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Convergent Science and Technology as a New Concept in Engineering Education at Northern Illinois University

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ABSTRACT: *Presented is a chronicle of Northern Illinois University's development of a Convergent Science and Technology program. Northern Illinois University's Engineering program has existed as a four-year program for less than twenty years. The program has grown to approximately 1600 students in four departments with both Bachelors and Masters programs. Recently the Engineering School has become involved heavily with the Physics Department in developing a core nanotechnology research program. This research will also be used to improve both undergraduate and graduate education. We will extend this information into high school and junior high. The program is federally funded and includes both faculty and students in the Physics and Engineering curriculum. Due to the interdisciplinary nature of Nanotechnology, traditional engineering schools are challenged to adapt to the changing research climate. This challenge will require traditional "silos" or academic boundaries to be broken down. The paper will attempt to reach out and create joint programs with Math, Chemistry and Biology, as well as our Physics partnership.*

1 INTRODUCTION

Northern Illinois University is a comprehensive university with more than 40 departments and 70 degree programs offered by seven colleges. The university, which started as a basic teacher school, has blossomed into one of the prominent comprehensive universities in the region. Currently, NIU is rated as a doctoral extensive I university and is one of the eighty nine members of the prestigious University Research Association. All colleges have quality programs with appropriate accreditation. The university is accredited by the Higher Learning Commission formerly known as North Central Association (NCA). The university has recently refocused its interest in interdisciplinary studies. Cross disciplinary studies in areas such as nano-science and materials are being discussed among many departments.

The College of Engineering and Engineering Technology, which is one of the seven and youngest colleges at NIU, is an active participant in all of the endeavors. Founded in 1986, the college has established quality professional programs that have the capability of providing avenues for cross disciplinary studies.

History has witnessed a high focus in disciplinary studies in engineering programs. For the last 100 years, the field of engineering has focussed on disciplinary programs providing specific specialization. This increasing specialization tends to fragment engineering programs into more and more subgroups. This form of technological entropy has also tended to isolate engineers from the sciences to some extent. This process could be called divergence. Recently, the confluence of nanotechnology, biotechnology, cognitive science, and information science has begun to reverse this process [Radnor and Strauss]. The merging of these topics has been supported by the National Science Foundation (NSF) of the United States as a priority for the twenty-first century. The name that has been given to this confluence is Convergent Technologies (CT).

Along with the concept of CT, there is another concept that is rapidly being realized. This new concept is Concurrent Manufacturing (CM) [NAP/NSF]. Concurrency will require the rapid utilization of information, rapid system reconfiguration, and quick training of workers, new simulation tools, and seamless communication. It can be conceived that the intersection of both CT and CM will propel the major technological advancements of the twenty-first century. Recent developments in human machine interfaces have just begun to explore what could be achieved with technology.

Universities and Engineering programs will have to grow to meet this challenge. Engineering programs tend to be grounded heavily in the past due to the basic nature of Academia. Large schools have large bureaucracies that tend to promote the status quo. However, explicit funding priorities by agencies such as NSF, DOE, NIH is providing an incentive for all of the universities to engage in cross-disciplinary studies. Added to the funding priorities, one can also see a shift in the expectations of the employers of engineering graduates. Almost all of the successful companies understand and engage in the process of simultaneous engineering/manufacturing thereby requiring the entry-level engineering workforce to have diverse skills and to be cross trained in more than one area of engineering. Fields such as Mecha-tronics, Nano Science, Bio Engineering, Bio Technology, and Entrepreneur Engineering are becoming an established reality at major universities interested in innovation. Convergent technologies will give the programs that are willing to adapt to the new challenges, an opportunity to lead the way. State universities have a special charter to support not only their student bodies but also their local and regional interests.

Northern Illinois University is an accredited institution of higher learning based in the northern region of Illinois. The surrounding towns and cities have had their economies fueled by traditional manufacturing. The legacy of this tradition is in the mascots of the local secondary schools. An example of this is the De Kalb "Barbs" (short for barbed wire). The town that NIU is based in, De Kalb, is a good example of the history of manufacturing in the United States [De Kalb Park District]. The first factories, for the automated production of barbed wire, were founded in De Kalb during the late nineteenth century. By the middle twentieth century, the factories had all closed. De Kalb is a microcosm of the Midwestern US experience. Those who cannot innovate and adapt are likely to be left behind. The mission of the College of Engineering and Engineering Technology (CEET) is to provide high quality undergraduate and graduate programs in engineering and technologies for the people of Illinois and to respond to the increasing demand for highly qualified professionals in the industries in the university's service region. To achieve this goal, it is first necessary to attempt to ascertain what will be necessary for education in the five, ten and twenty years. There are two basic models for models for engineering and technology education [G. M. Whitesides and J. Christopher Love]. The model that we use in the United States is a top down model that centers on the doctoral levels. The competing model is the European model, which relies heavily on skilled technological craftsmen. It has yet to be determined which model will be the most successful.

2 LNSET ORGANIZATION AND RESEARCH OBJECTIVES.

A national nanotechnology initiative has been launched to insure that the U.S. benefits from 21st century technologies forecast to continue the "silicon" revolution of the 20th century. In year 2000, Dr Alan Genis from Electrical Engineering and Dr. Clyde Kimball of Physics wrote the first nanotechnology white paper at NIU. This white paper eventually became our first nanotechnology program. Since the initial authoring of the white paper, NIU has received nanotechnology funding from a Federal Nanotechnology Initiative from the United States Congress. This research collaborative is aptly named the Laboratory for Nanoscale Science Engineering and Technology (LNSET). The program is truly interdisciplinary with researchers from the Electrical Engineering, Mechanical Engineering and Physics Departments. Additional collaborators from Argonne National Laboratory also participate in this research program, giving students access to world class investigators. There are four joint appointments presently between ANL and NIU. These appointments are for persons with exceptional research records.

A principal scientific reason that nanoscale materials and structures are of interest is that size constraints frequently lead to qualitatively new behavior. When the sample size becomes comparable with a given physical scale, e.g., magnetic domain size, coherence length of phonons or the electron mean-free-path, the corresponding physical phenomena are strongly affected. In addition, thermodynamic properties that determine the stability of the crystal structure and collective behavior, e.g., ferromagnetism or superconductivity, are altered. There exists little experience or intuition for predicting the resulting behavior. Nanotechnology arises from the application of these new properties. Thus, the nanoscale (~1 to ~100 nm; that is, from a few to a few hundred atomic lengths) is qualitatively different, requiring quantum considerations to describe physical behavior and its application to technology. Nanomaterial Science encompasses three concepts: 1) organization of nano-objects into architectures that lead to new phenomena with no macroscopic analog; 2) proximity interactions between adjacent nano-objects that lead to modification of the properties of each, resulting in a new material; and 3) confinement of a material to length scale too small to support the interactions responsible for macroscopic behavior. Hence, the process of discovering the physics, chemistry and biology of phenomena on the nanoscale is a new subject. LNSET is centered at and administered by Northern Illinois University. Figure 1 shows an organizational diagram of the LNSET program. Clyde Kimball, (Distinguished Professor of Physics), is the Director of LNSET; the Deputy Director is Michel van Veenendaal (Associate Professor of Physics).

Oversight will be provided to ensure the critical collaborative and interdisciplinary nature of the scientific and technical thrusts so that the scientific and technological objectives in nanoscale science and technology are achieved. A key aspect of LNSET is that the purchased equipment is owned by the center and not by individual investigators. The equipment will remain accessible for outside users, thereby guaranteeing optimal use of the equipment. An individual will be responsible for operation and creation and overview of user programs. The use of the equipment will be monitored so that the center remains focused on completing the goals in nanoscale science and technology. Assessment of LNSET's performance will be made by an Advisory Committee composed of Frank Fradin, Associate Laboratory Director, ANL; Sam Bader, Director, ANL/DOE Center for Nanoscale Materials; George Crabtree, Director, Materials Science Division, ANL; M. van Veenendaal, NIU; and J. Shaffer, Chair, Physics Dept., NIU. The committee shall overview quality, performance, and relevance to the development of a nanoscale science and engineering program at NIU. NIU's relationship with Argonne National Lab is shown in Figure 2. This relationship is primarily through the Advanced Photon Source and the Materials Science Division (MSD).

Northern Illinois University has an extensive experience in the synthesis of high-purity complex oxides using our high-temperature, high-pressure furnaces. High-sensitivity thermogravimetric analysis, x-ray diffraction, Mössbauer spectroscopy, and transmission electron microscopy will ensure a high sample quality. This capability has been very successful in areas such as high-Tc superconductivity and the colossal magnetoresistive manganites. The facility will be expanded by acquisition of a pulse-laser deposition (PLD) system. This technique uses laser ablation of materials with faithful stoichiometry. This apparatus is among several different deposition systems housed in the LNSET Class 100 clean room. Other methods available are ion-beam deposition, magnetron sputtering, and e-beam evaporation. The laboratory has both nanolithography (e-beam) and PG photomasks available for patterning films. LNSET also has a share in the focussed ion-beam system (FIB) which will be set up at ANL's Center for Nanoscale Materials. This enables the creation of quantum dots and other nanoscale devices. The acquisition of this PLD system, shown in Figure 3, will allow LNSET to investigate the structural properties of ferromagnetic-nonmagnetic (and ferromagnetic-superconducting) heterostructures suitable for tunneling magnetoresistance junctions. As the building blocks of the heterostructures, ferromagnetic La1-xSrxMnO3 or La1-xCaxMnO3 will be used. These materials are chosen for their high degree of spin polarization. Several different perovskite oxides with structural affinity to the ferromagnetic layers will be tested as insulating barrier layers. The ferromagnetic and nonmagnetic layers will be first deposited in the form of super-lattice structures with varying relative thickness of the alternating layers. Structural studies of the fabricated superlattices will be performed. By analysis and modeling of the positions and intensity of the satellite peaks related to the superlattice structure we will be able to estimate the interface roughness and correlate the interface quality with the magnetic and magnetoresistive properties of the super-lattices to find optimal compositions and modulation. The application of antiferromagnetic barrier spacer will enable the study of the role of the magnetic interface roughness to the exchange bias interactions in the ferromagnetic-antiferromagnetic heterostructures.

LNSET plans to laterally pattern the fabricated heterostructures into nanosize tunneling junctions, which may be a prototype of high-density magnetic recording media elements. The proposed structural studies of the ferromagnetic-nonmagnetic super-lattices will allow us to select the optimal tunneling barrier material with respect to the CMR compounds.

Recent developments in the field of giant magnetoresistance (GMR) materials and their successful application as magnetic reading heads for computer hard drives point at rising possibilities for the utilization of magnetic spins in modern electronics. Parallel alignment of the spins in the ferromagnetic layers, due to applied magnetic field, decreases spin-polarized scattering of the carriers and leads to a significant decrease of the resistance. This has led to an investigation into a next-generation spin-based device technology, where the spin adds a degree of freedom to the conventional charge-based technology. LNSET will study the unique magnetic, resistive, and structural properties originating from the coupled phononic, magnetic, orbital, and charge-ordering behavior on nano-scale. In addition, LNSET will investigate the origins and the practical potential of the large dielectric effect and the fast oxygen conduction recently discovered for novel compositions. Layered antiferromagnetic/ferromagnetic and superconducting/magnetic heterostructures will be studied as a function of thickness of artificial layers from 2 - 100 nanometers. LNSET future projects center on demonstrating the feasibility of producing nanoscale thin films displaying tailored magnetoresistive, spin-polarized transport, and dielectric behavior at room temperature or oxygen permeating properties will open the door for the development of powerful new sensors of magnetic field for hard drive reading heads, elements of next-generation spintronics, high dielectric constant materials, and fuel cells and oxygen separation membranes. Additionally the Mechanical Engineering Department has become involved in nanofluidics Argonne National Labs and the LNSET program.

LN*SET*

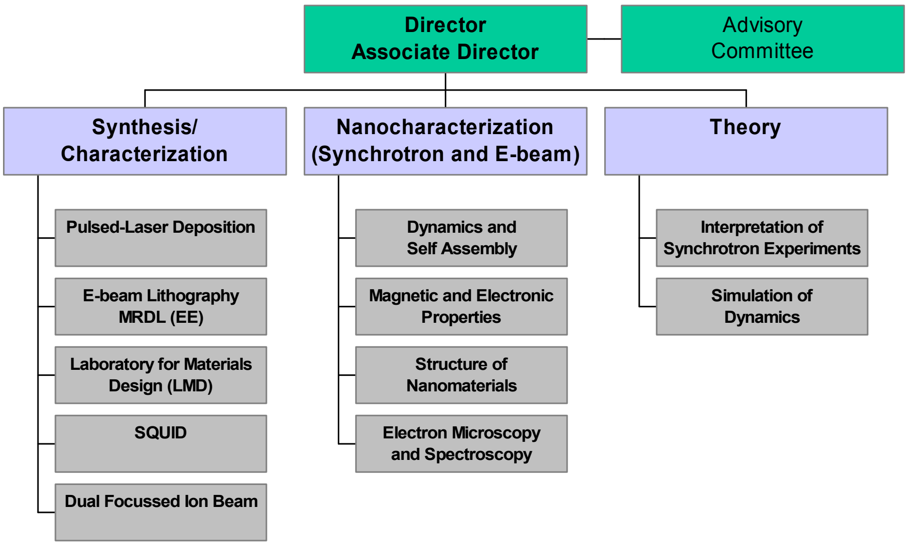

Figure 1 - LNSET Research organizational chart. The general thrust is toward the structures of advanced magnetic oxides, with additional work in the areas of self-assembly.

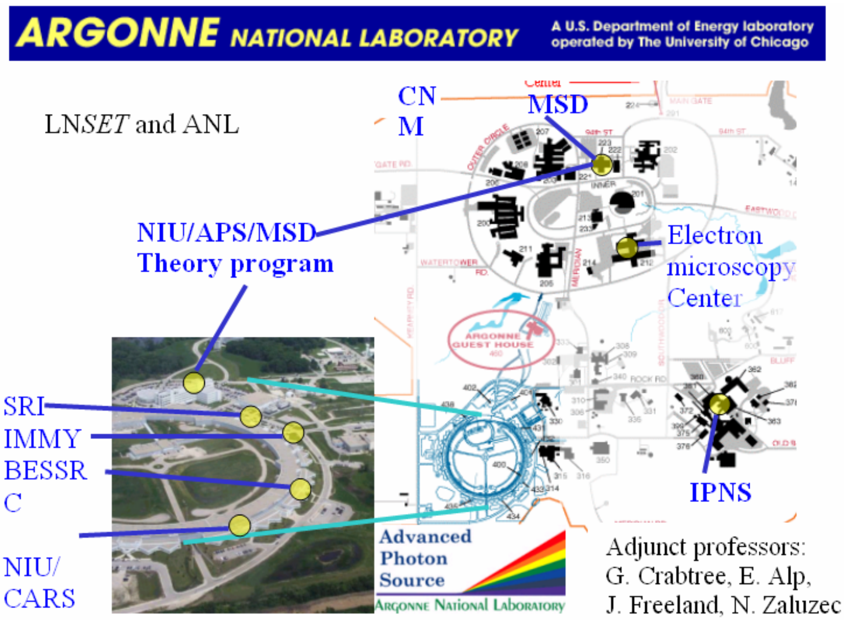

Figure 2 - LnSET and Argonne National laboratory relationship. LNSET has funded four joint positions with Argonne.

Figure 3 - PLD system which is presently installed and in use at NIU. This system was installed and completed in December 2003.

3 ACADEMIC PROGRAM DESCRIPTION

It is important to note that the research is only one aspect of any academic institution. Any academic institution must focus on undergraduate education. For nanotechnology it must eventually filter down from the post-doctoral and doctoral levels to high school and undergraduate levels for it to have broad impact. The NIU Engineering program grants Bachelor and Master of Science (B.S./M.S.) degrees. The lack of a regular flow of Ph.D. students forces us to concentrate on shorter and more focussed research projects. A typical MS student is at NIU for 24 months with the first 12 months concentrated on course work. This gives only 12 months to run an experiment and write a thesis. The interaction with the Physics through LNSET allows the Electrical Engineering students to interact with their masters, doctoral and post-doctoral students. NIU Engineering has a special mission within the Illinois Higher Education system. The knowledge created and research experiences gained during the project will be taught to students. Therefore, the broader impact of this research includes teaching and curriculum development of both undergraduate and graduate programs and research experiences in engineering, science and technology. An additional objective of this work is to expand the presence of groups that are under-represented in engineering. The percentage of underrepresented groups of undergraduate students in the Department of Electrical Engineering in the last six years is about 50% as shown in the Table 1. The investigators will actively recruit students from all underrepresented groups to participate in these research activities.

Table 1. Diversity of Electrical Engineering Students

	Fall 98	Fall 99	Fall 00	Fall 01	Fall 02	Fall 03
American Indian	4	4	4	3	3	2
Asian American	42	54	67	68	64	50
African American	44	52	58	68	67	67
Hispanic	25	25	32	38	35	26
Woman	38	49	56	55	39	40
Total Minority Enrollment	153	184	217	232	208	185
Total EE Enrollment	362	404	403	419	418	381
Percentage of Minority Enrollment	**42.2%**	**45.8%**	**53.2%**	**55.1%**	**49.8%**	**48.6%**

The NIU Physics educational program has emphasized special topics in the analytical and experimental aspects of science; i.e., educating students in the "hands-on" aspects of the technological developments, as well as the scientific and academic contexts. These efforts have included participation of undergraduate and graduate students in experiments at the Advanced Photon Source, Argonne National Laboratory and Fermi Lab. The Physics Department has installed a new Internet tool, the TELEPRESENCE collaboratory, which is filled with promise for application to science teaching.

Telepresence allows a computer user to effectively be present at some other location, by incorporating video-linked, real time, virtual experimental environments with remote computer control, linked to, e.g., major experimental facilities at Argonne National Laboratory, the Advanced Photon Source, and Northern Illinois University Physics Department. The Telepresence Initiative in Physics establishes a basis for interactive teaching of undergraduate laboratories and for graduate research using experimental facilities not available locally. This facility will become a component of the educational process in The Laboratory for NanoScience, Engineering and Technology. The advent of the Ph.D. in Physics (Fall 2000) provides a basis for increasing student participation at all levels, strengthening upper level undergraduate and the Masters in Applied Physics. Moreover, an educated and trained workforce is essential for U.S. industry, government laboratories, and universities in nanoscale science and engineering. Physics at NIU is especially well equipped to perform this function, since the Graduate program in Applied Physics at NIU was ranked amongst the best in the U.S. by the American Physical Society. This judgment was based not only on academic knowledge, but also on preparation of the student for the workplace.

4 ACADEMIC PROGRAM PROGRESS

The goal of any University research program is the ability to include students from all levels and all ethic backgrounds to advanced concepts in science and technology. One of the first ways any research project can effect education is in the hands on interaction of students with direct research. The LNSET nanotechnology program presently has seven MS students from Engineering working on projects in both the Electrical Engineering department and the Physics department. The LNSET program also has several undergraduate students working as assistants in the areas of self-assembly and one undergraduate student working on a nanolithography project for senior design. We will attempt to double the number of students in this program in the next year. At present funding levels it should be possible to double this number again in the following year. This hand on interaction will eventually translate into a convergent technology/nanotechnology curriculum. The EE department has initiated courses in MEMS and Nanotechnology in 2003 with the goal of including more concepts in convergence. NIU has both Class 100 and Class 1000 Cleanroom facilities that are accessible to both graduate and undergraduate students. The College of Engineering and Engineering Technology is presently looking at joint curriculum programs with the Physics department and the Math department. In the Spring 2005 we will offer courses in magnetic sensors to both undergraduate and graduate students. This material will include concepts that can be incorporated into nanotechnology. The next level to try to introduce the groundbreaking convergent technology concepts to is grades 9 through 12. This will be performed using the TELEPRESENCE collaboratory. For this concept of convergence to be completely successful, convergence will have to be accepted by the general public. In the Spring of 2004, the NIU Graduate School recognized the importance of the concept of convergence and initiated a university wide initiative on nanotechnology. This initiative will allow NIU to create a new graduate program on convergent technology. The initial goal of this group is to develop a “silo” free zone with respect to existing academic boundaries. This nanotechnology group will work on educational incentive programs and on research proposals in its goal to create a novel educational opportunity. Group members come from Engineering (Electrical and Mechanical), Physics, Mathematics, Chemistry, Computer Science, and Biology. Additionally some thought should be placed in including Law, Business and Philosophy to help understand the intense sociological implications, which will become more evident in time.

5 CONCLUSION

NIU has taken the initial steps in creating an inclusive program in convergent technologies. This program was started at the faculty level but is being embraced at the Administrative levels. This program has started with Engineering and with Physics but has spilled over into other major programs at NIU. This program will, in time, change the way in which the Science and Engineering programs visualize the world around us. Initial seed funding will allow for interaction with people from various departments. This funding will allow researchers to cooperate without the classic academic turf wars. Attempts to create joint programs have initially met with good reviews from faculty in general. Engineering traditionalist have raised some objections to this fusion. Their objections are bucking the tide of history.

Science and engineering, by its very nature, is a process of discovery and change. We should converge and diverge as needed to advance the collective knowledge of our species.

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