"CONVERGING TECHNOLOGIES" THE NEW FRONTIER IN ENGINEERING EDUCATION

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Abstract

In recent years a wide variety of industries and technologies have been intersecting to create new products and solve new problems. Since these new technologies typically occur at the interfaces of science and engineering (producing new fields such as "nanotechnology"), we call this phenomenon "Converging Technologies." In view of the continuing rapid growth of technology, it appears that the Converging Technologies phenomenon will continue to define the world for the foreseeable future.

Union College is implementing a new initiative that brings cutting-edge Converging Technologies into our classrooms in innovative ways. We see special opportunities to integrate topics in bioengineering, nanotechnology, mechatronics, and pervasive computing into our undergraduate engineering and liberal arts programs.

Converging Technologies includes various skills and disciplines across the campus. For example, combining the skills of a computer scientist with the needs of a graphic artist, or those of an engineer with the needs of a biologist or a chemist or a physicist, often producing unique results. At Union College we are currently adding Converging Technologies topics to existing engineering and liberal arts courses and developing new undergraduate introductory courses in specific Converging Technologies areas. As a college with historic and well-known programs in both engineering and the liberal arts, we are building on our strengths to produce highly informed citizens for the 21st century.

Background

The phrase "Converging Technologies" is most commonly used to signify the recent merging of communications and computer technologies. This convergence produced the digitization of text, voice, and graphical communication modes that were traditionally delivered by distinctly different technologies. However, in this paper, we use the phrase "Converging Technologies" to signify any confluence of traditional technologies (often catalyzed by digital technology).

It is easy to become confused by this because the convergence process may cover vast time periods. For example, we have had communication technologies such as text and graphics for many centuries, but newer electronic communications technologies such as radio, telephone, and television have existed for only a few decades. All of these technologies have recently converged through digital technology into a single hand-held device, and their descriptive vocabularies have become intermixed.

When we begin to use the tools provided by these new "Converging Technologies" as practicing engineers and scientists we are excited by the complexity and range of applications and results. However, as educators, we are faced with questions about how we will teach this new intermingled material, where do we begin, what parts of traditional engineering analysis and design are still relevant and which need revision?

Why do we need to worry about this at all? Won't the normal evolution of engineering pedagogy continue to absorb all the necessary changes in technology? Not necessarily! Educational evolution tends to be generational, with significant changes occurring every 20 years or so. Technological development today is much faster than this and has the potential to push engineering education to the edge of obsolescence. Perhaps Abbott & Masterman[1] said it best:

> *"Students who do not understand how the new and converging technologies work, how they construct meaning, how they can be used, and how the evidence they present can be weighed and evaluated are, in contemporary cultures, considerably disadvantaged and disempowered."*

Where is all of this leading us? Recently various segments of the popular press (e.g., Time Magazine, June 19, 2000; Business Week, August 23, 1999; New Scientist, February 10, 2001; Scientific American, September, 2001) have tried to explore the impact of new rapidly emerging technologies. For example, MIT's popular magazine, *Technology Review*[2], discusses the following important leading edge converging technologies:

- nanotechnology (the new frontier of science and engineering that is likely to change the way almost everything is designed and made, as well as produce objects not yet imagined),
- ubiquitous computing (including smart environments, with computers made from inexpensive materials, etc.),
- biocomputers (organic based molecular level computers and brain-machine interfaces),
- data mining (knowledge discovery in databases),
- digital rights management (managing intellectual property in a digital Internet world),
- biometrics (identifying individuals through specific biological traits - fingerprint, iris, voice, and face recognition, etc.),
- natural language processing (verbal computer interface),
- microphotonics (optical switching technologies for directing light on a microscopic scale that will move telecommunications to the next level),
- intelligent robots (complex multitasking robots that can learn from their environment),
- microfluidics (microscopic lab on a chip technologies - DNA analyzer, cell sorter, implantable drug delivery devices, etc.).

And there are other traditional fields converging today such as business (marketing, sales, patents, risk analysis, organizational design, venture capital), engineering, and the design arts to produce a new breed of "entrepreneurial engineer."[3,4] For example, the faculty and administration of new F.W. Olin College of Engineering has worked closely with the National

Science Foundation, the American Society for Engineering Education, and the Accreditation Board of Engineering and Technology to craft an engineering program for the new millennium (see www.olin.edu). Their emphasis will be on providing a rigorous preparation in engineering science, team-based design, communications, independent projects and research, and principles of business management and entrepreneurship*.

Finally, in June, 1996, Robert A. Lutz, President and CEO of Chrysler Corporation (currently Chairman of GM North America), made the following comments to a national engineering college advisory committee[5]:

> "Five or six years ago Chrysler Corporation once again found itself in very serious trouble. And the reason had to do with our companies thinking. We weren't taking a holistic approach to how we ran our business. Our functional hierarchies had become ossified-, inter- and intra-competitive; and, perhaps worst of all, self-serving, self-indulgent, and self-possessed. The name we came to give to these functional duchies within Chrysler was 'chimneys.' For my money, I want the holistic-thinking person working at Chrysler in today's highly-uncertain, super-competitive global economy. So, what can all you deans and faculty do to better appeal to companies like Chrysler?
>
> <u>Idea number one</u> - How about taking a holistic approach yourselves?
>
> The fact of the matter is, at Chrysler we thought we were chimneyized - until we started dealing with academia. I don't know, but maybe we were pikers compared to some schools and some programs.
>
> <u>Idea number two</u> - Get back to basics.
>
> We have no quarrel whatsoever with the scientific skills we see in students coming out of this nation's engineering schools. But what we do have a problem with is their ability to see the big picture. Program management, problem solving, timing, the principles of quality - these basic business principles need to be an integral part of the core curriculum. And the fact of the matter is that teams are becoming the norm out of necessity - because that's the only way we can be competitive.
>
> <u>Idea number three</u> - Get off the dime.
>
> Figure out ways to dramatically shorten the time it takes you to bring programs to fruition. I know its easy sometimes to say 'if it ain't broke, don't fix it.' But, believe me, that attitude is the exact antithesis of what excellence is all about.
>
> If, at the end of the day, your own chimneys, your own red tape, your own conceits or your own plain inertia is standing in the way of developing programs or curricula that are going to help prepare students as well as humanly possible for productive careers, then I think you've got some soul-searching to do."

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* The student outcome goals of the new F.W. Olin program are: rigorous background in engineering science; broad base in liberal arts, writing and communication; superior computational skills; experience in small team project design and project based problem solving; exposure to cutting edge research activity in corporate and university settings; firsthand knowledge of business and entrepreneurial practices; philanthropic spirit; confidence.

A “holistic” view is exactly what the concept of Converging Technologies is all about. With it we continue to emphasize the basics in the traditional engineering majors, while broadening student horizons and giving them the ability to see the “big picture.”

What is “Converging Technologies”?

Converging Technologies (CT) are the new and often unexpected technologies that appear when engineering and the liberal arts (primarily the sciences) are brought together (i.e., converged or focused) on a single issue. In other words, they are the new technologies that emerge when the liberal arts and engineering are combined in new ways to solve specific problems. They may be the catalyst for emerging educational disciplines in the future.

Because CT is inherently multidisciplinary, it faces the profound difficulty of eliminating the “silos” (or Lutz’s “chimneys”) that contain traditional liberal arts and engineering programs. In the past, technological advances have generally proceeded along linear paths imbedded within specific disciplines; seldom were disciplinary boundaries crossed. However, in recent years the most significant advances have occurred at the multidisciplinary interfaces of the liberal arts and engineering, producing previously un-imagined results.

The cross-disciplinary CT phenomena are certainly not new, they have occurred at various points in the past, often spawning new disciplines. For example, applying the fundamentals of engineering to biology produced an interface known today as bioengineering. This CT field has now been joined by computer science to produce new ways of addressing classical medical problems that significantly advance our quality of life. There are also CT interfaces within the various fields of engineering. One of the interfaces between mechanical and electrical engineering produced the area of process control. When computers are added to this interface we generate new technologies like robotics and automatic control. We now call this interface “mechatronics,” a field that has grown significantly in recent years.

The Areas of Converging Technologies at Union College

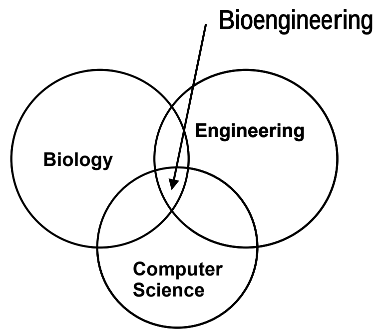
Union College is an independent, coeducational, residential, liberal arts college with Civil, Computer, Electrical, and Mechanical Engineering programs. Founded in 1795, the College was the first to be chartered by the Regents of the State of New York, the first to offer chemistry (1809), the first to create a bachelor’s degree in science and mathematics (1822), and the first to establish a degree program in engineering within the liberal arts (1845). Union’s 2,000 full time undergraduates come from more than forty states and abroad, although the majority are from the northeast. Typically, about twenty percent of the entering freshmen express an interest in majoring in engineering or computer science.

Although Converging Technologies covers many disciplines today, educational institutions need to build on their academic strengths. Recently, Union has identified a faculty resource issue that, when combined with our desire to define a new direction for engineering education, precipitated the decision to phase out the Civil Engineering program and align our new CT areas with the remaining engineering and liberal arts programs. Accordingly, Union College has selected the following four CT areas for emphasis: bioengineering; nanotechnology; mechatronics & intelligent systems; and pervasive computing. These area are briefly described below.

1) Bioengineering: The convergence of engineering, computer science, and biology.

Bioengineering combines the analytical and experimental methods of the engineering and computer science professions with the biological and medical sciences to achieve a more detailed understanding of biological phenomena and to develop new techniques and devices. The computer scientist and engineer's quantitative and analytical approach; traditional competence in the processing and control of information, sensors, and materials; and ability to design and analyze systems are powerful tools when applied to biology, medicine, and quantitative studies of relationships between biological systems and their environments.

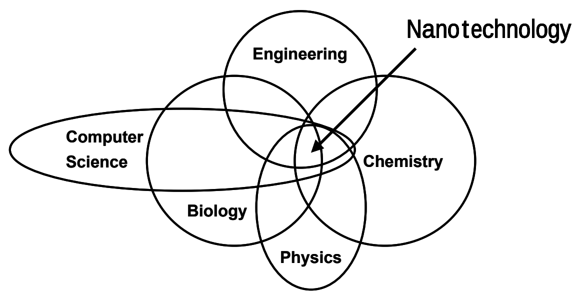
BIOENGINEERING - The Convergence of Engineering, Biology, and Computer Science



2) Nanotechnology: The convergence of chemistry, physics, biology, computer science, and engineering.

Nanotechnology is the creation and utilization of materials, devices, and systems through the control of matter on the nanometer-length scale, that is, at the level of atoms[**]. Nanotechnology is the frontier of science and engineering most likely to change the way almost everything is designed and made in the future. The scanning tunneling microscope (STM) and the atomic force microscope (AFM) provide the "eyes" and "fingers" required for nanostructure imaging and manipulation. Direct manipulation of atoms and molecules, the basic building blocks of all matter, will result in a technological revolution that is expected to have a larger impact on our lives in the 21st century than the combined influences of antibiotics and microelectronics did in the 20th century[6].

NANOTECHNOLOGY - The Convergence of Chemistry, Physics, Biology, Computer Science, and Engineering



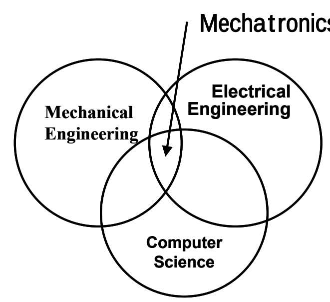
[**] A nanometer is one-billionth of a meter. Five hydrogen atoms side by side are about one nanometer wide. The head of a pin is about one million nanometers. An excellent white paper on the future of nanotechnology entitled "Nanotech - The Tiny Revolution" can be found at www.nrwpr.com and the American Chemical Society has recently initiated a new journal dedicated to nanoscience and nanotechnology called "Nano Letters."

Control of matter on the nanoscale already plays an important role in physics, chemistry, materials science, biology, medicine, engineering, and computer science. Carbon nanotubes are ten times as strong as steel with one sixth of the weight, and even today nanoparticles are commonly used in cosmetics and advanced composites. Global government spending on nanotechnology research and development over the past two years was about $2 billion, and it is estimated that the total market for nanotechnology products and services will reach $1 trillion by 2015[7].

3) <u>Mechatronics and Intelligent Systems</u>: The convergence of electrical, mechanical, and computer science.

This broad area includes the coverage of basic mechanical design, systems analysis, control systems, and decision analysis. It includes courses at the introductory level that combine mechanical and electrical design, and courses at a more advanced level covering topics such as sensors and actuators, digital systems design and microprocessors, VLSI, fuzzy logic, neural networks, digital control systems, and artificial intelligence. While this focus would be on systems that combine electrical and mechanical components, it would not exclude the study of non-motive intelligent systems.

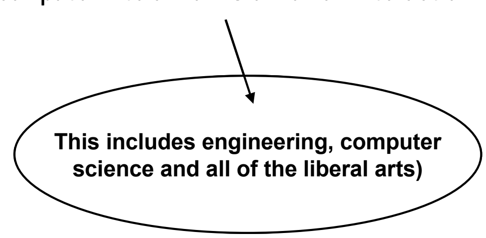
MECHATRONICS - The convergence of Mechanical and Electrical Engineering with Computer Science



4) <u>Pervasive Computing</u>: The convergence of communication, computer science, and engineering to create a ubiquitous computing human environment.

This area emphasizes the increasingly blurred line between computation and communication. It focuses on topics such as wireless networks, information transmission and information processing, and it involves introductory courses in digital and analog communication systems, computer networks, and database systems, with advanced courses in signal processing, VLSI, image processing, information theory, coding, and relational databases. It also includes ethics (privacy, property rights), aesthetics, language and culture, politics and law (funding, patents, basic decision-making, leadership), economics, and psychology (assessment, perception – this is potentially key in pervasive computing, if people are to be subjected to a continuous data stream)***.

PERVASIVE COMPUTING - The integration of the computer into all forms of human interaction



*** Note that the IEEE has just introduced a new journal titled "Pervasive Computing" dedicated to mobile and ubiquitous computing.

Implementation Strategy

Our Converging Technologies implementation strategy does not include developing entirely new engineering or science programs; rather it is a dynamic, new, educational approach. Various engineering and science courses from the freshman through the senior years will touch on elements of these new emerging technologies, as well as provide enhanced exposure to the digital computer. The program will feature increased opportunities for industrial internship programs and further weave internationalism throughout the curricula. By embracing Converging Technologies, Union, we believe, will be among the first undergraduate engineering institutions to acknowledge the impact of Converging Technologies on a global basis.

The core strengths of engineering at Union college are engineering fundamentals, liberal learning, communication skills, foreign experience, undergraduate research, and a capstone experience wherein students individually or in teams address a full engineering or research problem provided by industry, faculty, or from the student's own background experience.

Because the Converging Technologies initiative is something that we will implement without extensive additional resources, the areas that the College decides to pursue should satisfy the following criteria:

1) Feasible: We must have the staff and facilities to support the initiative in the near term and it should build on our strengths.
2) Relevant: Because we wish to maintain our emphasis on undergraduate discipline specific engineering programs, we must choose areas that combine or reinforce basic topics that we agree should be part of an undergraduate engineering degree.
3) Non-invasive: CT areas should augment, enhance, and possibly repackage our current curricular foci, but they should not prevent our students from focusing on traditional areas within the engineering disciplines.
4) Meaningful: Because we want to ensure that students gain a depth of understanding in the CT areas, we are not constraining the areas to be accessible to all engineering students; there will be prerequisites for many courses that go beyond the core of our engineering programs.

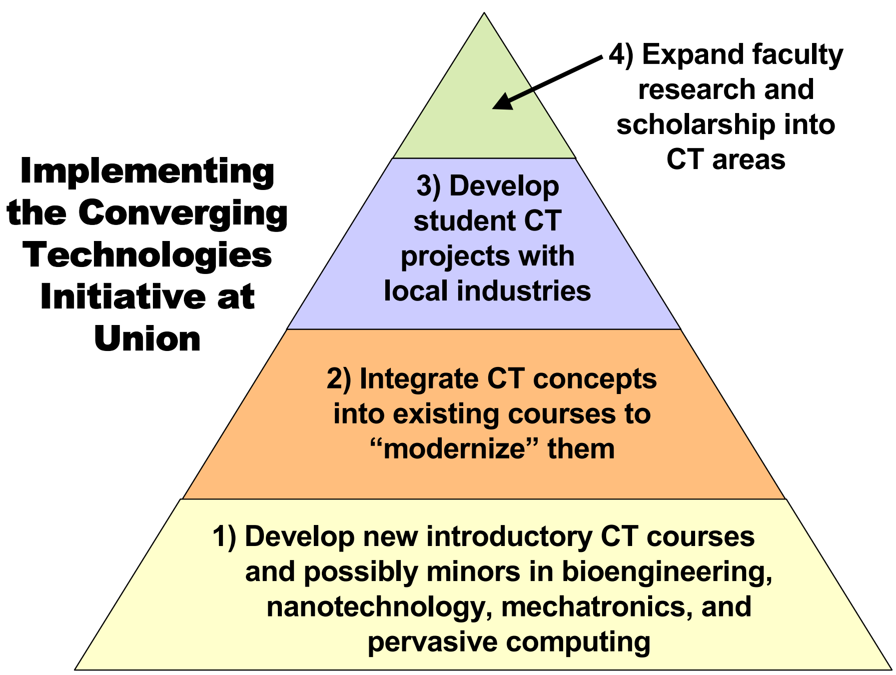
Union College began to design and implement an engineering curriculum for the 21st century with a major four-year grant from the General Electric Foundation in 1993. The new engineering curriculum, which was fully revamped and implemented in the 1998-99 academic year, included a common freshman "Introduction to Engineering" course, integrated mathematics and physics (IMP) courses, and a third year foreign experience requirement. We began to embrace the Converging Technologies concept in the spring of 2001 in a continuing effort to create a unique merger of engineering with the liberal arts.

By this time Union was, in many ways, already invested in the Converging Technologies theme. It was reflected in the theme for the freshman introduction to engineering course, "Smart Cars" - a discussion of converging mechanical, electrical, and computer technologies in the automotive industry, and it was reflected in the convergence of mathematics and physics into Union's integrated mathematics and physics (IMP) courses. And Union's Computer Engineering program, created in the late 1990s, represents another example of Converging Technologies since it was formed from a convergence of the traditional disciplines of Computer Science and Electrical Engineering.

Once a firm commitment had been made to implement the Converging Technologies concept across the campus, the following general strategy was developed.

1) Develop "elective" introductory courses in each of the CT areas with the goal of having as many as possible open to both engineering and liberal arts students. This requires a multidisciplinary faculty team effort to design and implement the courses. Once these courses are designed, advanced courses and perhaps minors in the area can be developed.
2) Faculty, individually or in teams, introduce various CT topics to their existing courses (e.g., nanotechnology into materials, chemistry, and physics courses; microfluidics and non-Newtonian behavior into fluid mechanics courses, etc.). This tends to "modernize" traditional courses and attract student interest, and hopefully enhance retention.
3) Develop student capstone CT projects with local industry (many of whom welcome the exposure to both graduating seniors and to emerging CT areas).
4) Expand faculty research and scholarship into appropriate CT areas.

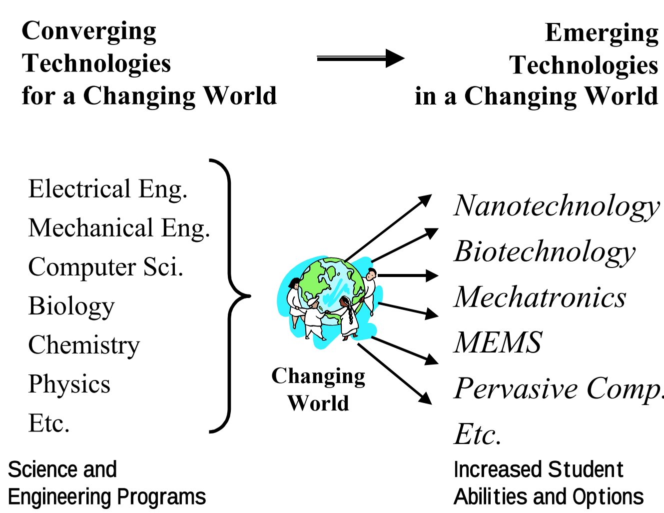
This process is shown in the illustration below.



Conclusions

The Converging Technologies (CT) initiative at Union College seeks to act upon the interaction of various technologies in our global economy through a dynamic, interdisciplinary approach to learning. We believe that our CT initiative will foster an environment in which faculty discover innovative ways to have students think across traditional disciplinary lines. We believe that CT has the following seven advantages to Union College: 1) attract better engineering and liberal arts applicants from around the world; 2) create new learning options for both engineering and liberal arts students; 3) help students enter graduate school or get better jobs by meeting or exceeding industry expectations; 4) create opportunities for interdisciplinary research and teaching collaborations between engineering and liberal arts faculty; 5) create concrete ways for alumni to make major gifts; 6) create ways for leading corporations, financial institutions, and consulting firms to make contributions of funds, internships, and equipment to support the new curriculum; and 7) create opportunities for faculty to publish research that will enhance the reputation of Union College as an innovative, multi-disciplinary, institution.

We have learned that problems seldom fit into the neat disciplinary boxes (or “silos” or “chimneys”) that academia has evolved over the past two centuries. In engineering, not only do solutions to complex technical problems tend to require many technical skills, but the solutions tend to be more responsible when viewed in a wider social and moral context. Courses that mix engineering and liberal arts students produce graduates with a broader background that goes beyond that provided by their traditional major. Elective courses from such fields as bioengineering, nanotechnology, mechatronics and intelligent systems – all examples of Converging Technologies – have been developed at Union College. The introductory CT courses can also be used as part of Union’s general science requirement and can be chosen by liberal arts majors. Minors in the core CT areas are now evolving as well as student projects with industry.



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Biographical Information

Robert T. Balmer is currently Dean of Engineering and Computer Science at Union College in Schenectady New York. He has BSE and MSE degrees for the University of Michigan, and an ScD degree from the University of Virginia. Before coming to Union he was Professor and Chair of the Mechanical Engineering Department and then Associate Dean in the College of Engineering and Applied Science at the University of Wisconsin-Milwaukee. He is the author of over 50 articles on a variety of engineering topics, and published an engineering thermodynamics textbook (West Pub. Comp., 1990).