Nano Revolution – Big Impact: How Emerging Nanotechnologies Will Change the Future of Education and Industry in America (and More Specifically in Oklahoma) An Abbreviated Account

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Abstract

Scientists are creating new and amazing materials by manipulating molecules at the ultra- small scale of 0.1 to 100 nanometers. Nanosize super particles demonstrate powerful and unprecedented electrical, chemical, and mechanical properties. This study examines how nanotechnology, as the multidisciplinary engineering of novel nanomaterials into atomically precise products, is expected to disrupt most industries.

Past industrial revolutions, driven by water power, internal combustion power, electrical power, and computer power, have greatly affected our economy and forever changed the course of society. Nanotechnology represents more potential power than all previous technologies combined. The primary methodology of this study involved comparing the current literature on developments in nanotechnology to the historical development of electricity to assess if the nanotech revolution is reaching a true "critical mass," based on acceleration of technological change today and at other times in history. Data was collected from technical and business books on nanotechnology, testimonies from scientists before Congress, policy letters from the President's Office of Science and Technology, presentations at major nanotech conferences, perspective surveys from the international to the local level, studies on the dangers and regulation of nanotechnology, and studies on the general and scientific educational landscape of America.

Although nanotechnology is growing in national academic intensity, is gathering public recognition, and is based on patentable science, Oklahoma and the West South-Central Region received only 9.6 percent of nanotech funding (NSF Award DMI-0450666, 2005). This study establishes recommendations for business and academic planning with specific strategies, goals, and objectives for community college workforce education in Oklahoma.

Introduction

The discovery and utilization of basic enabling technologies such as fire, wheels, alchemy, electricity, magnetism, metallurgy, and combustion were watershed events in the destiny of humankind. These technologies incrementally changed the thinking about reach of life and richness of life on this planet. The next watershed event is rapidly swelling as scientists discover how to manipulate matter at the molecular level to produce materials with extraordinary properties that have never before existed or been understood. These hyper-functional materials, characterized at the nano scale, have the potential to overwhelm all the collective contributions of past technologies. "Nanotechnologies will eventually disrupt, transform, and create whole industries" (Morse, 2004). Not just the industrial landscape will change dramatically but "because of nanotechnology, we will see more change in our civilization in the next thirty years than we did during all of the twentieth century" (Uldrich & Newberry, 2003). Although nanotechnology has been only a buzzword for the masses, it is approaching "critical mass" for the next "Industrial Revolution."

Study Purpose

Because nanotechnology reflects a multidisciplinary convergence of physics, chemistry, biology, and engineering, the definitions, predictions, and concerns for this emerging science/technology are biased in many directions. The purpose of this study is to bring into focus the many perspectives that nanotechnology has already created by establishing a consensus of technical facts, realistic timelines, economic potentials, security interests, and ethical issues. Nanotechnology is like a gathering storm that represents very intense yet diverse interest for all stakeholders. Like the tracking of a developing hurricane that is headed for land, this study intends to track the gathering forces of nanotechnology that are building toward the next "Industrial Revolution." The study also addresses the major impact of how the nano revolution will change the educational and industrial landscape for America, specifically in the rural sector. No industry will go untouched: transportation, agriculture, chemicals, plastics, electronics, computers, cosmetics, healthcare, medicine, and many more will benefit from this "Fantastic Voyage" to the center of matter. Nanoscale technology is not just another step toward miniaturization; it is a qualitatively new scale that requires new ways of thinking.

Study Objectives

1. Identify socio-technical relationships between past Industrial Revolutions and the development of nanotechnology from 1959 to present.

2. Establish present and pending socio-technical impacts of nanotechnology on American educational and business institutions.

3. Investigate the knowledge, attitudes, and planning of business professionals concerning the impact of nanotechnology in Oklahoma through a Chamber of Commerce sponsored survey.

Study Significance

This study is important for addressing the nonscientists on scientific issues that may very well affect their employment, health, education, finances, and security. Because of striking diversity among scientists, those outside the research community have a significant gap in practical knowledge, which leads to unsettling confusion over nanotechnology buzzwords and futuristic predictions. This study is also important for clarifying the socio-technical impact of a rapidly growing yet still technically clouded science/technology. Putting nanotechnology to work will require investing in a new generation of highly skilled technologists. This study will be significant for defining educational objectives that applied science colleges should consider to supply nanotechnologists for emerging nano product commercialization and for micro-level companies that are migrating to nano level.

Impact Survey Questions

The Oklahoma Nanotechnology Impact Survey (ONIS) was developed to further test the thesis that nanotechnology will significantly affect Oklahoma business and education. To investigate the knowledge, attitudes, and planning of business professionals concerning their view of how nanotechnology has and will impact the state of Oklahoma, the ONIS was provided as a project to the Oklahoma State Chamber of Commerce whose findings were shared with the Oklahoma Center for Advancement of Science and Technology (OCAST). The ONIS was disseminated to a database of 4,542 Oklahoma businesses. The six survey categories are (1) interest & knowledge, (2) economic effects, (3) strategic planning, (4) Oklahoma perception, (5) regulation, and (6) state support. Survey results for 2006 and 2007 are located at http://www.oknano.com/pdf/ONIS.pdf and http://www.oknano.com/pdf/NanoSurvey07.pdf.

Study Rationale

"The ability to build anything we can design, by manipulating molecules under direct computer control, will be a jolt to the system" (Treder, 2004). That jolt will be seen as technical and social developments from nanotechnology that include: novel production methods and new products with advanced properties; nano-factories that replicate more nano-factories in an exponential proliferation of manufacturing; rapid and low cost prototyping that greatly reduces product time to market; very low cost raw material and capital investment requirements that can introduce major discontinuities for the economy; and portability and secrecy of major manufacturing capability that can disrupt social norms and national security.

Consistent with the "jolt to the system" view, the rationale of this study is driven by five concerns: (1) Core values need to be evaluated based on the overwhelming properties of nanotechnology. (2) Strategic planning needs to align with the acceleration of nanotechnology development. (3) Markets and security threats need to be developed based on global competitiveness in nanotechnology. (4) Ethical applications of nanotechnology should be at the forefront of policy making decisions in business, education, and government as continued research and development reveals the ever growing potential of nanotechnology. (5) Educational and business models need to lead not follow nanotechnology developments.

Review of the Literature & Survey

What is the History and Nature of Nanotechnology?

Nanotechnology was an unexplored scientific frontier until 1959, when theoretical physicist Richard Feynman invited fellow scientists to consider the possibility of manipulating matter at the molecular and atomic levels to build ultra-small machines and information storage devices. Though Feynman was convinced that physics would allow for atoms and molecules to be individually controlled and manipulated, he did not know what tools would be required and he did not know the amazing materials that would result to form new atomic structures (Keiper, 2003). Because nanotechnology is growing rapidly and gaining momentum, it does not share a unified conceptual understanding across all disciplines and that creates a problem in defining it. “Definitions of nanotechnology are as broad as its applications” (ENA, 2004, p. 7).

Nanotechnology results from deliberate design and processes, but some confusion and controversy complicate an accurate definition by the fact that there are naturally occurring nanosize materials residual in industrial processes. Some differences in definition are of only academic interest, but “the way nanotechnology is defined in a regulatory context can make a significant difference in what is regulated, how it is regulated, and how well a regulatory program works” (Davies, 2005, p. 7).

The National Nanotechnology Initiative (NNI) encourages a strict definition of nanotechnology by including only activities at the atomic, molecular, and supramolecular levels, in the length scale of approximately 1 – 100 nm range that create materials, devices, and systems with fundamentally new properties and functions because of their small structure. The NNI definition focuses on new contributions that were not previously possible because of novel phenomena, properties, and functions at the nanoscale. The abilities to measure, control, and manipulate matter at the nanoscale in order to change those properties and functions are the hallmark of nanotechnology (Roco, 2003).

Nanotechnology is developing a very disruptive nature. In fact the view of industry experts is that “It's hard to think of an industry that isn't going to be disrupted by nanotechnology” (Uldrich & Newberry, 2003). This view of a pervasive invasion is reflected in the studies and presentations of Smalley (1999), Murdock (2002), Roco (2003), Bordogna (2003), Treder (2004), and Dareing and Thundat (2005). One way to keep the disruptive potential of nanotechnology in perspective is to ponder the disruption that would occur if electricity were suddenly unavailable. Utilities, transportation, communications, commerce, education, much of the country’s infrastructure, and almost all products that we use on a daily basis would cease to operate.

Products enabled by nanotechnology will evolve, but as Treder (2004) points out – “with all that change compressed into just a few years.” Bordogna (2003) is also certain that nanotechnology is not just transformational but “with nano, change is about to go ballistic.” Emerging nanotech businesses that prevent health problems from occurring will displace businesses that supply cures and treatments for diseases. Similarly, if nanotechnology identifies molecules responsible for depression and assists in binding new drugs to modify those molecules then Eli Lilly who manufactures antidepressant drugs like Prozac might find that nanotechnology has disrupted their business (Uldrich & Newberry, 2003).

“Nano has been called a ‘general purpose technology’ to capture the expectation that – like electricity – nanotechnology will enable and reconfigure a wide range of technologies, touching most sectors of the economy” (Bordogna, 2003). The disruptive properties of nanotechnology extend beyond the science because most people do not comprehend its transformative nature and how rapid transformations could take place. Cross-discipline communications is a difficult and common behavioral science problem that nanotechnology could also address by creating technological synergy that has never before existed (Phoenix, 2003). This opportunity for synergy was recognized by Smalley (1999) when he stated that “Nanoscience is an opportunity to energize the interdisciplinary connections between biology, chemistry, engineering, materials, mathematics, and physics in education.”

At the very highest levels of government, the National Nanotechnology Initiative has a very aggressive and disruptive vision that targets K-12, universities, vocational, and public domains for nanoscience and nanotechnology education. In the *National Nanotechnology Initiative Strategic Plan* prepared by the National Science and Technology Council, co-chairs Russell and Bond (2004, p. I) set four goals to accomplish the NNI vision: (1) “Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology; (2) Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit; (3) Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; (4) Support responsible development of nanotechnology.”

How is Nanotechnology Perceived by the General Public?

Based on their study, Cobb and Macoubrie (2004, p. 395) conclude that "perception and knowledge are important parts of public understanding of science." Their National Science Foundation-funded survey conducted at North Carolina State University in 2004 found that 80 to 85 percent of the general public in America had not heard anything or at most very little about nanotechnology. The *"Oklahoma Nanotechnology Impact Survey"* (ONIS), which was conducted online and at business conferences during April of 2006, found that 92 percent of Oklahoma citizens were generally not informed about nanotechnology as perceived by Oklahoma business professionals. According to a "European NanoBusiness Survey" (2004), 87 percent of European citizens were either not much or not at all informed about nanotechnology (ENA, 2004). The European NanoBusiness Association (ENA) survey was biased with respondents from companies that had an interest in nanotechnology.

In 2005, the Project on Emerging Nanotechnologies published results of a study entitled "Informed Public Perceptions of Nanotechnology and Trust in Government." The report reveals that American consumers are eager to learn more about nanotechnology, and they are generally optimistic about the possibilities that nanotechnology will improve their quality of life. The public is most interested in major medical advances, particularly new and improved treatments for cancer, Alzheimer's, and diabetes (Rejeski, 2005). When Oklahoma business professionals were asked if nanotechnology will have a significant effect on the lives of Oklahoman citizens, a high percentage (78%) agreed that it would. The tension between acknowledging lack of knowledge and anticipating significant impact is striking and begs the question of how uninformed citizens may react to unfolding events that nanotechnology will engender, both real and perceived.

Public perception of nanotechnology depends on democracy and outreach to citizens. Roco (2003) recommends fostering public awareness and understanding of nanoscale science and engineering through development of media projects and exhibits that address benefits as well as unexpected consequences. Even with a negative public perception of nanotechnology, a majority of Oklahoma business professionals would continue to utilize nanotech products. A similar question in the ENA (2004) survey indicated that 74 percent of Europeans businesses would not change their attitude about using nanotechnology, even if there was negative public perception.

What Risks Are Associated with Nanoscale Molecular Manipulating?

Nanoscale agents that are produced by molecular manipulation can be introduced into consumer products to achieve certain benefits, but the penetrating properties of ultra small size also introduces certain and to-date unpredictable risks. As Germany's Federal Institute for Risk Assessment is investigating 97 cases of intoxication from a cleaning product called "Magic Nano," America's counterpart, the Food and Drug Administration, announced plans for discussions on nanotechnology materials being used in drugs, foods, cosmetics, and medical devices (Associated Press, 2006). Environmental situations are endless, ranging from the distribution of nano dust on American highways as nano-enhanced tires wear down to the eventual pollution of ground water because of the unstoppable mobility of nano size materials (Brown, 2002). Medical risk studies by Southern Methodist University and the University of Rochester have shown that carbon buckyballs (C60 hexagonal spheres) and other nanoscale materials can enter and be absorbed by the brain; however, the levels of damage and the required exposure rates are still under study (Feeder, 2004).

In most every public discourse on nanotechnology, including testimonies before the U.S. Congress and statements from the Executive Office of The President of the United States, the ethical and social concerns are elevated to a "high priority" status, yet, few decisions seem to reflect the urgency (NSF Award ESI-9730727, 2000; Roco, 2003; Davies, 2005; Marburger & Bolten, 2005). Policies become an afterthought rather than being fully integrated into the planning process. As Rejeski (2005) stated, "Our approach to social and ethical issues has largely involved an 'outsourcing' model where the scientists do the science and 'ethics' are dealt with in separate institutions and centers." Many nanotech companies already fear public reaction because of the current lack of regulation (Davies, 2005). Rejeski (2005, p. 64) recommends that we "create a Nano Safety Reporting System where concerned people working with nanotechnologies in laboratories, companies, or in shipping and transport situations can share safety issues and concerns."

In spite of the looming risks, the initial reactions to nanotechnology by Americans have thus far been mostly positive. Most Americans have a positive view of science and expect the benefits of nanotechnology to be more prevalent than the risks. When the potential benefits of nanotechnology are seen as new and better ways to overcome human diseases, people feel more hopeful about the technology. The greatest risks people express are the loss of personal privacy due to possible nano surveillance and the inability of business leaders to minimize nanotechnology threats to human health (Cobb & Macoubrie 2004). Americans do have trust in regulatory agencies as shown from a study by the 2005 Woodrow Wilson Center's "Project on Emerging Nanotechnologies." The internet can also provide opportunities to inform and involve the public (Davies, 2005).

What Economic Forces Will Drive Nanotechnology Commercialization?

Joseph Finkelstein (1992, p. XV) wrote: "We are at the beginning of a Third Industrial Revolution that will reshape not only our industrial processes but also bring with it great changes that will affect all our lives for the next century." Twelve years later, Mike Treder (2004, November), Director for the Center for Responsible Nanotechnology, wrote: "The combined impacts of nanotechnology will equal the Industrial Revolutions of the last two centuries – but with all that change compressed into just a few years." Treder's (2004) view is that we have been in the Fourth Industrial Revolution since 1950 and that we are now on the eve of the Fifth Industrial Revolution that is driven by nanotechnology.

Industrial revolutions have been observed to develop in three stages: one sector of the economy undergoes rapid change, then this sector grows more rapidly than the rest of the economy, and finally this advanced sector affects the rate of development in all other sectors (Mokyr, 1985). Restating this model in modern terms would say that first a technology emerges rapidly, then the technology matures having specific socio-economic benefits, and finally this technology becomes so disruptive that it affects all other technologies that define our socio- economic system. The first stage is marked by innovators' research, the second stage is marked by investors' forecasts, and the third stage is marked by consumers' adaptation.

Cloth weaving had been unchanged for thousands of years until flying shuttle technology emerged in 1733. This technology matured with the inventions of the spinning jenny in 1764, the power loom in 1785, and the cotton gin in 1793. By the early 1800s this collective technology was developed and became disruptive to the textile industry. Consumers preferred the high performance, low cost, and pattern options that mechanically woven fabrics provided. Hand weavers were displaced with violent opposition yet the textile revolution was evident and irrevocable (CBS News, 1997).

The difficulty of judging when and how an industrial revolution unfolds is complicated by the "failures to anticipate future development of new technologies" (Alcaly, 2003, p.66). Actually, enabling technologies can precede or follow the basic science that contains the latent potential of the industrial revolution. The striking phenomenon of failing to see latent potential is seen repeatedly over decades in the statements of some very high profile industry leaders, for example: (1) Western Union refused Alexander Graham Bell's telephone patent for just $100,000.00, insisting that the telegraph would never be replaced; (2) The British journal, *Engineering*, wrote that Thomas Edison's electric light was "unworthy of the attention of practical or scientific men" (Clarke, 1962, p. 2); (3) Thomas Watson, Chairman of IBM, stated in 1943 that he thought "there is a world market for maybe five computers" (National Research Council, 2006, p. 13); (4) Again in 1968, IBM's Advanced Computing Systems Division questioned the microchip saying *"What is it good for?"*; and (5) Ken Olson, President, Chairman, and Founder of Digital Equipment Company stated in 1977, "There is no reason anyone would want a computer in their home" (Clarke, 1962, p. 13).

Industrial revolutions are by definition benchmarks in technology that forever change the landscape of national wealth, social norms, and technical education. Alcaly (2003) points out that "we underestimate the time it took for the technologies to establish a critical standing in the economy." Dr. Joseph Bordogna, Deputy Director and Chief Operating Officer for the National Science Foundation, includes electricity, information technology, and communications as the most disruptive revolutions of the past century (Bordogna, 2003). A technology with an enormous disruptive potential usually has a long formative delay and is implemented with great difficulty and opposition. "As with information technologies, and for many of the same reasons, it took almost half a century before electric power had a significant impact on productivity growth" (Alcaly, 2003, p. 68). Hughes (2001, p. 15) also identifies electricity as a major component of the Second Industrial Revolution and further explains the reason why technological determinism stalls: "While correctly anticipating momentous changes, they frequently erred in anticipating the nature of those changes although they thought their predictions were value-free, they unwittingly imposed their values upon the technological future."

Perhaps it was the delayed impact of electrification that shadowed its significance as perhaps the greatest enabling technology of all time. Initially, most of the power increases took place in cities and "it took until 1956 for farm homes to have the same percentage of electric service (98 percent) as non-farm homes" (Milham & Ossiander, 2000, p. 1). In explaining why electrification took so long, Alcaly (2003, p. 68) writes that "Electrification of American homes and industry did not gather 'real momentum' until after World War I, when central generating capacity expanded widely and rates fell substantially, reflecting advances that had been made in producing electric power, extensive construction of new generating plants, and scale economics."

The correlation between technologies and industrial revolutions is certain but fixing causation can be problematic. More complex yet is defining cause and effect relationships between education and industrial revolutions. There has been much debate as to whether industrial revolutions expose the effectiveness of education or the serious lack of it. Nanotechnology is entering the marketplace at an ever-increasing pace. As of March 8, 2006, the Project on Emerging Nanotechnologies had counted 212 product lines that use nanotechnology.

What Emerging Nanotechnologies Will Redefine the Oklahoma Workforce?

In a report on essential nanotechnology studies, the Center for Responsible Nanotechnology indicated "that a tenfold improvement (one order of magnitude) is sufficient for a new product or method to displace existing ones" (Phoenix, 2003, p. 43). New companies that manufacture products in a "nanofactory" will greatly exceed the tenfold criterion and would displace existing companies that are not quick to change. This reflects the disruptive nature of nanotechnology on businesses, the workforce, and the economy, especially with manufactured products (Phoenix, 2003). For this reason, "push strategies" for small businesses and nano start-ups should be encouraged. "Push strategies" involve governments at all levels offering small nano businesses of 8-10 persons with useful technical assistance that addresses environmental, health, or safety issues and possibly financial support (Rejeski, 2005). If small nano businesses cannot sustain the financial burden of risk and capital investment overhead, then most start-ups may not market their own products. They will seek large company partners who can utilize their nanotech developments to improve existing commercial products (Davies, 2005). A common problem is that many large companies do not want to talk openly about their nanotechnology involvements. These companies do not want to put their resources and assets at risk with uncertainties concerning public reaction and government regulatory intentions (Rejeski 2005).

Any industry involved in R&D will need a long-term view and patience to develop a roadmap for their involvement in nanotechnology. For example, in 1947 when the transistor was developed, its cost was known, but it would have been impossible at that time to predict the cost of that transistor within an integrated circuit containing thousands of transistors in the year 2001. Predicting the actual cost of devices, circuits, and networks fabricated at the nano scale several decades from now is impossible, but like the transistor, it will likely be low enough for mass production. Because very few small start-ups or even large companies can afford to spend decades pursuing future bonanzas without near-term profits, universities and national laboratories need to provide the interdisciplinary research to establish the groundwork for the most profound breakthroughs in nanoscale technology. This type of research and partnerships are not what most universities currently foster ("Small Wonders, Endless Frontiers," 2002).

There is good reason for Oklahoma to make changes since the state's economy has grown slowly compared to neighboring states. Salehezadeh and Kickham (2002, p. 2) stated in a gnosis report for the Oklahoma Department of Human Services that while employment has been growing in Oklahoma at the 11th highest rate nationally, "the highest proportion of employment is in low-paying jobs." The top three employment sectors in Oklahoma are services (38%), retail trade (19%), and manufacturing (13%). The services sector is first in employment but near the bottom in average weekly wages because these jobs require little or no formal training or education. Manufacturing is third in employment and also third in average weekly wages, preceded only by mining jobs and public service jobs (transportation, communication, utilities). Within an eight-state region, Oklahoma is next to last in college degrees and households with computers and internet access. Oklahoma also falls below the national average in technology and education. It is no wonder that over the last decade the purchasing power of the average worker in the two largest Oklahoma counties has decreased. According to the gnosis report, Oklahoma has "failed to adapt, to evolving economic imperatives." The report references Peter Drucker who as early as 1969 began urging the anticipation of "knowledge workers" in a postindustrial society. The report concludes that "investment in education and training would therefore appear to be a strategy worth considering, as would strategies that improve capital productivity (Salehezadeh & Kickham, 2002, p. 1). The Oklahoma Nanotechnology Initiative may be the very strategy for improving productivity and increasing real income for the workforce by increasing the number of "knowledge workers" in the state.

How Will Nanotechnology Impact Strategic Planning for the Oklahoma Business Community?

Since only 22 percent of business professionals are well informed about nanotechnology, perhaps it is not surprising that less than 20 percent of them are making any adjustments to their strategic business plans for the coming nanotechnology impact. When the business professionals were asked if they evaluate emerging technologies for strategic planning, over 50 percent agreed that they were proactive. At this time it is apparent that nanotechnology has not been one of the emerging technologies that they include. This will likely change in the future since a high percentage of business professionals are interested in learning more about nanotechnology, and 74 percent agree that nanotechnology will have a significant impact on the Oklahoma economy.

When Oklahoma business professionals are asked about nanotechnology hiring decisions, the neutral responses rise to nearly 50 percent. This may be attributed to the modest 22 percent who are well informed about nanotechnology. The 22 percent who see a pending need to increase both the nano technologist and the non scientific workforce create a significant concern to plan for workforce training.

When business professionals were asked about their attitudes in the face of potentially negative nanotech situations, the neutral responses were again the majority of percentages. Most may feel that they are just not well enough informed to make a sound judgment. Of those who did make a decision, most of them disagreed that regulation or negative public perception would change their business. The group was about split over the issue of diminished competition without changes to the nanotech revolution. This could clearly reflect the attitude of how nanotechnology may impact different industry categories.

The attitudes toward investing in nanotechnology seem very positive in Oklahoma with very few in disagreement. A much higher percentage of business professionals are willing to invest in a nanotech start-up business than the percentage of them that are well informed about the technology. This may indicate that positive public perception is more influential for investment than actual knowledge about the science.

What Reforms Are Needed To Integrate Nanotechnology into America's Educational Institutions?

Historically, when the security or economy of the United States has been threatened, leaders have responded with successful educational reforms. After World War II, President Franklin D. Roosevelt commissioned a team to review and recommend reforms that were needed in scientific research and education for the future well-being of our country. Only a decade later, the Soviet Union launched the first earth-orbiting satellite, and America responded with unprecedented educational reform in science and mathematics, focused on developing youthful talent in science and engineering (Jackson, 2004).

Following these educational reforms in the 1940s and 1960s, the National Commission on Excellence in Education in the 1980s again urged reform for science education in its report called, *"A Nation at Risk."* Educators then took a hard look at what had been passing for science education and began making commitments to do things differently (NSF Award ESI-9730727, 2000). Despite these efforts, a quiet crisis was developing in the United States with a rapidly growing imbalance between supply and demand of technically skilled workers that threatened to jeopardize the nation's leadership position and security. According to the BEST (Building Engineering and Science Talent) report, "the same wheels are being re-invented and the same mistakes made on a daily basis in every part of the country" (Jackson, 2004, p. 5).

Due to poor forecasting of America's need for scientists and engineers, the National Science Foundation's credibility was put in question by Rep. Howard Wolpe, Chairman of the Subcommittee on Investigations and Oversight of the House Committee on Science, Space, and Technology. NASA's administration also testified before the House Science Committee that not only was NASA disadvantaged in competing for technical talent but confirmed the general competitive problems due to a lack of scientists and engineers (Teitelbaum, 2002).

The NSF Award ESI-9730727 (2000) concluded that integrated science is a valuable and viable educational reform alternative because:

- Integration engages a greater diversity of students
- Integration presents the unifying concepts and principles of science
- Integration reflects the reality of the natural world
- Integration encourages comprehensive thinking about a complex world.

Integrated science unifies concepts and principles of science, making science seem relevant and connected to life. Project-based problem solving blurs the boundaries of the sciences and encourages students to investigate a range of disciplines and concepts based on the student's "need to know." Answering "why" and "how" questions about broad themes and unifying principles provides a rich context for a creative learning experience.

Another pedagogy for student-focused learning is "design education." Design education involves students in the process and methods of realizing an engineering artifact. This integrated and interactive education provides students with the hands-on design-build-operate experience to understand engineering concepts (Vest, 1995). Sheppard and Jenison (1996), writers for the *International Journal of Engineering,* concluded that students should understand the "how to" of generating design specifications, going from design specifications to final artifact, establishing objectives and criteria, investigating alternatives, synthesizing, analyzing, constructing, testing, and evaluating. The Accreditation Board for Engineering and Technology (ABET) requires engineering students to accomplish a major and meaningful integrated engineering design experience that brings together the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, and communication skills.

In his position as Subcommittee Chairman of Nanoscience, Engineering and Technology (NSET) of the National Science and Technology Council (NSTC) and Senior Advisor for Nanotechnology, National Science Foundation, Dr. M. C. Roco urges unifying science and education by integrating research and education. In his *"The Future of the National Nanotechnology Initiative"* presentation to the NSET, Roco states that systemic changes are needed to make every laboratory a place of learning as well as research and particularly undergraduate nanotechnology education. His vision of integrated interdisciplinary or unified sciences includes "development and dissemination of new teaching modules for nanoscale science and engineering that can be used in existing undergraduate courses, particularly during first and second year studies." And to "introduce nanoscale science and technology through a variety of interdisciplinary approaches into undergraduate education, particularly in the first two collegiate years" (Roco, 2003, p. 30).

Conclusions

Nanotechnology is a catch-all word that has come to mean everything through the collective perspectives of people in multiple disciplines both technical and business, including the problem of calling things nano that are not in order to capitalize on the veiled mystery of a supercharged technology. This catch-all phenomenon is unfortunate but understandable since nanotechnology is not a product nor is it a discipline-specific application like biotechnology.

Nanotechnology is a "general purpose" technology that enhances all other technologies very much like the generation of electricity. Batteries as a source of electricity are not useful unless they are installed in a product to power the application, and the usefulness of nanotechnology is measured by the power it brings to many applications. Nanotechnology is an empowering catalyst that unlocks latent and unique properties in existing elements through molecular manipulation using scanning probe microscopy, crystalline growth, and high temperature processes. New materials that result from nanotechnology have a "general purpose" utility value for combining with other materials to optimize physical, thermal, magnetic, electrical, and optical properties or for creating devices that operate at the cellular level for biological and medical applications. Previous "general purpose" technologies (e.g., electricity generation, internal combustion, and advanced materials) have changed the very infrastructure of our country and the fabric of our society.

More of the study details, results, findings, conclusions, recommendations, and supporting documents are included in the 130-page report, "Nano Revolution: Big Impact" and it is available from steve.holley@okstste.edu. A two-year AAS degree program in "Nano-scientific Instrumentation" based on this study is being developed under a NSF ATE grant that can be reviewed at http://www.osuit.edu/academics/engineering_technologies/nanotechnology/ .

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