School of Mines stated that economic development was an initial motivation for establishing the Ph.D. program, but actual employer involvement in the program has been limited to date. However, both the South Dakota School of Mines and the University of New Mexico discussed involvement with government research laboratories to develop curricula and help shape program development.

The most notable example of graduate programs that appear to have a strong link to economic and workforce development is found at The College of Nanoscale Science and Engineering of the University at Albany, State University of New York. As noted on its Website, the school has developed a NanoTech Complex, "a $4.5 billion megaplex that has attracted over 250 global corporate partners – is the most advanced research complex at any university in the world." (The College of Nanoscale Science and Engineering, 2009) As mentioned above, the college was established as part of a statewide investment in nanotechnology education and research that was part of a larger state economic development initiative.

Several proposed, but not yet functioning, programs were found in the course of the research. Two programs that are likely to open, but that are still in the planning stages include a joint school of nanotechnology involving North Carolina Agricultural and Technical State University and the University of North Carolina at Greensboro that is to be designed similarly to the College of Nanoscale Science and Engineering at the University of Albany (North Carolina Board of Science and Technology, 2007). The University of California at San Diego also plans to launch a Department of Nanoengineering that will offer bachelor's, master's and doctoral level degree programs in nanotechnology (University of California interview, 2009). It is anticipated that both of these planned programs will open by 2010. Other programs, such as an associate's degree program at Foothill College in California, and several associate's

programs at community colleges in the Santa Barbara region of California were set to open, but did not receive funding (Foothill College interview, 2009; Ventura County Community College District interview, 2009).

Key Obstacles and Challenges

According to interviews, key obstacles institutions faced when starting nanotechnology degree programs included lack of funding, bureaucratic hurdles, lack of student interest, difficulties convincing faculty of the merit of the program, lack of qualified faculty to teach courses, inadequate student preparation, and lack of employer interest.

At community and technical colleges, concerns centered around lack of student interest in and awareness of nanotechnology, inadequate math and science preparation of incoming students, and difficulty finding qualified faculty. Some also reported difficulties funding equipment purchases or other funding barriers. Several schools address the issue of a lack of qualified faculty and limited access to equipment through partnerships with four-year institutions. Among the four associate's degree programs that were proposed, but not begun, lack of funding, not lack of employer interest, was the primary barrier.

Among higher-level degree programs, issues that acted as barriers to degree program development were more related to faculty concerns and bureaucratic hurdles. For example, one university mentioned that they had to convince faculty that implementing a nanotechnology degree program would not be "a zero-sum game" – the program would not take resources from existing departments. (University of New Mexico interview, January 2009) Faculty at several institutions were also concerned about losing the rigor of existing disciplinary programs by implementing an interdisciplinary program that is "too general" (University of Washington interview, 2008) The need to get approval from several schools, departments,, or administrative units within the university was also a challenge for some programs. Proponents of two B.S. level programs that were proposed but never implemented cited lack of a faculty leader, institutional barriers, and a lack of local employer support as reasons for not pursuing the programs further(California Polytechnic State University interview, 2009; Rutgers University interview, 2009).

Program Approach to Interdisciplinary Aspects of Nanotechnology Education

Approaches to the interdisciplinary aspects of nanotechnology varied among programs. Many faculty members interviewed stressed that students maintain a strong link to a core, traditional discipline or department while pursuing the nanotechnology degree. Programs at all levels require students to take a mix of pre-existing courses from a variety of core disciplines, such as physics, biology, chemistry, or materials science, an approach known in the scholarly literature as "synthetic interdisciplinarity" (Lattucca, 2001). The mix of required courses was variable and depended partially on the focus of the program. For example, a program in nanobiotechnology requires more emphasis on biology that other programs tend to require. Few programs noted requirements for learning about the social and ethical implications of nanotechnology.

At several institutions, however, faculty discussed more intensive collaboration across departments and even schools to create, and sometimes to co-teach, nanotechnology-specific courses and lab work. These courses were generally offered or required in addition to a set of pre-existing courses across disciplines. Known as a "transdisciplinary" approach in the scholarly literature (Lattucca, 2001), these newly developed courses or sequence of courses are meant to emphasize the common elements that link various disciplines together. For example, at the University of New Mexico, faculty stated that the nanotechnology degree is a "program without a department, because we sit between the College of Engineering and the College of Arts and Sciences" (University of New Mexico interview, 2009). Faculty from this program noted that four of their required courses were developed collaboratively among faculty from various departments, with one being developed based on an existing course, and three being entirely new material that stressed the interdisciplinary nature of nanotechnology and core nanotechnology skills.

Overall, given the concern among many faculty about "diluting" the rigor of core disciplines, many degree requirements are related to traditional disciplines. Given that a detailed analysis of course data was outside the scope of this study, it was difficult to gauge the exact nature and extent of interdisciplinary approaches within programs. Further study of this aspect of nanotechnology degree programs is required.

Partnerships with Other Academic and Research Programs

A number of programs, especially those at the associate's degree level, have established partnerships with other educational institutions. Two key multi-institution partnerships that were stimulated through funding from the National Science Association include the **Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership** and **NANO-LINK**. Each links several degree programs to a required university-based capstone semester.

The **Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership** links the 18 nanotechnology associate's degree programs in Pennsylvania that were identified in this study, as well as several other programs in the state at various education levels that did not meet the criteria for formal degree programs established for this study. The Partnership involves an 18-credit capstone curriculum offered at Pennsylvania State University's University Park campus that is required for degree completion at member colleges. This program was funded by the National Science Foundation and is coordinated through the Penn State Center for Nanotechnology Education and Utilization. According to its Website, the Center is "the home of the Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership and the National Science Foundation (NSF) Regional Center for Nanofabrication Manufacturing Education, an NSF-sponsored regional Advanced Technology Education (ATE) Center." (Penn State Center for Nanotechnology Education and Utilization (CNEU) Website, 2009)

The Midwest Regional Center for Nanotechnology Education, known as **NANO-LINK**, is a similarly-designed program that links six associate's degree granting institutions across five Midwestern states - North Dakota, Minnesota, Wisconsin, Illinois and Michigan with the University of Minnesota and Northwestern University. Currently, only five of the six associate's degree programs in NANO-LINK offer degrees, including Chippewa Valley Technical College in Wisconsin, Dakota County Technical College and Minnesota State Community and Technical college in Minnesota, Harper College in Illinois, and North Dakota State College of Science in North Dakota. A sixth associate's degree program is under development at Lansing Technical College in Michigan (Nanotechbuzz.com, 2008). Like the Pennsylvania model, the NANO-LINK offers a capstone semester at the University of Minnesota. According to the NSF award abstract for the NANO-LINK:

> NANO-LINK focuses on seven key goals: establish a Midwest Regional Industry Advisory Board; develop multidisciplinary nanoscience programs; partner with the University of Minnesota to provide remote access delivery for nanoscience experiences in pre-capstone and capstone courses; partner with the NSF National Center for Learning and Teaching Technology in Nanoscale Science and Engineering (NCLT) at Northwestern University to provide professional development for secondary educators and college faculty; establish a clearinghouse infrastructure for undergraduate instructional materials; develop outreach activities to enhance recruitment of students into nanoscience programs, with an emphasis on underrepresented students; and provide venues for dissemination including an annual nanoscience conference for faculty, students, alumni, and industry.
> (NSF **Award Abstract #0802323**
>
> **Midwest Regional Center for Nanotechnology Education (NANO-LINK**
> http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0802323)

Interestingly, the universities offering capstone semesters for associate's degrees in the Pennsylvania NMT and NANO-LINK partnerships do not offer formal nanotechnology degrees at the bachelor's or the graduate level. However, minors, certificates, or other options were available. In both cases, associate's degree programs were designed to articulate into related, but traditional, discipline-based degrees at the four-year partner school.

Other associate's degree programs around the country reported sharing lab facilities with four-year institutions and establishing articulation agreement to traditional nanotechnology degree programs. Such relationships were found at schools in North Carolina, New York, Washington, Texas, and other states. However, while formal partnerships or linkages among different institutions and levels of education were common, linkages with related research centers/other educational activities within schools tended to be informal. This may be related to the de-centralized and loosely coupled nature of most higher education institutions (Meyer & Rowan, 1977).

Student Outcomes

The majority of programs reported that either there had not been any graduates yet to track, or that no data was available on those that did graduate. Of those that had graduates, reports of employment and education outcomes were anecdotal. Most programs that had graduates and knew something about what happened to them after the program reported that some students continued their studies, while students that entered the labor market had little difficulty finding relevant jobs and that salaries were similar to those of other graduates. Faculty at the University of Washington even mentioned that some students have dropped the program, which requires two years of additional work on top of a traditional Ph.D. program, to pursue nanotechnology job opportunities (University of Washington interview, 2009).

Some faculty that were interviewed noted that defining a "nanotechnology job" or a "nanotechnology employer" is difficult, making it difficult to easily determine if graduates are obtaining employment related to their nanotechnology-focused education. First, employers themselves do not always label the work as "nanotechnology". In addition, since nanotechnology is employed in so many different arenas, employers that use nanotechnology are generally defined by some other feature of their work. As one faculty member noted "One would not consider Haggar or Eddie Bauer as 'nanotechnology' companies." (Richland Community College interview, 2009) Another faculty member at an associate's degree granting school noted that, "a key to success with nano students has been their ability to engage in internships with local defense contractors that recognize the value of nanotechnology skills in a variety of business activities." (Harrisburg Area Community College interview, 2009)

CONCLUSIONS, POLICY IMPLICATIONS, AND OPPORTUNITIES FOR FUTURE RESEARCH

Nanotechnology education is, like the technology itself, still emerging. With only the beginnings of consensus around the "big ideas" that are important to teach in nanotechnology (Wansom et al., 2008) there is still considerable work to be done to identify the most effective content, form, and teaching methods in this area.

The findings noted in this study, therefore, are reflective of the emerging nature of nanotechnology. Nanotechnology degree programs are largely experimental endeavors supported largely by state and federal investments. The variation among programs in everything from content, to teaching methods, to level of employer involvement is neither surprising, nor problematic. It is simply they way that postsecondary institutions attempt to deal with new, ill-defined areas of knowledge.

Given that there is some reported level of employer involvement in all associate's degree programs contacted and some programs report anecdotal success in placing graduates in employment, these degrees may be a useful tool for addressing the technician-level skill needs of nanotechnology employers. Additional research on the effectiveness of these associate's programs would help inform the possible expansion of nanotechnology education in community colleges.

Overall, however, it is difficult to determine how important formal nanotechnology degrees are to addressing the skill and workforce needs of employers for more highly skilled workers. Previous research on the skill needs of nanotechnology employers indicates that, at least in the present job market, employers prefer to hire highly skilled workers who have earned a degree in a traditional discipline (Van Horn & Fichtner, 2008; Van Horn et al., 2009). Further, while formal degree programs represent an institution-level commitment to imparting nanotechnology knowledge, the motivations for starting nanotechnology degree programs at the bachelor's level and above are often not directly connected to meeting the skill needs of employers. In addition, most universities interviewed for this study that partner with associate's degree programs report high levels of employer involvement, but do not offer full nanotechnology degrees themselves. This may be further indication that there is little demand for workers above the associate's level to earn nanotechnology specific degrees. The current lack of alignment between the location of

nanotechnology degree programs and areas of high nanotechnology publication also calls into question the importance that degree programs play in supporting innovation in nanotechnology.

Degree programs may, however, prove to be more useful as the field of nanotechnology matures. Employers themselves are only just beginning to tap into the potential of the new technology, so many may not be able to accurately gauge the true education requirements for nanotechnology positions in the future.

To further the goal of creating a skilled nanotechnology workforce, The National Science Foundation (NSF) should consider supporting degree programs that have strong employer involvement. Policymakers should also promote greater involvement of employers in nanotechnology curriculum development. Evidence of interdisciplinary cooperation across departments and disciplines, as well as strong connections to nanotechnology research facilities and related degree programs at other levels of education, may also be important considerations for targeting programs, and/or areas where NSF may wish to direct additional technical assistance for programs. Such partnerships may be important for establishing career ladders that allow students to acquire increasing levels of skill, knowledge, and academic credentials over time. Further research on the employment and education outcomes of nanotechnology degree program graduates is also recommended.

To better understand the value of nanotechnology degrees and other forms of nanotechnology education to preparing a nano-literate workforce, further study of these programs is needed. NSF should consider supporting further process and outcomes-based research on the various educational responses that colleges and universities are developing in response to nanotechnology. Research on effective approaches to nanotechnology education at the primary and secondary levels of education is also needed.

Specifically in regard to nanotechnology degree programs and other postsecondary approaches, more information on the employment and education outcomes of graduates is needed to understand how effective various program models are at meeting the emerging skill and workforce needs of nanotechnology employers. Policymakers also require a more detailed understanding of how educators are structuring their approach to the interdisciplinary aspects of nanotechnology.

Due to the fact that many nanotechnology degree programs are new and the fact that graduates may not enter the labor market for some time, process studies of postsecondary education approaches in nanotechnology are particularly important. In particular, studies that identify structural, human resources, and other factors that facilitate various program models at colleges and universities can be helpful. Such studies may help policymakers to identify program elements that are important to foster to develop particular types of program models in the future.

Appendix A – List of Higher Education Institutions, Nanotechnology Degrees, and Interviews Conducted

Note: The asterisk (*) and the number following the institution indicate the number of interviews that were performed at that institution.

Arizona State University
PSM: Nanoscience

Bucks County Community College : Newtown, PA * (1)
AAS : Nanofabrication Technology

Butler County Community College : Butler, PA
AAS : Nanofabrication Technology

Chippewa Valley Technical College : Eau Claire, WI
AS : Nanoscience Technology

Dakota County Technical College : Rosemount, MN
AAS : Nanoscience Technology

Delaware County Community College : Media, PA
AAS : Nanofabrication Manufacturing Technology

Forsyth Technical Community College : Winston Salem, NC * (1)
AAS : Nanotechnology

Harper College : Palatine, IL
AAS : Nanofabrication Manufacturing Technology

Harrisburg Area Community College : Harrisburg, PA
AAS : Nanofabrication Manufacturing Technology

Lehigh Carbon Community College : Schnecksville, PA
AAS : Nanofabrication Technology

Lock Haven University of Pennsylvania : Lock Haven
AAS : Nanofabrication Technology

Louisiana Tech University : Ruston, LA
BS : Nanosystems Engineering
MS : Molecular Science and Nanotechnology
PHD : Micro/Nanotechnology and Micro/Nanoelectronics

Luzerne County Community College : Nanticoke, PA
AAS : Nanofabrication Technology

Minnesota State Community and Technical Collage : Moorhead, MN
AAS : Nanoscience Technology

Montgomery County Community College : Blue Bell, PA
AAS : Nanobiotechnology
AAS : Nanofabrication Technology

Normandale Community College : Bloomington, MN
AAS : Nanotechnology
AS : Nanotechnology

North Dakota State College of Science : Wahpeton, ND
AAS : Nanoscience Technology

North Dakota State University-Main Campus : Fargo, ND
PHD : Materials and Nanotechnology

Northampton Community College : Bethlehem, PA *(1)
AAS : Nanofabrication Manufacturing Technology

Northwest Vista College : San Antonio ,TX *(1)
AAS : Nanotechnology

Oklahoma State University : Okmulgee, OK
AAS : Engineering Technologies Nanoscientific Instrumentation Technology

Penn State Fayette Campus : Uniontown, PA
AAS : Nanofabrication Manufacturing Technology

Penn State Hazleton Campus : Hazleton, PA
AAS : Nanofabrication Manufacturing Technology

Penn State Wilkes-Barre : Lehman, PA
AAS : Nanofabrication Manufacturing Technology

Penn State York : York, PA
AAS : Nanofabrication

Pennsylvania State University Greater Allegheny : Mckeesport, PA
AAS : Nanofabrication Manufactruing Technology

Reading Area Community College : Reading, PA
AAS : Nanoscience Technology

Rice University : Houston, TX *(2)
MA : Nanoscale Physics Professional Master of Science

Richland Community College (Dallas County C.C. District) : Dallas, TX *(1)
AAS : Nanotechnology

Schenectady County Community College : Schenectady, NY
AAS : Nanoscale Materials Technology

Seattle Community College-North Campus : Seattle, WA * (1)
AAS : Nanotechnology

South Dakota School of Mines and Technology : Rapid City, SD * (1)
PHD : Nanoscience & Nanoengineering

Texas State Technical College-Waco : Waco , TX * (1)
AAS : Nanotechnology

University of Albany, State University of New York : Albany, NY
MS : Nanoscale Engineering
MS : Nanoscale Science
MS/MBA : Nanoscale Engineering + MBA
MS/MBA : Nanoscale Science + MBA
PHD : Nanoscale Engineering
PHD : Nanoscale Science

University of New Mexico : Albuquerque, NM *(1)
MS : Nanoscience and Microsystems
PHD : Nanoscience and Microsystems

University of North Carolina Charlotte : Charlotte, NC
PHD : NanoScale Science

University of Washington-Seattle Campus : Seattle, WA *(1)
PHD : Nanotechnology

Westmoreland County Community College : Youngwood, PA

AAS : Nanofabrication Manufacturing Technology
AAS : Bionanotechnology

Additional Interviews Conducted

Three additional interviews with directors of ***active degree programs*** were conducted at **Pennsylvania State University, University Park Campus (2)** and the **University of Minnesota**. While neither institution offers a degree program, administrators and faculty at these schools are directly involved in active degree programs offered at other institutions in partnership with the universities. Interviewees discussed degree programs in the Pennsylvania Nanofabrication Manufacturing Technology Network and NANO-LINK , respectively.

In addition, researchers conducted a total of 14 interviews with representatives from 13 institutions that were later determined to have inactive or ineligible programs under the criteria established for this study. The following is a list of these ***inactive degree institutions.***

California Polytechnic State University : San Luis Obispo, CA

College of the Canyons : Santa Clarita, CA

Drexel University : Philadelphia, PA

Foothill College : Los Altos Hills, CA

Johns Hopkins University Baltimore MD

Rutgers University : New Brunswick, NJ

Santa Barbara City College : Santa Barbara, CA

Stanford University : Stanford, CA

University of California-Berkeley : Berkeley, CA

University of California-Santa Barbara: Barbara, CA (2)

University of California-San Diego : La Jolla, CA

University of Central Florida : Orlando, FL

University of Michigan : Ann Arbor, MI

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