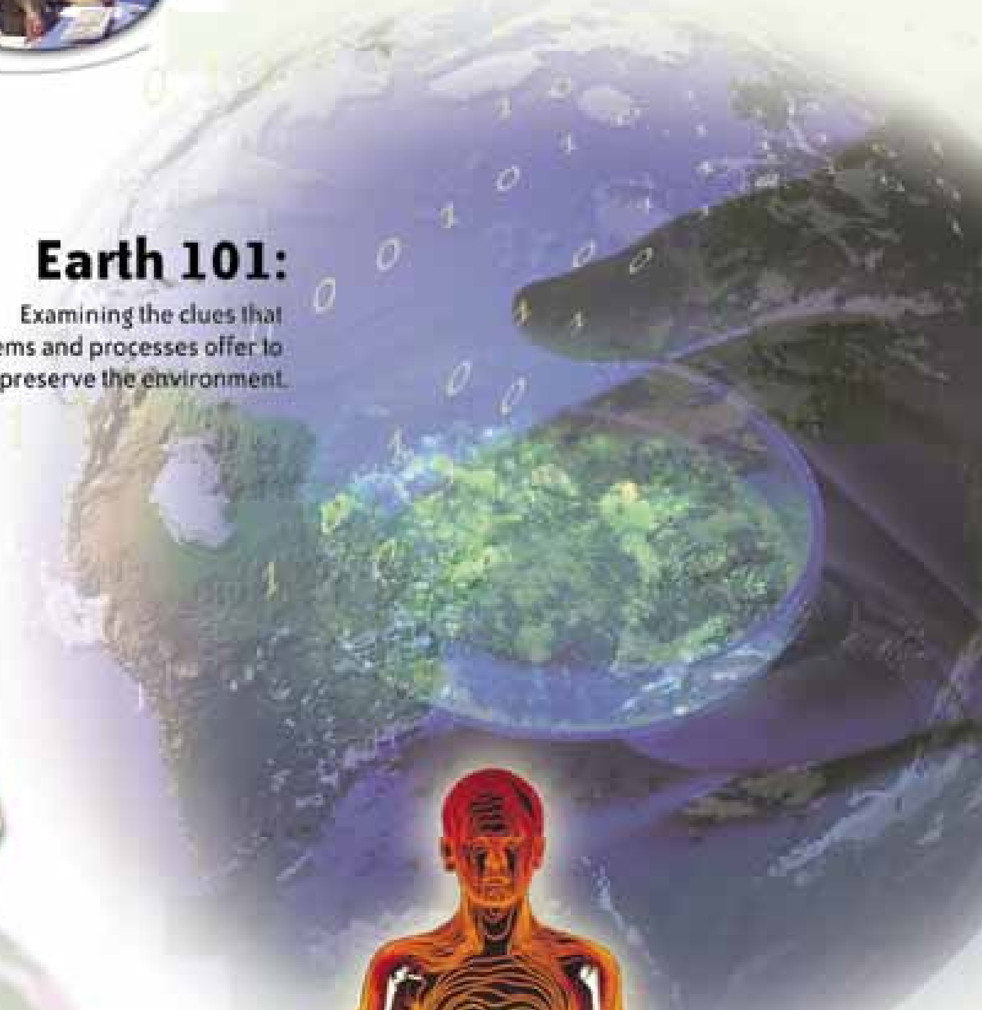
SIGNATURES

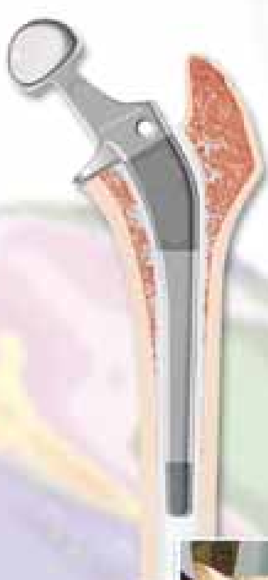
Engineering Education in the 21st Century

Which comes first ... learning or doing?



Earth 101:

Examining the clues that natural systems and processes offer to better preserve the environment.



How teams of engineers, biologists, and physicians are improving the quality of life.

The Bio Revolution

Engineering Advances at the University of Notre Dame

Volume 4, Number 1
2002

While terms such as **cross-disciplinary** and **multidisciplinary** have been endemic to the academic lexicon for at least the last three decades, more often than not they have been used to describe a desired attribute, rather than an actual characteristic, of education and research. All that is changing, as increasingly the boundaries between traditional disciplines are blurring with the concurrent integration of subject matter across disciplines.

As academics who have worked hard to acquire our specialized knowledge and who take pride in accomplishments based on that knowledge, we may be reluctant to undertake challenges (and opportunities) that transcend our expertise. Yet, it is evident that the solution to important problems will increasingly lie at the intersection of existing disciplines, and successful programs will be those that retain core competencies while melding other expertise central to addressing critical needs and technologies.

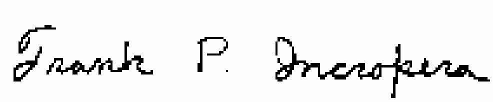
A case in point is **information technology (IT).** No longer the exclusive purview of electrical engineers and computer scientists, **IT** is ubiquitous to education and research in all engineering disciplines. And **biotechnologies** are not far behind.

In this issue of Signatures, we have highlighted some of the multidisciplinary educational and research activities in Notre Dame's College of Engineering. The article entitled "Passing The Torch" describes existing activities in the college's prototype Learning Center, as well as activities planned for a significant expansion of the Learning Center in a new building to be constructed for the college. The major role of the prototype facility is to provide first-year students with multidisciplinary, interactive, and team-based learning experiences. But the facility also provides faculty with an excellent environment for developing and testing novel teaching and learning techniques. Through support provided by the GE Foundation, several projects relate to the development of multidisciplinary learning modules by teams of faculty from two or more of the college's five departments.

Other multidisciplinary activities are described in the articles entitled "Quality of Life: The Next Frontier for Engineers" and "Circle of Life," which deal with biomedical and environmental issues, respectively. As with much that we do, these activities involve teams of faculty and students integrating engineering education and research with human needs.

As always, we welcome your interest in our programs and any input you wish to provide.

the dean's view



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S I G N A T U R E S | INSIDE

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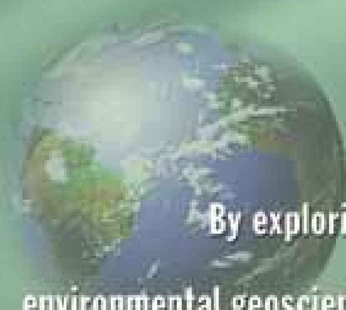
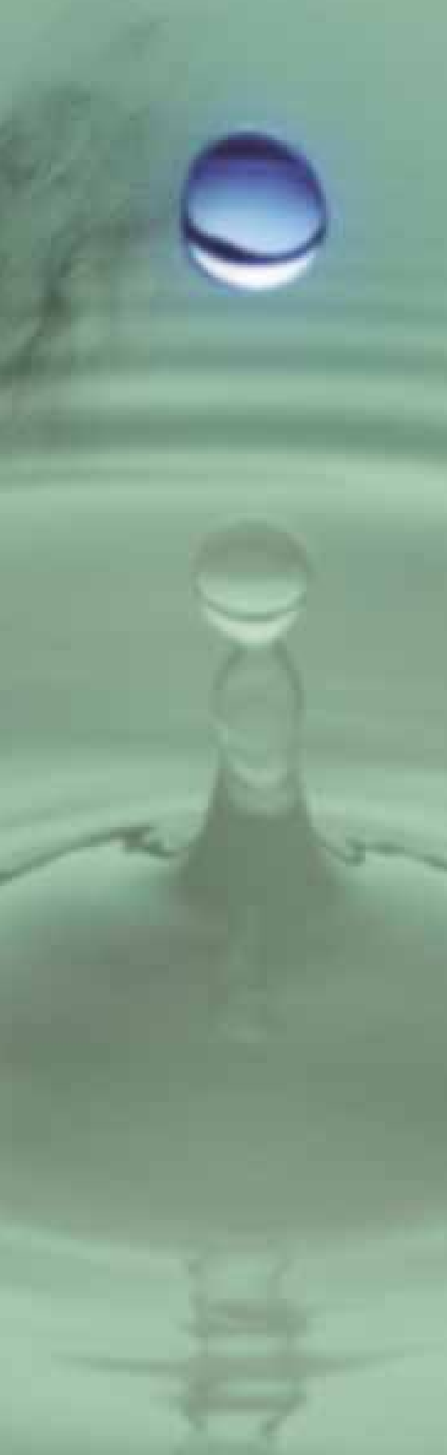
the circle



By exploring how the Earth works, environmental geoscientists at Notre Dame are finding clues to pollution remediation that are

earth-friendly.

# of life



Hollywood's Julia Roberts made a big splash as Erin Brockovich, the feisty young mother who fought and won a monumental law suit against the giant corporation responsible for contaminating the water supply of a small town, causing devastating illnesses and several deaths. The movie, perhaps more than any single event in recent history, brought the issue of safe drinking water to the surface.

From the time the Earth was formed, water has been continuously circulating; it's called the hydrologic cycle. As water evaporates, it forms clouds, eventually returning to the earth as precipitation. It is the precipitation that becomes part of the groundwater supply. Fifty percent of the population of the United States depends solely on groundwater generated from the cycle for its drinking water.

Groundwater is generally a safe source of drinking water. However, just as they did in the movie *Erin Brockovich*, pollutants can contaminate water supplies. Compounds from the Earth's surface or man-made "products," such as storage tanks, hazardous waste sites, landfills, even catalytic converters, can potentially move through the soil and leach into groundwater supplies and the food chain in a variety of ways, affecting the circle of life.

The water cycle is just one example of the natural systems and processes that environmental geoscientists study. Environmental geoscience is the examination of Earth's natural cycles that potentially impact or are impacted by mankind. Thus, environmental geoscientists engage in a wide variety of research from the atomic to the planetary scale to provide a unique and quantitative perspective of Earth's complex systems, including an understanding of the role time plays in natural processes.

Environmental geoscientists observe, measure, and analyze air, water, soil, and rock formations to make recommendations on how best to preserve the environment. They use their knowledge to design and monitor waste disposal sites, safeguard water supplies, and reclaim contaminated soil. They also study the composition and structure of the physical aspects of the Earth — past and present — in order to make predictions about its future.

"In many ways," says James A. Rigert, C.S.C., associate professor of civil engineering and geological sciences, "environmental geoscientists build on the role of the traditional geologist. The environmental thrust provides an added enthusiasm to students, while faculty continue to emphasize the fundamental knowledge of geology that will help mankind understand the physical systems of the earth and remain good stewards of its resources."

There are many environmental study and geoscience programs at universities across the country. What makes Notre Dame's program unique is the fact that it melds the two disciplines into a broad field which includes aspects of geology, environmental engineering, chemistry, physics, biology, and mathematics. Notre Dame's program combines fundamental and applied research to help students understand how the environment impacts humanity, as well as how humanity impacts the environment.

"Environmental geoscience is very interdisciplinary," says Patricia A. Maurice, associate professor of civil engineering and geological sciences. "Students need to know geology, chemistry, physics, math, and biology, and they have to be able to integrate them." Why? Because environmental geoscientists look at the big picture. For example, researchers have to understand the mineral cycle, plate tectonics, and how continents move. As the foundation of this knowledge, they must also be familiar with the history of the earth and significant changes that have occurred over time.

Consider volcanic activity, natural occurrences which strongly impact human life and ecosystems. The Hawaiian Islands wouldn't exist if it weren't for such activity. On the other hand, whole communities have been badly damaged and some totally destroyed by volcanic eruptions. Environmental geoscientists might study methods of diverting lava flows or ways to predict eruptions. They might also study the earth's movement over time to predict where the next earthquake will hit or to offer advice on construction and land use projects.

Environmental geoscientists spend a lot of time in the field, but they also spend a great deal of time in their laboratories in pursuit of answers. What follows is a sampling of the current research efforts of the faculty in the environmental geosciences program at Notre Dame:

By its very nature, environmental geosciences is an interdisciplinary field. Faculty in the Notre Dame program often collaborate with colleagues in other departments, colleges, and research facilities on and off campus.



The Geologic **Time Scale**

It looks very different from a Hallmark® calendar. Rocks, fossils, and other artifacts mark its "pages." The function of the geologic time scale is to help researchers understand the world in which we live. Since the Earth is constantly changing, knowledge of its features and the natural processes relating to the Earth's past are just as vital to understanding the planet today as are mineralogy, petrology, structural geology, oceanography, and environmental geology.

Contrary to what the *Jurassic Park* movies would have people believe, fossils encompass more than dinosaur bones. They are the remains — bones, shells, leaves, and other evidence such as tracks, burrows, or impressions — of life on earth millions of years ago. Researchers who study fossils are called paleontologists. The purpose of their work is to determine what happened in earth's history and when it happened. The three most important things to remember about fossils are:

- They represent the remains of once-living organisms.
- Most of the fossils found belong to extinct species.
- The fossils found in rocks of different ages are also different because life on earth has changed throughout time.

Often the rocks in which fossils were formed provide as much useful information about the environment or a historic natural event as do the fossils themselves. For example, in 1999 a team led by **J. Keith Rigby,** associate professor of civil engineering and geological sciences, studied an area near the village of Chuanjie in the Yunnan Province of China in order to determine the age of the materials found there and develop an understanding of what happened to the dinosaurs buried at the site. "What we discovered," says Rigby, "indicates three separate burial events, meaning the site was visited continually or at least predictably for some time."

Rigby believes there was some kind of mechanism to draw the animals into the area, such as a playa lake, much like the temporary lakes formed in the mountain basins of the western United States. It is likely that the water grew so rich in mineral deposits that it became toxic and killed the creatures that drank from the lake. Clues from the soil and rock at the site support the theory that the site was covered by three individual mud flows, probably during rainy seasons, burying the carcasses and setting the stage for the next playa lake and burial event.

Rigby has also been very involved in several digs and a museum project at Fort Peck, Mont. When completed, the Fort Peck Interpretative Museum will feature a display of up to 60 dinosaurs with supporting specimens from the environment of their day ... all based on the information found in the fossils themselves and the rocks surrounding them.

The information gained from studying the past will hopefully help in understanding the world of today, its natural chemical and physical processes. Clues from the past can guide industry in the search for new sources of water, oil, and coal. They may help researchers determine where to expect earthquakes, floods, or landslides. They can also assist mankind in becoming better stewards of the environment. By knowing what happened on earth in the past and why, man can make the future world a better one.

the roles of bacteria, organic compounds, and climate in nutrient cycling and pollutant transport

Patricia A. Maurice, *associate professor of civil engineering and geological sciences, adjusts the equipment in the Atomic Force Microscopy Laboratory. Her research includes field and laboratory studies of mineral-water interactions, the remediation of metal contamination, the hydrology and biogeochemistry of freshwater wetlands, and investigations on global climate change.*

Patricia A. Maurice, associate professor of civil engineering and geological sciences, studies microbial trace metal and organic interactions with mineral surfaces from the atomic scale up to the scale of entire water sheds, like the Lake Erie Basin or portions of the Atlantic Coastal Plain. She also examines how extreme climates affect ecosystems. "My research is very broad," states Maurice, "but it always uses fundamental molecular-scale investigations to understand large-scale phenomena like pollutant transport or the effect of global climate changes on ecosystems. I apply this fundamental approach to a variety of field situations."

For instance, in collaboration with Diane McKnight, a professor in the Department of Civil, Environmental, and Architectural Engineering at the University of Colorado, Maurice has been studying the McMurdo Dry Valleys of Antarctica, some of the coldest, driest places on Earth.

She suggests that the unique environment of Antarctica actually aids her research by highlighting processes that can't be studied in other locales due to the existence of multiple and concurrent interactions. The research focuses on the few weeks each year when the glaciers melt and water flows into the valleys.

What Maurice and her team have found conflicts with their original expectations. Namely, they found a system of bacteria and algae that blooms quickly and extremely efficiently in water, demonstrating that at least certain types of bacteria have the ability to adapt to an ecosystem's environment. Their study also showed that minerals in the water experienced chemical erosion at surprisingly fast rates, perhaps because of the previously unanticipated microbiological processes.

Another study focuses on the degradation of biological material. Consider the many different materials present — such as leaves — in soil and other organic matter. As water passes through the soil, it carries with it some of the molecules from the biological material. When these molecules pass into the lower soils and eventually aquifers or streams, they begin to control the biological and chemical reactions and, essentially, determine the fate of pollutants.

Graduate student Christina Progess *spends many hours in the Aquatic Geochemistry Laboratory as part of the Water-Rock Interactions course taught by Patricia A. Maurice, associate professor of civil engineering and geological sciences.*

If, for example, there are a multitude of these natural organic materials that get into streams, they function as a sun block, preventing ultraviolet light from penetrating the streams and damaging the organisms in the water. "Understanding the reactions that control organic matter on the molecular level," says Maurice, "will help us predict how the organic matter will respond to climate change. If we understand the hydrology and how the water flow affects the amount of organic matter that enters the streams, as well as the reactions that occur once it is in the streams, then we can better predict how climate change will influence the sun-blocking mechanism and perhaps develop ways to lessen potential ecosystem damage."

According to Maurice, the purpose of her research is to engineer solutions. She believes that with a fundamental knowledge of how a system works, researchers from a variety of disciplines in the College of Engineering and throughout the University can design solutions for a wide range of complex environmental problems. "That's one of the benefits of being among a group of engineers," she says "Instead of working in isolation with 'science' taking place in one building and 'engineering' in another, we are bringing them together to find answers."

bacteria-water-rock interactions

Funded by the National Science Foundation and the American Chemical Society, Jeremy B. Fein, associate professor of civil engineering and geological sciences, applies chemical thermodynamics to environmental geomicrobiology as he studies the biochemical interactions of bacteria, rock, and water. "I fill a gap between geology and biology," says Fein.

"We've known for a long time that there are bacteria in the ground, even to great depths under the earth's surface." According to Fein, both geologists and microbiologists have traditionally ignored the effects of bacteria on contaminant transport in groundwater due to a lack of understanding each other's discipline. "The exciting part about this work is that it bridges the gap between these two disciplines," says Fein. "There is a lot of evidence that bacteria interact quite extensively with the minerals in geologic systems. So we're studying important reactions no one has considered before."

In the last five years environmental geoscientists have developed qualitative evidence that bacteria strongly influence how metals and organic solvents are distributed on the earth's surface and in groundwater supplies. For example, if lead is dumped at a particular location, it may be bound by the bacteria — meaning that the lead will come out of the solution and become attached to structures on the cell walls of the bacteria. Bacteria evolved these structures to absorb nutrients like calcium, magnesium, and low levels of zinc and iron. But, bacteria cannot differentiate between those nutrients and metals like lead, copper, cadmium, or uranium. Once the metal attaches to the bacteria, it becomes as mobile as the bacteria. If the bacteria move, they carry the contaminants with them. If not, the pollutants are immobilized. So it is crucial to develop models that determine the extent of attachment and the mobility of the bacteria in groundwater aquifers.

Working with researchers from Argonne National Laboratory, and using the Advanced Photon Source synchrotron, Fein and his team are gathering information with which to develop models. "Our goal," he explains, "is to try to isolate the unique reactions between heavy metals and bacterial surfaces. We use a specific bacteria species and place it in contact with a specific groundwater contaminant to determine how they interact."

There are countless species of bacteria in soil and groundwater systems. Fortunately, the

geomicrobiology team doesn't have to study each species of bacteria. Instead they are looking for common threads. "One of the most exciting things we've found," says Fein, "is that all the bacteria we have tested behave in the same way. There's a common structure to the bacterial cell wall that makes predicting bacteria-metal interactions much easier." It's important to note that these experiments are the first to quantify the effect of bacteria on aqueous metal, organic adsorption, and mineral dissolution. In addition, the results can be used to make groundwater clean-up efforts more efficient and to design more effective contaminant treatment strategies.

Fein works with two graduate students and approximately four undergraduates each year. He believes the size of the College of Engineering is a benefit for graduate students, but perhaps more so for undergraduates. "The undergraduates who work in the Environmental Geochemistry and Geomicrobiology Laboratory participate in independent research, in much the same manner as do the graduate students," explains Fein. "It is one of the tangible advantages of being at a top research university as an undergraduate." In fact, as a result of their lab activities, most of the undergraduates under Fein's supervision have been listed as authors in research publications.

Kelly Johnson, *a graduate student in the environmental geosciences program, works with Associate Professor Jeremy B. Fein in the Environmental Geochemistry and Geomicrobiology Laboratory. Equipped with an autoclave, incubator, automatic titration system, and wet chemistry facilities, the lab also features a sterile clean room for bacterial culturing.*

Traditionally an undergraduate's opportunities for hands-on research are quite limited. That's not the case in the College of Engineering, especially in the Department of Civil Engineering and Geological Sciences. In addition to faculty, visiting scholars, and graduate students, a total of 21 undergraduates work in the department's research labs. **Jonathan Roller,** a senior majoring in environmental geosciences, is one of them.

In fact, he's worked in two different labs over the last three semesters. During his junior year, Roller worked with Clive R. Neal, associate professor of civil engineering and geological sciences and director of Notre Dame's Inductively Coupled Plasma-mass Spectrometry Facility. Roller's main responsibility was to prepare samples for testing.

This year he's working with Jeremy B. Fein, associate professor of civil engineering and geological sciences, and Peter Wightman, a doctoral candidate, in the Environmental Geochemistry and Geomicrobiology Laboratory. Roller spends approximately three hours every day in the lab. "We're testing a specific bacteria — *Bacillus subtilis* — varying the range of pH and the amount of electrolyte in the solution, then adding a concentration of heavy metal to determine how the pH and electrolyte concentrations affect the level of metal adsorbed onto the surface of the bacteria," said Roller. "It's a very strict regimen. You have to be in the lab exactly 24 hours after you initially feed the bacteria or the results could be skewed."

Jonathan Roller *uses a combination of experimental, theoretical, and field approaches as he investigates bacteria-water-rock interactions.*

Roller has enjoyed the experience so much it's encouraged him to apply to graduate school. The biggest benefit to working in the labs, he says, is two-fold. "You see the data firsthand so it becomes more than something in a textbook. And, I think it gives students an excellent idea of what graduate school is about. My experience here as an undergraduate is the main reason I will be pursuing a graduate degree."

Field Research Opportunities in **Environmental Geosciences**

In addition to traditional on-campus research, students in the College of Engineering have opportunities to participate in study-abroad and off-campus research projects that add to their classroom experiences.

For example, students entering their junior year may choose to spend a semester studying **in Australia.** Curricula and fieldwork opportunities, developed in conjunction with the University of Western Australia and six local companies, provide students with practical hands-on experience.

According to Clive R. Neal, associate professor of civil engineering and geological sciences and coordinator for the study-abroad program in Australia, students often find themselves in unique field situations where they must apply what they've learned in class ... from prospecting for nickel deposits in the outback to finding ways to convert sewer sludge into diesel fuel. Neal has worked closely with representatives of companies like Collie Mining, Rio Tinto Mining, Western Mining Corporation, and The Department of Conservation and Land Management to create service-learning activities for the students. "Course work is vital," he says, "but there's nothing like firsthand experience."

It helps the companies too. Many of the activities developed for the students revolve around problems the companies have intended to address but have been unable to do so because of manpower limitations. At the end of each semester, students write reports and make formal presentations of their findings to company representatives. Corporate input is also used in determining students' grades. Since its inception, a total of 42 engineering students has participated in the Australian study-abroad program. And, 80 percent of their suggestions have been implemented by the companies.

The **University of Notre Dame Environmental Research Center (UNDERC)** is located on both sides of the state line between northern Wisconsin and the upper peninsula of Michigan. Thirty lakes, several bogs and marsh habitats, three streams, and thousands of acres of forest preserves make UNDERC an ideal location for both aquatic and terrestrial studies. Although relatively few students from the College of Engineering have visited UNDERC in the past, Patricia A. Maurice, associate professor of civil engineering and geological sciences, says that is about to change. "The UNDERC facility is ideal for a great deal of our research," says Maurice. "It offers a variety of different and very complex systems to study, from the water ... to the bacteria in it ... to the larger organisms that interact with it. If we can understand an entire ecosystem, then we may also be able to find a way to engineer solutions to global environmental problems."

Katie Young, one of Maurice's graduate students, will spend summer 2002 at UNDERC investigating how the chemical characteristics of natural organic matter (NOM) are affected by adsorption of NOM to bacteria and to mineral surfaces. The National Science Foundation-funded project will also analyze the photodegradation of NOM by ultraviolet radiation. Young plans to sample three sites around the UNDERC property in order to compare NOM reactivity from streams containing a wide range of physicochemical characteristics. "The physicochemical properties of NOM are important," says Young, "because they help control mobility, adsorption kinetics, pollutant binding properties, adsorption affinity, and bioavailability."

the environmental effects of heavy metal pollution

Since 1975 catalytic converters have been used to remove gaseous pollutants from automotive exhaust. Chemical reactions within the converters change the targeted pollutants into less toxic substances. Today catalytic converters are mandatory on automobiles, and — as a result of the Clean Air Act of 1990 — they are also required on small gasoline engines such as those on lawn mowers, chain saws, and other power tools.

The material used to excite the reactions within the converters is filled with platinum, palladium, and rhodium — platinum-group elements (PGEs), which can potentially become carcinogenic when they complex with organic matter. "It's ironic," says Clive R. Neal, associate professor of civil engineering and geological sciences and director of the college's Inductively Coupled Plasma-mass Spectrometry Facility, "that man's efforts to prevent pollution may prove as toxic to the environment as the pollutants society originally hoped to abate."

A recent study focusing on the catalytic converters on automobiles and conducted by Neal and other researchers in the colleges of

***Graduate students** Will Kinman, left, and Georgiana Kramer work in the University's Inductively Coupled Plasma-mass Spectrometry Facility (ICP-MS), one of the most sophisticated in the country. The versatility of Notre Dame's technique and its contaminant-free sample preparation make the ICP-MS a unique tool which can be used for sub-parts per billion and trillion analyses in a variety of fields.*

engineering and science, the University's Center for Environmental Science and Technology (CEST), and Wichita State University confirms that catalytic converters are releasing PGEs. Samples taken at various distances along several roadways in the United States and Australia contain significant amounts of these PGEs, quantities above background levels, in each of the soil samples, especially those closest to the roads. The study suggests that the amount and rate of PGE release is largely dependent upon the speed of the vehicle, the type of engine, the type and age of the catalyst, as well as the use of fuel additives.

Initial data also indicate that only the platinum is taken up by plants. However, platinum is a known allergen and has been linked to asthma, sensitive skin, and other health problems. Although physicians have yet to determine the main cause of asthma, statistics show an alarming increase in the United States over the past 15 years. During this time, asthma rates have increased more than 150 percent in children under five years of age. Is there a correlation? That's what Neal and his colleagues are trying to determine.

"We know that PGEs are being released, and we know they're somewhat mobile," says Neal. "The next step is to identify how they are being transported. Are they being oxidized, dissolved in groundwater, or taken up by food crops? Are they being distributed by the wind? And, most important, how mobile are they?"

According to Neal, related studies show that glaciers and other ice formations on Greenland contain elevated levels of platinum. Given the fact that there are few highways in Greenland, he believes the obvious conclusion is that PGEs are somehow transported in the atmosphere. Studies conducted in Germany and England support this theory.

Neal is also investigating the increasing environmental hazard caused by contaminated water feeding into groundwater systems. Although sources of heavy-metal pollution include manufacturing processes, smelting and refining, electricity generation, and agricultural fertilization, Neal — in collaboration with CEST — has been concentrating on the areas

around abandoned mines.

Mining operations usually require large stabilization ponds covering many acres. Tailings from the mines — such as arsenic, copper, nickel, lead, cesium, zinc, and molybdenum — are stored in these ponds and often seep into groundwater supplies. For example, metal contaminated waters from the Berkeley Pit, part of the Butte Mine Flooding Superfund Site in Montana, threaten the groundwater supply of the Butte metropolitan area.

Conventional technologies for removing metals from water supplies rely on expensive mineral adsorbents or chemical agents. Neal and a team of researchers from Wichita State University, Argonne National Laboratory, Notre Dame's Department of Biological Sciences, CEST, and members of the Department of Civil Engineering and Geological Sciences have developed a remediation strategy using biomass byproducts that can effectively remove large amounts of heavy metals while keeping costs to a minimum.

Using a biomass material, in this case the spillage that remains after ethanol is distilled from corn and ground corn cobs, the biomass team was able to remove toxic heavy metals more efficiently and cost effectively than other current processes. As promising as the results of this study are, what Neal believes to be as exciting is that both the biomass and catalytic converter projects evolved from brainstorming sessions. "Good ideas, or rather good solutions," he says, "are seldom developed in a vacuum. We have a vibrant environmental geosciences program with faculty, graduate students, and undergraduates all participating in quantitative research. When this kind of interdisciplinary team work is applied, the probability of continuing to engineer practical and earth-friendly solutions to environmental issues is tremendous."

Techniques developed *and used in the Inductively Coupled Plasma-mass Spectrometry Facility and the Electron Microprobe Laboratory by Clive R. Neal, associate professor of civil engineering and geological sciences, and students like John Shafer, left, include trace element analyses of paint samples, blood, brain tissue, platinum-group elements, zircons and zircon-bearing rocks, superconductors and ceramics, and plant and resin samples.*

Environmental Mineralogy and Nuclear Waste Disposal

During the last five years Peter C. Burns, Massman Associate Professor of Civil Engineering and Geological Sciences, and his team of researchers in the Environmental Mineralogy and Crystal Structures Laboratory have increased the number of known crystal structures of uranium compounds by approximately 25 percent. They have also increased the number of known uranium mineral structures by almost 40 percent. This is especially noteworthy given the emphasis of the research; Burns focuses on the geologic disposal of nuclear waste and the mobility of actinides in the environment. "We now have sufficient understanding of the solid phases of uranium," he says, "to conduct very specific experiments which can help predict the mobility of radionuclides in a geologic repository."

Funded by the Environmental Management Science Program of the Department of Energy, Burns' research is helping to identify how spent nuclear fuel breaks down over time, what alteration phases form, and how those alteration phases impact the mobility of radioactive waste. According to Burns, the most critical step in preventing radionuclides from being released is understanding and controlling the waste form. If it is a stable entity, the nuclear waste can sit in the repository for 10,000 years — the number of years specified by the Nuclear Regulatory Commission as necessary before a repository can be deemed safe — without a problem.

"On the other hand," says Burns, "if the waste forms are problematic from the start, then safety becomes more a function of the geology of the region and the engineered barriers in the repository. The risk of something going wrong increases considerably."

__Peter C. Burns,__ Massman Associate Professor of Civil Engineering and Geological Sciences, and Bridget McCollam, a graduate student, prepare samples in the Environmental Mineralogy and Crystal Structures Laboratory. The lab is equipped with extensive facilities for the synthesis of low-temperature minerals of environmental importance, a portable X-ray diffraction system, and a Siemens "smart" charge-coupled single-crystal X-ray diffractometer.

Burns and his team have been providing many of the research parameters for the complex performance assessment models involving a nuclear waste repository and the geologic area surrounding it, specifically Nevada's Yucca Mountain.

Yucca Mountain is currently the only site being considered for development as the nation's first long-term geologic repository for high-level radioactive waste. The physical characteristics of Yucca Mountain that many researchers cite as favorable for a repository include its distance from a large population. It is 100 miles from Las Vegas. Nevada's dry climate, less than six inches of rainfall a year; an extremely deep water table, 800 to 1,000 feet below the proposed repository floor; and the unique combinations of rock around the site have also been identified as positive and "safe" characteristics. Burns' focus has been less on the location and more on getting the storable form of the nuclear wastes right. "Then," he says, "everything else is just a redundant barrier, adding factors of safety."

Another project being examined in the Environmental Mineralogy Lab deals with dioxin-bearing clays, chickens, and farm-raised catfish. Both the Environmental Protection Agency (EPA) and Georgia-Pacific Corporation found dioxins in the clay binder of soybean meal used as feed for chickens and farm-raised catfish. After several months of investigation and extracting soil from the mine where the clay was taken, the EPA found that the samples were heavily contaminated with dioxin but were unable to identify its source.

Andrew Locock, *a graduate student in the Department of Civil Engineering and Geological Sciences, records data from a uranyl crystal sample, part of the extensive research in uranium mineralogy taking place in the department.*

Dioxins have a congener profile, a fingerprint based upon their atomic weights. The congener profiles found in the soybean meal did not match with any known source: Agent Orange, standard pesticides, pulp mill emissions, etc. However, further studies of clay deposits in the geologic area called the Mississippi Embayment indicated similar levels of dioxins with the same general profiles of the dioxins found in the soybean meal.

Burns and his team have a grant from Georgia-Pacific Corporation to identify the origins of the dioxins. They have begun characterizing the mineralogy of 40 to 50 samples taken by both Georgia-Pacific and the EPA. "We are finding that the mineralogy of these dioxin-bearing clays is very complicated and variable. But we believe there is a correlation between the dioxin content and the mineralogy," says Burns. "The dioxins may have been laid down millions of years ago, or they may have been introduced through slowly percolating groundwater, which would still mean they were natural. If they're not natural, then some as yet unknown mechanism transported them from the surface into the clay very rapidly." According to Burns, unnatural dioxins have only been in existence for roughly a century. So, if the dioxins are not natural, there remains an undiscovered geologic process that has modified the congener profile so it is no longer recognizable. The dioxin project presents a very interesting question from an organic chemistry and geologic point of view.

As part of a course emphasizing regional field geology, *students in the Department of Civil Engineering and Geological Sciences toured Nevada's Yucca Mountain facilities during the spring of 2002. At that time Yucca Mountain had recently received a Presidential recommendation as the U.S. site for the disposal of 70,000 metric tons of high-level nuclear waste. The recommendation initiated an automatic series of events including a congressional review — for approval or disapproval; the submission of a construction license to the Nuclear Regulatory Commission (NRC), if approved by Congress; and a review of the construction license by the NRC, which can take up to four years. The Department of Energy could begin construction of the world's first geologic repository for high-level nuclear waste upon receiving NRC approval.*

The Debate Over **Yucca Mountain**

Most experts around the world agree that the safest method for disposing of radioactive waste is to store it deep underground. Based on this consensus in 1982, Congress passed the Nuclear Waste Policy Act, which instructed the Department of Energy (DOE) to identify a suitable site for an underground geologic repository.

In 1983 the DOE targeted nine locations for consideration. Preliminary studies on each site were reported in 1985, narrowing the field to three possibilities: Hanford, Wash.; Deaf Smith County, Texas; and Yucca Mountain, Nev. As a result of additional feasibility studies, Congress amended the Nuclear Waste Policy Act in 1987 when it directed the DOE to concentrate its site characterization efforts on the Nevada location.

On February 15, 2002, President Bush notified Congress that he considers Yucca Mountain qualified for a construction permit application. His announcement was based on a recommendation by Secretary of Energy Spencer Abraham and more than 20 years of scientific study demonstrating the unique characteristics of Yucca Mountain. In his letter to Congressional leaders, President Bush indicated that proceeding with the Yucca Mountain project was "necessary to protect public safety, health, and the nation's security because successful completion of this project would isolate in a geologic repository at a remote location the highly radioactive materials now scattered throughout the nation."

The decision on what to do with one of the most dangerous substances known to man has brought much criticism of the President's recommendation. The Sierra Club has urged the President to reject Yucca Mountain as a possible location, stating that the contamination of groundwater is a tremendous threat to Nevada residents. Citizen's Alert, a 25-year-old grassroots environmental group based in Nevada, also opposes the use of Yucca Mountain as a nuclear waste repository, citing a high earthquake probability and the potential for groundwater contamination as the top two reasons it "is a bad place for nuclear waste."

Whether or not Yucca Mountain becomes the nation's first long-term nuclear waste repository is uncertain; the debate is still raging. But there is little doubt about the fact that the future of Yucca Mountain may well determine the future of nuclear technology in the United States.

a new environmental geosciences curriculum for undergraduates

Without a doubt the environmental geosciences faculty are involved in cutting-edge research, but they are also very active teachers. For the past two years they have been developing an undergraduate environmental geosciences program that will be launched in fall 2002.

The new curriculum is unique and has been designed to dovetail with the strengths of each faculty member. Students will still be taught the core concepts of geology but with an emphasis on applied environmental issues. The curriculum will also involve a substantial field component, on and off campus.

The **New Curriculum**

The new environmental geosciences curriculum for undergraduates draws on engineering, biology, chemistry, mathematics, and physics, providing students with a quantitative foundation for professional careers or continued higher education. A summary of requirements for graduation with an environmental geosciences major includes:

Courses	Credits
Environmental geosciences	50
Mathematics	18
Technical electives (science and engineering)	12
Physics	8
Chemistry	7
Philosophy	6
Theology	6
Civil engineering	4
Fine arts or literature	3
Free electives	3
History	3
Social science	3
University seminar	3
TOTAL	**126**

Students graduating with a degree in environmental geosciences from Notre Dame can become registered as professional geologists, a requirement in many states for working in geoscience related industries. They may join consulting corporations, national laboratories, or environmental firms. They may also opt to continue their education in graduate school.

According to the Department of Labor, in 1998 geologists, geophysicists, and oceanographers held about 44,000 private sector jobs. Many more individuals held positions in colleges and universities. Of salaried positions nearly 1 in 3 were employed in engineering management services, and 1 in 6 worked for oil and gas extraction companies or metal mining companies.

The federal government employed about 5,800 geologists, geophysicists, oceanographers and hydrologists in 1998. Over half worked for the Department of the Interior, mostly with the U.S. Geological Survey. Others worked with the Departments of Defense, Agriculture, Commerce, and Energy, as well as the Environmental Protection Agency.

Gainful employment, however, is just one of the goals of the program. Ideally, each graduate will use his or her knowledge of the physical makeup of the Earth, past and present, to predict the behavior of the Earth's systems and the universe, to find adequate supplies of natural resources, to conserve soils, to maintain agricultural productivity, to develop natural resources in ways that safeguard the planet, to maintain the quality of water supplies, to reduce human suffering and property loss from natural hazardous events, to determine the geologic controls on natural environments and habitats while predicting the impact of human activities upon them, to understand and interpret global climate patterns, and to apply the lessons learned about Earth to planetary exploration.

Their individual work and career paths may vary widely, but it is the hope of the faculty in the environmental geosciences program and the College of Engineering that each undergraduate will help define the balance between society's need for natural resources and the need to sustain healthy ecosystems.

For more information on the environmental geosciences program at Notre Dame, visit **http://www.nd.edu/~envgeo.**

QUALITY OF LIFE:

THE NEXT FRONTIER FOR ENGINEERS

If the physical and chemical laws that govern the biology of living systems are the same as those that govern inanimate objects, isn't it logical that the quantitative skills engineers bring to the table can substantially add to the biological revolution taking place today?

There's an old saying: "Two heads are better than one." And, it's true. For years while ethicists, theologians, human rights groups, and the medical and insurance professions have been debating when life starts, how it should end, or even the quality of life, engineers and physicians — often with biologists — have been quietly working in teams to solve some of the most pressing physical needs of society. The keyword the media uses to describe these efforts is bioengineering.

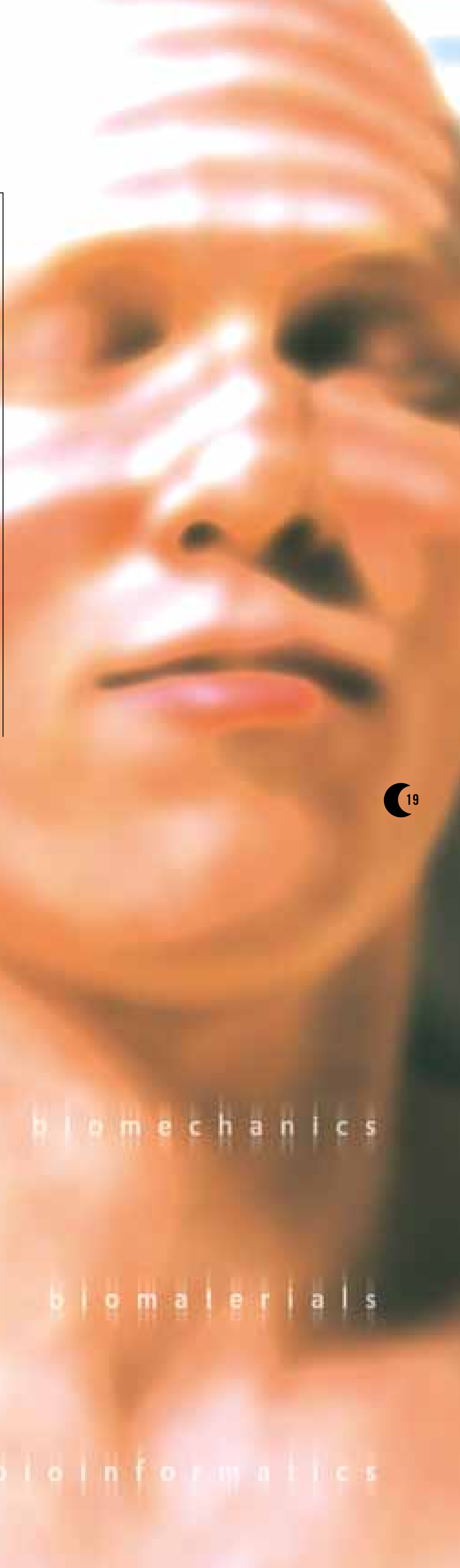
Bioengineering is the generic term that attempts to encompass the newest, and potentially most far-reaching, technological revolution. In fact, the National Science Foundation and National Institutes of Health have identified bioengineering as "an essential underpinning field for the 21st century." Combining the traditional strengths of engineers — analytical and experimental methods, a knowledge of materials, experience in the design and control of systems, and expertise in the processing and control of information — with those of biologists, who work on the molecular and cellular levels to understand biological functions and phenomena, the scope of bioengineering is as vast, and as intricate, as life itself.

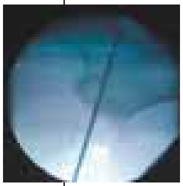
For instance, in the field of biomedical engineering, there are already well established specialty areas, such as biomechanics, the study of motion and devices in the body; biomaterials, which includes living tissue as well as synthetic materials for use in implants; and bioinstrumentation, the development of electronics and measurement devices for diagnostic and treatment applications.

Another field within bioengineering, bioinformatics employs algorithms and mathematical methods to model and analyze biological behavior. Often called computational biology, bioinformatics uses computers to mimic the movements and "thought patterns" of simple life forms in order to better understand, interpret, and predict real-life actions and functions. Bioinformatics also includes imaging systems and devices which aid in medical diagnoses and treatment plans. Imaging technologies that deal with vision identification or face recognition are in the field of biometrics.

Engineers and biologists also collaborate in the field of bioremediation, the use of biological systems to promote environmental stewardship. *(See The Circle of Life on page 2.)*

Researchers in Notre Dame's College of Engineering are focusing their bioengineering efforts in the areas of biomechanics, biomaterials, bioinformatics, and bioremediation. Their successes promise to be at the forefront of innovations in medical treatment plans and surgical procedures, the development of chemical and optical sensors for medical applications, the creation of a synthetic blood with a longer shelf life than whole blood, and the invention of new drug-delivery systems.





The Biomechanics and Biomaterials in Orthopaedics Group at Notre Dame is comprised of researchers from several departments within the College of Engineering, as well as from other sectors of the University and industry. “One of the benefits of being at Notre Dame,” says James J. Mason, associate professor of aerospace and mechanical engineering, “is location. Three of the five largest orthopedics companies in the country are headquartered in Warsaw, Ind., less than an hour away from the University. Several of our graduate students, and even undergraduates, travel to Warsaw on a regular basis to work with the orthopedics teams there.” A majority of the current research in biomechanics and biomaterials is the result of a partnership with Zimmer, Inc., a world leader in the design, manufacture, and distribution of orthopedic implants and fracture management products. In addition to working with Zimmer, College of Engineering researchers collaborate with faculty from Purdue University and Indiana University Medical School on other projects, a number of which are funded by Indiana’s 21st Century Research and Technology Fund, the National Science Foundation, and the National Aeronautics and Space Administration.

Mason and Steven R. Schmid, associate professor of aerospace and mechanical engineering, have led the University’s efforts in orthopedic research, garnering more than $4 million in funding for orthopedic implant research in the last two years. The majority of those projects include the design of devices that promote minimally invasive orthopedic implant surgery (MIOIS). While many of the group’s projects concentrate on the biomechanical aspects of MIOIS, several focus on the biomaterials and bioinformatics also needed as part of diagnoses and treatment procedures.

***Working with researchers** from Zimmer, Inc., Notre Dame undergraduates Peter Mack and Rebecca Brownlee prepare to monitor the temperature distribution of bone cement on a cadaver during the cement curing process. The device they are testing is the new hip fracture implant developed as a result of the collaboration between Notre Dame and Zimmer.*

Consider the almost 350,000 hip fractures recorded each year with more than 90 percent of those fractures occurring in people 65 and older. In one of the most common fracture repair procedures, an orthopedic surgeon makes a six-inch incision in the side of the patient, just over the hip and thigh. This incision cuts through muscle tissue, nerves, and blood vessels, exposing approximately six inches of the side of the femur. A screw is driven through the bone into the head of the femur, which acts as the ball of the hip’s ball-and-socket joint. A plate is then attached to the side of the femur.

Because the incision cuts through so much muscle and other soft tissue, the leg is substantially weakened, causing instability and requiring lengthy rehabilitation times. For example, today all hip fracture patients require walking aids during the several-week to several-month rehabilitation process after surgery. Approximately 50 percent of those people need a cane or walker permanently, and 40 percent of all of the patients require ongoing nursing home care. Other serious complications from the surgery can also arise, largely due to the patient's decreased level of activity.

Yet, this type of structural reinforcement to strengthen fractured bones, such as hips, has been employed and has remained relatively unchanged for decades. A hip fracture implant and surgical procedure developed as a result of the collaboration between Zimmer and Notre Dame offers hope. The new implant device and surgery requires only a one to two-inch incision and avoids cutting through the muscle, nerves, and blood vessels. The curable, metallic polymer components of the device, which provides the same strength as traditional implants, will be located in the canal of the femur. By avoiding the dissection of much of the area around the ball-and-socket joint, the leg should maintain the same stability and strength after the surgery as it had before the fracture. All in all, the new implant and procedure are expected to significantly reduce surgical recovery time, increase mobility immediately following the surgery, decrease rehabilitation time, and offer a much greater chance of resuming a normal level of activity after the surgery, which, in turn, will decrease the risk of pulmonary and other serious complications.

"Because of our successes to date, we have other orthopedic implants in the works," says Schmid. "All of our projects follow the philosophy of being minimally invasive, not causing the patient a lot of pain or physical trauma. The idea is that joint replacement should be about as painful as getting a wisdom tooth pulled. Even working on the projects, it's hard to grasp the scope of what we're doing, because the pain level patients experience, the way surgeons treat patients, and the outcome of many types of surgery are about to change forever."

A second MIOIS project within the group involves spinal fixation. Current treatment methods call for the removal of the ruptured disc, which compromises the strength of the spine. Thus, at the same time they remove the disc, surgeons often attach a system of steel rods, retainers, and screws to the spine, covering the weakened area. The metal rods must be bent by the surgeon and then manually threaded through the stationary retainers to properly support the spine. Many patients, when confronted with the probable side effects of the surgery — paralysis, numbness, or loss of function of the lower extremities — decide to live with the pain of a ruptured disc.

Although relying on the same procedure of drilling screws into the vertebrae to hold a supporting "bar," the Notre Dame group, in collaboration with Zimmer, has developed a new device to replace the steel rod. A prefilled bag

boning up on the stats ...

- Nearly 350,000 hip fractures occur in the United States each year. Four percent of those people undergoing hip fracture repair surgery die during their initial hospital stay. Twenty-four percent of those over 50 years old die within one year of surgery. Close to 40 percent of the total number of patients require long-term care, and half of them never walk unassisted again.
- More than 90 percent of all hip fractures in the United States each year occur in people 65 and older and are often associated with osteoporosis.
- Of the total number of hip fractures that occur each year, 90 percent are the result of a fall.
- By the year 2050, the American Association of Orthopaedic Surgeons estimates the number of fractures rising to 650,000 per year, nearly 1,800 per day.
- The average cost of hip fracture care in America today is $33,000 per patient.

— American Association of Orthopaedic Surgeons, 2001

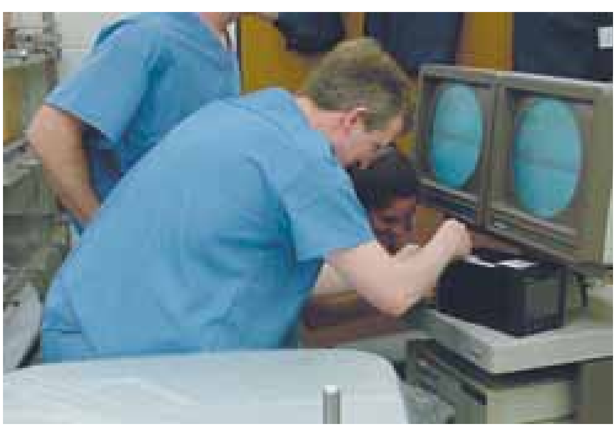
***James J. Mason,** associate professor of aerospace and mechanical engineering, adjusts the fluoroscope during cadaver tests to better monitor the location of the thermocouples and changes to the bone cement during the curing process.*

the father of hip replacement surgery

The modern method of hip replacement surgery was invented in 1962 by Sir John Charnley, an orthopedic surgeon from Wrightington, England. Charnley's work was one of the greatest advances of 20th century surgery. Two revolutionary features of his technique were the use of polymethyl methacrylate bone cement to attach the artificial components of the replacement hip stem to the bone and the use of a metal ball and stem with a plastic socket. The plastic socket offered very low frictional resistance and a low wear rate against the metal ball. Knee and shoulder replacement techniques were also developed as a direct result of Charnley's work. Today the stem portions of most hip implants are made of different alloys. They also come in different shapes and use different design features. But the overall design of the device and the surgical method Charnley developed are basically the same.

Although a different procedure than hip replacement surgery, hip fracture repair can be just as invasive. Research at the University of Notre Dame is contributing to dramatic changes in the hip fracture repair procedure, cutting surgical time and drastically reducing the length of both the initial hospital stay and rehabilitation.

of liquid polymer will snap quickly and easily onto the screws. The surgeon will then apply either a plastic curing agent or ultraviolet light to begin the curing process. This method locks the spine into place with little stress on the spine or spinal column.



Steven R. Schmid, *associate professor of aerospace and mechanical engineering, works with undergraduates to connect the data acquisition unit for recording temperatures during a cadaver test. The purpose of the test was to determine the thermal damage factor, which combines temperature and duration of exposure, of the bone cement as it cured. Temperatures were recorded at the cement/implant interface, the center of the cement mass, cortical wall/cement interface, and inside the cortical wall. Ambient and cement control temperatures were also recorded.*

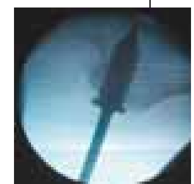
Another aspect of biomechanics being explored in the College of Engineering is the mechanical behavior of bone, particularly cancellous bone which supports joints and is the type of bone most affected by osteoporosis and osteoarthritis. "Instead of studying metal or traditional structural elements, we're studying the mechanical properties of bone," says Glen L. Niebur, assistant professor of aerospace and mechanical engineering. "We're trying to determine how bone, especially the porous bone around joints, responds to loads. What causes it to break? Why do bones break more easily as people age? And, if bone is damaged, does that affect its strength?"

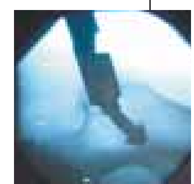
According to Niebur, what the group is doing is extending the boundaries of traditional engineering, working directly with biologists, biophysicists, and physicians to answer questions that no single group can answer alone. One of the devices Niebur uses is a high-resolution micro-computed tomography system, one of approximately 20 machines of its kind in the United States, to study the structure and strength of both normal and osteoporotic bone. The system used by Niebur is a modified version of a hospital CT scanner that is able to image structural features 100 times smaller than a hospital's system.

"Actually," says Niebur, "bone is a great material to work with. It's self-repairing. We also know that it is very oriented, much stronger in one direction than another. It's like trying to break an egg from the ends, which is very

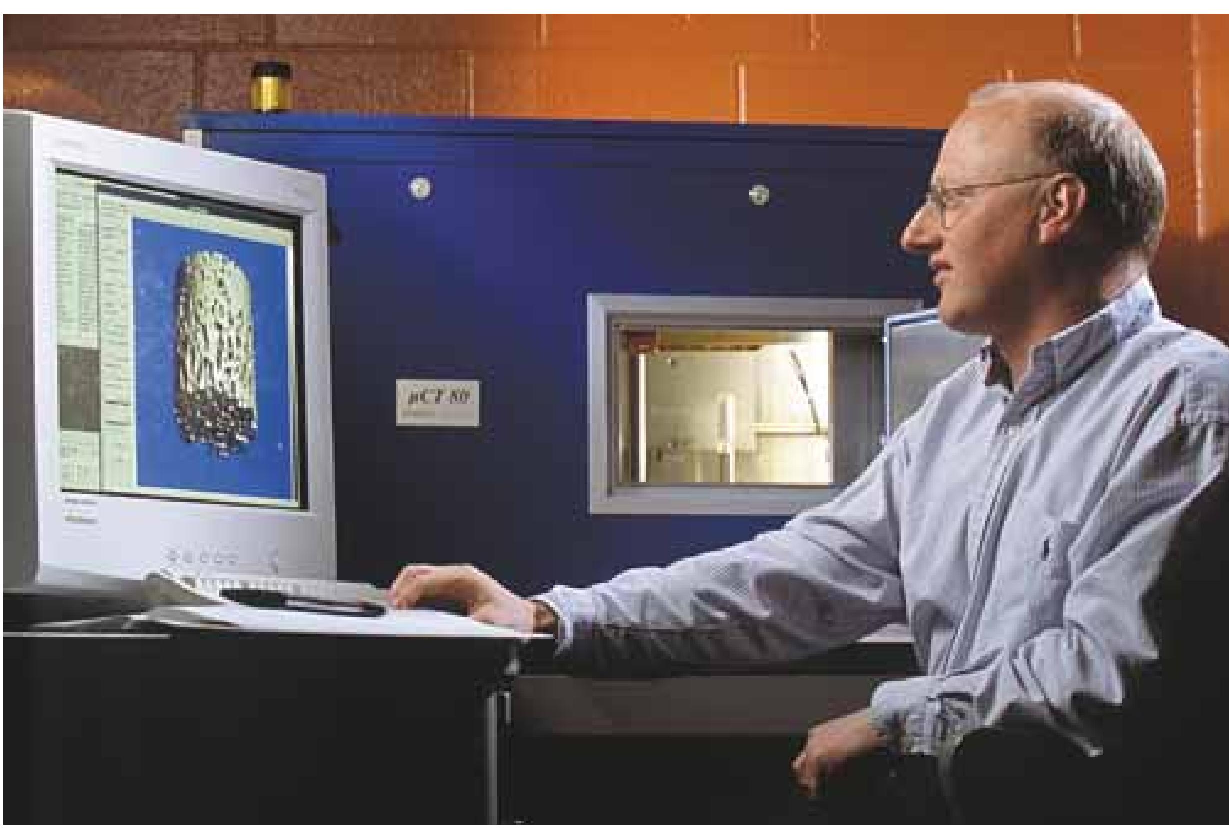
difficult. We believe the repair process works in this same 'direction.' If we can understand how this works and the mechanics of it, perhaps we can find a way to prevent osteoporosis rather than just treat it." Niebur is working on this project with JoEllen J. Welsh, professor of biological sciences. The collaboration, he believes, is successful because it builds on the strengths of engineering and biology to quantify their research. "We're trying to advance the state of human knowledge," he says. "The information we uncover will be put into the public domain to help other researchers, as well as physicians, help people." Niebur and colleagues believe that the information gained through this research will ultimately lead to better designs for medical devices and more effective treatment methods for all types of bone disorders.

As Notre Dame's biomechanics and biomaterials group has grown, it has added faculty members with expertise in machining and shape optimization, in the design of machines — for testing prostheses and other medical implants — and in the characterization and creation of materials for use in surgical procedures. Three new faculty members were added last year. Additional faculty and expanded research funding are expected in the next academic year.

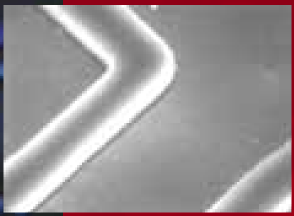




The micro-computed tomography system *used by Glen L. Niebur, assistant professor of aerospace and mechanical engineering, is one of 20 of its kind in the United States. Niebur studies the strength and structure of normal and osteoporotic bone in order to determine its mechanical behavior. Although similar to a CT scanner, the University's micro-CT system is able to image features 100 times smaller than a typical hospital unit.*



Gary H. Bernstein, *professor of electrical engineering*



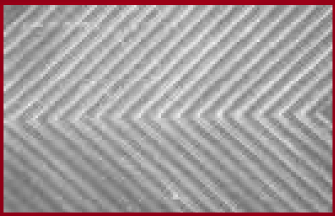
microwave medicine

No one bats an eye when discussions on "wireless technology" include telephones, computers, or satellites. But an inductively-powered wireless system for monitoring blood in which the chemical sensors are fabricated as microwave components ... that's a different story. For two years Gary H. Bernstein, professor of electrical engineering, and colleagues throughout the University have been working to develop a novel microelectromechanical system (MEMS) that could perform multiple medical tests — such as blood glucose, triglycerides, sodium, potassium, or alcohol — on a single diagnostic chip.

Similar to the way a diabetic performs an at-home test to monitor his or her glucose level, the "lab-on-a-chip" would be situated in a hand-held package. The individual taking the test, or medical personnel performing the test, would simply need to place a drop of blood onto the chip, and the "lab" would then be inserted into a small base unit to obtain a digital display of the information.

There are no electrical connections to the chip. Instead the information from the electrochemical detectors integrated on the chip — microwave compatible fluid sensors — would "radiate" the information from the chip to the base unit display, a new approach for MEMS systems. "We've made progress in many areas," said Bernstein, "the microwave circuitry, the algorithms for accomplishing the measurement, the design and fabrication of the external powering system, and the design of the fluidics system so it can work with the signals that are available from the inductive powering of the chip. What we need to do now is bring it all together in a prototype system."

One of the benefits of this research, aside from obvious medical applications, is its commercial promise. In addition to creating a product that society needs, the project has the potential to develop high-tech jobs in Indiana, a goal of the state's 21st century research and technology initiative. In a related effort Bernstein is also working to lessen the effects of Parkinson's disease tremors. "The commercialization of technology completes the entire process ... from concept through research and to actual development, the point at which a device or process changes peoples' lives," said Bernstein. "That's what being an engineer is all about."



Supported by Indiana's 21st Century Research and Technology Fund *and in conjunction with Bayer Diagnostics, Elkhart, Ind; South Bend Controls, South Bend, Ind.; and Serim Research Corporation, also located in Elkhart, faculty collaborating on the "Development of a Microfluidics-based Blood Monitoring System" are: Gary H. Bernstein, professor of electrical engineering; Jay B. Brockman, associate professor of computer science and engineering; Oliver M. Collins, professor of electrical engineering; Patrick J. Fay, assistant professor of electrical engineering; Mohamed Gad-el-Hak, professor of aerospace and mechanical engineering; Marya Lieberman, assistant professor of chemistry and biochemistry; Samuel Paolucci, professor of aerospace and mechanical engineering; Alan C. Seabaugh, professor of electrical engineering; and Gregory L. Snider, associate professor of electrical engineering. Over the past two years a number of graduate students and undergraduates have also participated in this project.*

THE BIOMECHANICS AND BIOMATERIALS IN ORTHOPAEDICS GROUP

This interdisciplinary team explores the interfaces between mechanical engineering, biomedical engineering, materials science, and biology. Projects focus on both basic and applied research and various aspects of experimental and theoretical solid mechanics, manufacturing, materials processing and characterization, tribology, biomedical imaging, and design.

DEPARTMENTS

Aerospace and Mechanical Engineering

- James J. Mason, associate professor
- Glen L. Niebur, assistant professor
- Timothy C. Ovaert, professor
- John E. Renaud, associate professor
- Ryan K. Roeder, assistant professor
- Steven R. Schmid, associate professor
- Michael M. Stanisic, associate professor

Computer Science and Engineering

- Danny Chen, Rooney associate professor
- Patrick J. Flynn, associate professor

Chemical Engineering

- Davide A. Hill, associate professor

Chemistry and Biochemistry

- Marya Lieberman, assistant professor

http://www.nd.edu/~amebio

PROJECTS

Biomaterials

- Anisotropic Damage of Cancellous Bone
- Anisotropy in Human Cortical Bone
- Application of Metal Foams in Orthopedics
- Bone Cement in New Orthopedic Procedures
- Continuum Properties of Cellular Solids
- Hydroxyapatite Whisker Reinforced Composites for Load-bearing Orthopedic Devices
- Multi-parameter Mechanical Characterization and Scratching of Polymers
- Synthesis of Anisometric Hydroxyapatite Particles
- Variable Diameter Fibers (VDFs) as a Novel Reinforcement in Biocomposites

Biomechanics

- Anisotropic Damage of Cancellous Bone
- Anisotropy in Human Cortical Bone
- Bone Marrow Flow in Cancellous Bone
- Continuum Properties of Cellular Solids
- Multi-parameter Mechanical Characterization and Scratching of Polymers
- Shape Optimization in Orthopedics and Biomechanics
- Staining Techniques for Micro-CT Imaging of Microdamage in Bone

Biomedical Imaging

- Minimally Invasive Orthopedic Implant Surgery (MIOIS)
- Shape Optimization in Orthopedics and Biomechanics
- Staining Techniques for Micro-CT Imaging of Microdamage in Bone

Orthopedic Devices

- Application of Metal Foams in Orthopedics
- Bone Cement in New Orthopedic Procedures
- Hydroxyapatite Whisker Reinforced Polymer Composites for Load-bearing Orthopedic Devices
- Minimally Invasive Orthopedic Implant Surgery (MIOIS) Shape Optimization in Orthopedics and Biomechanics
- Variable Diameter Fibers (VDFs) as a Novel Reinforcement in Biocomposites

FACILITIES

- Biomaterials Processing and Characterization Laboratory
- Design Automation Laboratory
- Nano-mechanical Characterization and Tribology Laboratory
- Solid Mechanics Laboratory
- Surface Science Laboratory
- Tribology/Manufacturing Laboratory

The mechanical devices implanted into biological systems are important; they have increased the length and quality of life and promise to provide even greater benefits in the near future. Equally as important are the materials from which they are made, as well as the materials that "glue" them into place. These "biomaterials" include living tissue as well as synthetic substances.

As they continue to pursue minimally invasive procedures and other avenues of research, Notre Dame engineers, biologists, and chemists are working together to improve existing materials and create new ones that will last longer, be more wear resistant, and even strengthen bone.

Peter Mack and Rebecca Brownlee, students in the Department of Aerospace and Mechanical Engineering, developed the procedure and apparatus, shown here, through which temperatures during the bone cement curing process could be measured in a cadaver model.

Understanding materials and how to engineer their properties on the molecular level is vital. Why? "You can't solve this problem if you don't understand the molecules," says Edward J. Maginn, associate professor of chemical engineering, of the cartilage wear project he is working on with Timothy C. Ovaert, professor of aerospace and mechanical engineering, and Schmid. "The phenomenon — that the proteins naturally present in synovial fluid lubricate cartilage joints much better than polyethylene joints — is due to molecular-level processes. Using molecular modeling, we can simulate proteins in the synovial fluid at the atomistic level as they interact with both natural cartilage and synthetic material to understand how they lubricate surface areas. With this information we can then work together on the macroscopic problem, engineering better, more wear-resistant materials."

Biomaterials, natural or synthetic, must also be in tune with the body's many systems. As strong as the body can be, it is delicately balanced. Not every metal or composite is appropriate for use as a biomaterial. For example, while steel and aluminum are common engineering materials, they should not be implanted into biological matter. Tantalum is the most biocompatible metal known. High-density polyethylene is also highly biocompatible; it is basically the same polymer used in milk jugs. And, polyurethane has been used extensively in artificial heart valves.

According to Ovaert, polymers are ideal for biomedical applications because there is a low level of toxicity with the body. "The human body accepts polymeric materials much more readily than a lot of metals or other types of inorganic materials," he says, "and they're inexpensive to process.

mimicking bone

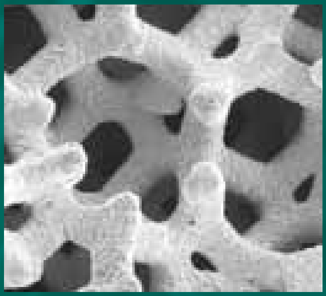
Imagine a sponge-like metal foam, a porous material that comprises or coats a medical implant. Now assume you can create that material using tantalum, one of the most biocompatible metals known to man, and that you can tailor the tantalum material to match the mechanical aspects and load-bearing functions of real bone. This new material, called Trabecular Metal, has been developed by the Implex Corporation and is being studied in collaboration with the University of Notre Dame, Zimmer, Inc., and Implex Corp.

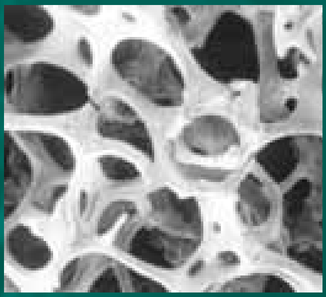
***Trabecular Metal** has the potential to be useful for sports medicine, spinal surgery implants, and hip fracture repair, as well as for cranial facial reconstructions and bone tumor surgeries.*

The cellular structure of Trabecular Metal resembles that of trabecular bone, the type of bone found in the joints of the body and replaced by joint implants. One of the unique characteristics of Trabecular Metal is that it approximates the physical and mechanical properties of bone more closely than other prosthetic materials. Its high strength-to-weight ratio and low elasticity results in nearly physiological loading, which encourages living bone to grow into the porous structure of Trabecular Metal more quickly and form a stronger bond than with other synthetic porous materials. The bond formed between the implant and living tissue extends the life of an implant, avoiding the expensive and painful revision surgeries often required about 20 years following an implantation which used traditional cement fixation techniques.

Although Trabecular Metal offers great promise as a material for joint implants, machining processes for this material are not mature. To date no products have been manufactured which required bending Trabecular Metal, even though this less expensive process would simplify fabrication. This is one of the projects that Steven R. Schmid, associate professor of aerospace and mechanical engineering, and Glen L. Niebur, assistant professor of aerospace and mechanical engineering, along with Paul S. Nebosky, a graduate student in the department, are researching. They, in partnership with Implex and Zimmer, are developing manufacturing processes that are more efficient, while also designing the materials and tooling that allow greater deformation of Trabecular Metal without damaging the porous structure that is critical to bone ingrowth properties.

The goal of the Notre Dame group is to form implants from the material while preserving optimum throughput in the foam-producing reactors. One approach is to bend flat pieces into a variety of shapes, such as the bone ingrowth pads on a hip implant. In recent experiments Schmid, Niebur, and Nebosky have achieved over 90-degree bends in specimens roughly two millimeters in thickness, a significant accomplishment for a material that does not normally deform to this high of a degree. Using different mathematical models of the foam behavior, Notre Dame researchers are also attempting to predict the viability of manufacturing operations before designing and building expensive tooling.





***Trabecular Metal,** a material composed of tantalum on a graphite scaffold, acts and looks like trabecular bone, bottom photo, the type of bone that supports the joints of the body. The porosity and flexibility of Trabecular Metal encourage bone to grow into its pores. Bonds between this material and ligament tissue are almost as strong as the bonds between the tissue and real bone.*

life blood

On any given day an average of 34,000 units of red blood cells are needed ... for trauma victims, heart surgeries, organ transplants, and patients receiving treatment for diseases such as leukemia, sickle cell anemia, and thalassemia. Each unit of whole blood is normally separated into several components. Red blood cells, which carry oxygen and are used to treat anemia, can be stored under refrigeration at 4 degrees Celsius for approximately 40 days. They may also be frozen for up to 10 years. Platelets, vital in controlling bleeding and often used in patients with leukemia and other forms of cancer, can be stored at room temperature for up to five days. Fresh frozen plasma, also used to control bleeding, is usually kept in a frozen state and is viable for up to one year. Containing a few specific clotting factors, cryoprecipitated AHF is made from fresh frozen plasma and can be frozen for up to a year. Granulocytes, sometimes used to fight infections, must be transfused within 24 hours of donation.

Donated blood is free, but there are significant costs associated with the collection, testing, preparation, labeling, shipping, and storage of blood. There are also costs stemming from the recruitment and education of donors and the commitment to keeping the blood supply free from contamination. Even if these costs were minimal, the blood supply level is constantly fluctuating while the number of places around the world that need blood is constantly increasing.

Andre F. Palmer, *assistant professor of chemical engineering*

Blood may be transfused as whole blood or one of its components. Because patients seldom require all the parts of whole blood, often only the portion needed by the patient is transfused. This type of treatment is called blood component therapy. However, almost all of the components have a limited shelf life, and most require some sort of refrigeration. In addition to these factors, blood types must also be considered when planning a transfusion.

Andre F. Palmer, assistant professor of chemical engineering, is working to create a universal blood substitute that will last for years without refrigeration. He is also developing a novel vehicle for delivering anti-cancer drugs.

"In our lab we make polymerized hemoglobin blood substitutes," says Palmer. "The unique aspect of this work is that we're developing new cross-linking agents to polymerize the hemoglobin." By creating large polymers of hemoglobin, Palmer will be able to control the amount of hemoglobin that travels through capillary walls into smooth muscle cells, where it normally sequesters nitrous oxide, causing blood vessels to constrict and leading to high blood pressure.

Funded by the National Science Foundation and the National Institute of Science and Technology, Palmer is also developing bubble-like drug-delivery "vehicles" which can be injected intravenously. Using sophisticated emulsion techniques, Palmer is creating a mechanically strengthened "bubble," similar to the polymerized hemoglobin, that can withstand the forces of the blood flow in the human circulatory system while targeting cancerous cells.

Palmer coats the surface of the vesicle with ligands that recognize specific receptors on a cancer cell. So, when the ligand covered bubble comes in contact with the cancer cell, the cell engulfs the vesicle, digesting its contents, which is where the cancer-fighting drug is stored. The cancer cell then dies from the inside out. Palmer hopes to create a bubble that will remain intact within the circulatory system.

Plastics (polymers) also offer greater wear-resistance features in some applications."

Mason, Schmid, and Davide A. Hill, associate professor of chemical engineering, are working to develop new polymers for use in hip replacement and spinal fixation applications. "The requirements for strength, fluidity, and viscosity for the material in the hip application are completely different from a spinal fixation project," says Mason. "For the hip application, we are working to modify bone cement." Traditional cements are currently used in thin layers between an implant and biological tissue, but new applications — like the minimally invasive procedures the Notre Dame group is developing — stretch the limits of the cements' properties.

One of the main issues under consideration is thermal necrosis, the term for the damage caused by the heat generated when a polymer cures in the body. If the temperature is too high, the tissue surrounding the cement is destroyed. "Bone cement heats when it hardens, and we've been working to modify that, bringing the temperature down to more acceptable levels," says Hill. "We've also been studying photocurable polymers, materials similar to what a dentist puts into a cavity to seal it. We know that photocurable polymers heat very little when they cure, which means less damage to surrounding tissue. What we are exploring is whether or not we can design a new material, a biocompatible photocurable polymer."

***Acetabular cups, tibial components, and hip fracture implants** are examples of the many devices that could feature Trabecular Metal, a material that mimics the type of bone found around the joints of the body. One of the challenges in producing this type of material is the ability to form it and bend it into a variety of shapes without affecting critical bone ingrowth properties. Notre Dame researchers have achieved over 90-degree bends in Trabecular Metal specimens roughly two millimeters thick. The traditional metal forming method shown here bends the material but also measures the load being placed on it.*

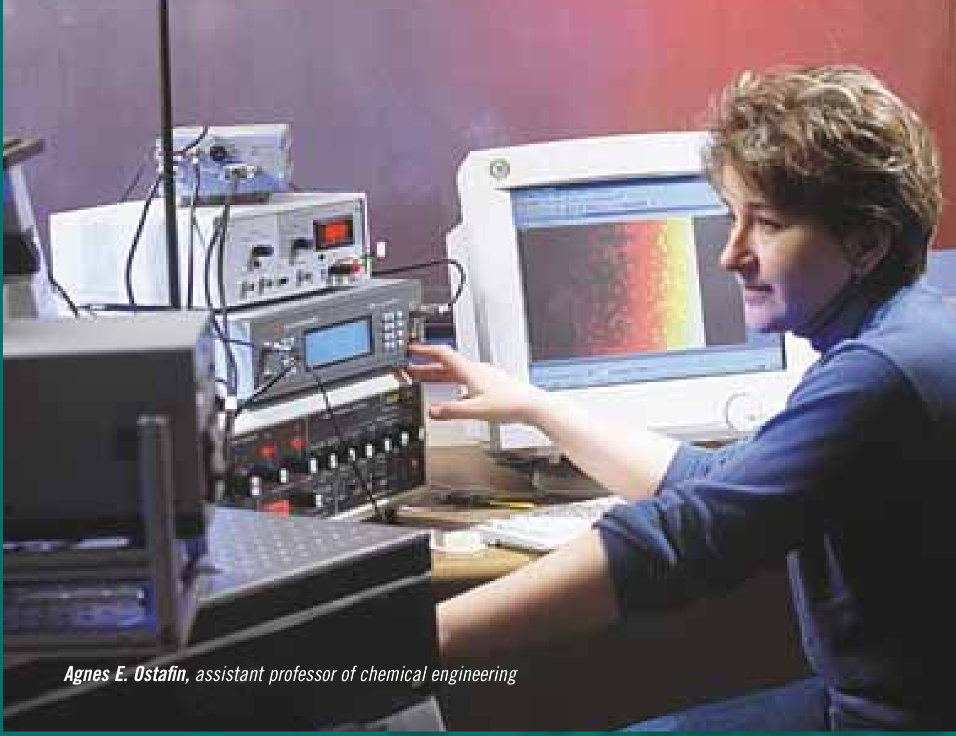
Creating new materials is also the thrust of Ryan K. Roeder's research. Roeder, an assistant professor of aerospace and mechanical engineering, is working to design biomaterials that more closely match the mechanical properties of human bone. "Bone is, in my opinion, the most original and most incredible composite material around," says Roeder. "While there's a great deal of excitement surrounding tissue engineering today, we still don't have a synthetic material that mechanically functions identically to bone."

Most of the materials currently used to replace or strengthen bone are an order of magnitude stiffer than bone. What often happens, according to Roeder, is that the stiffer material carries the load instead of the bone carrying the load. It's called stress shielding, and when it occurs, the bone — signaled by a decreased load and, hence, a decreased need to be strong — starts to resorb and pull away from the implant. An additional parameter of Roeder's ideal bone substitute is that it should be able to serve as a vehicle for delivering growth factors or cells to help bone repair and strengthen itself.

Given the nature of bone, this is a tall order. Bone consists of several hierarchical structural features, which at the simplest level are comprised of a biopolymer, namely collagen. The collagen is reinforced with elongated ceramic particles or bone mineral. The particles are calcium phosphates with a complex composition and crystal structure, which is most closely resembled by hydroxyapatite, the material Roeder grows in aqueous solutions in his lab and expects to use as a biomimetic reinforcement phase in new synthetic biocomposites.

Roeder anticipates that, as the field of biomaterials develops, there will be a shift from using relatively few materials for many different devices and applications to designing devices using a variety of unique materials, whose properties — mechanical, biological, or functional — have been tailored for a specific application.

***Ryan K. Roeder,** assistant professor of aerospace and mechanical engineering, works to create new orthopedic biomaterials that more closely match the mechanical properties of human bone. Using the procedure shown here, hydrothermal synthesis — an environmentally benign and highly controllable chemical process, Roeder manufactures hydroxyapatite particles of controlled size and shape. The closest synthetic equivalent to bone mineral, Roeder believes these particles may serve as the building blocks for new composites.*



Agnes E. Ostafin, assistant professor of chemical engineering

drawing a bead on disease

Between growing photosynthetic bacteria that could eventually be used as the primary ingredient of a mobile septic system for space travel and using the proteins in red blood cells to identify other deficient cells in the body, Agnes E. Ostafin, assistant professor of chemical engineering, is developing nanoshell biosensors for use in early disease-detection systems. These nanometer sized inorganic beads can be "programmed" to seek out specific proteins in the body. Because they are hollow, they can be loaded with dyes and other materials that can be detected by light, X-rays, or electrons.

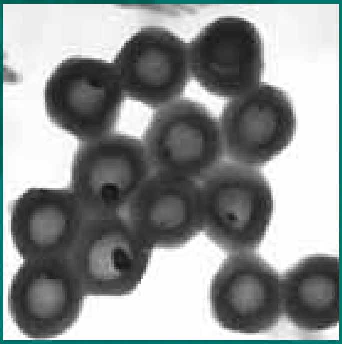
"The idea," says Ostafin, "is to be able to detect features of tumor cells and use these features to track the progress of the tumor, the effectiveness of the therapy, or to design targeted drugs." Currently, she is working with the Bayer Corporation, which is interested in using the beads in urine analysis and in developing the nanoshells for use in *in vitro* applications.

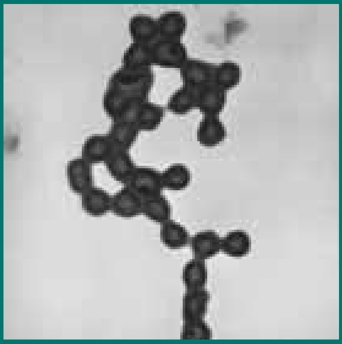
While the technology could obviously be useful to identify diseases in their early stages, it also offers a new method of drug delivery. For example, porous nanoshells could be filled with insulin and placed on a "patch" below the skin, a patch designed to release insulin when excess glucose is detected.

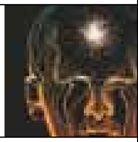
Silicate is one of the materials used to form the nanoshells. Ostafin's group has also successfully created calcium phosphate nanoshells. Hydroxyapatite, a form of calcium phosphate, is the material found in bone. If filled with a hormone that stimulates bone growth, the calcium phosphate nanoshells could provide an effective treatment for osteoporosis and bone replacement therapy.

However, Ostafin cautions that one nanoshell does not fit all applications. Each shell is designed differently for each specific application.

For more information on the nanoshell projects, visit the Nano-scale Bioengineering Laboratory web site at http://www.nd.edu/~aostafin.



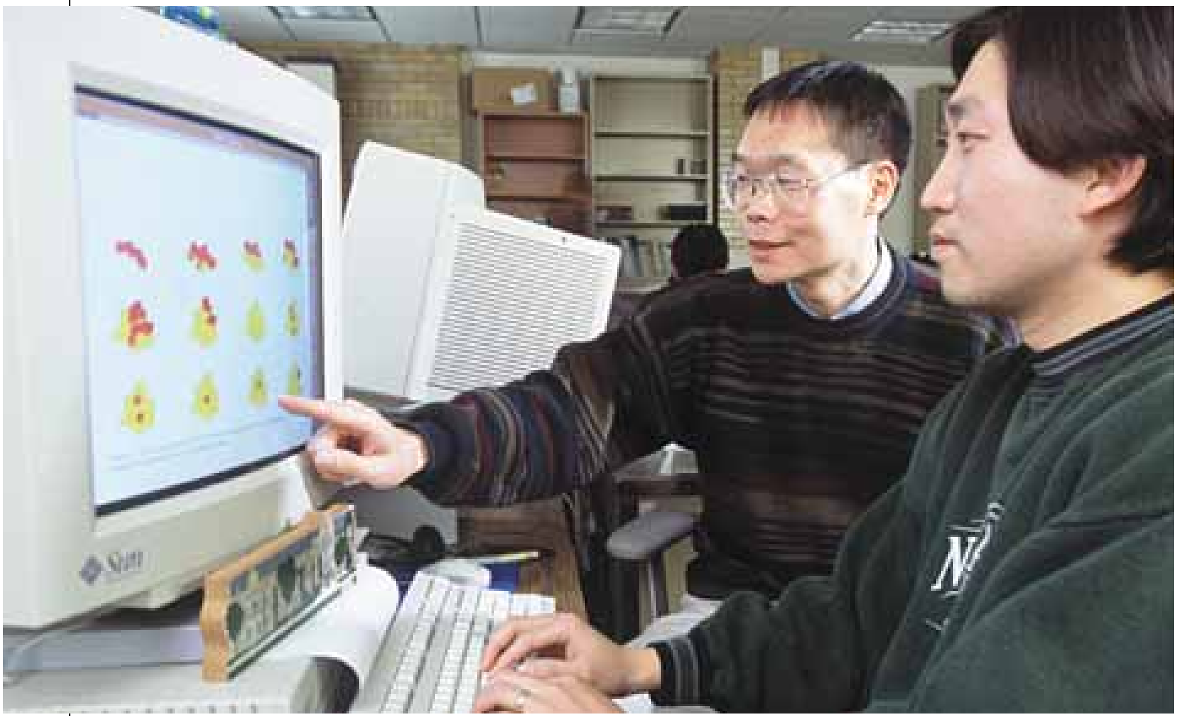




BioINFORMATICS

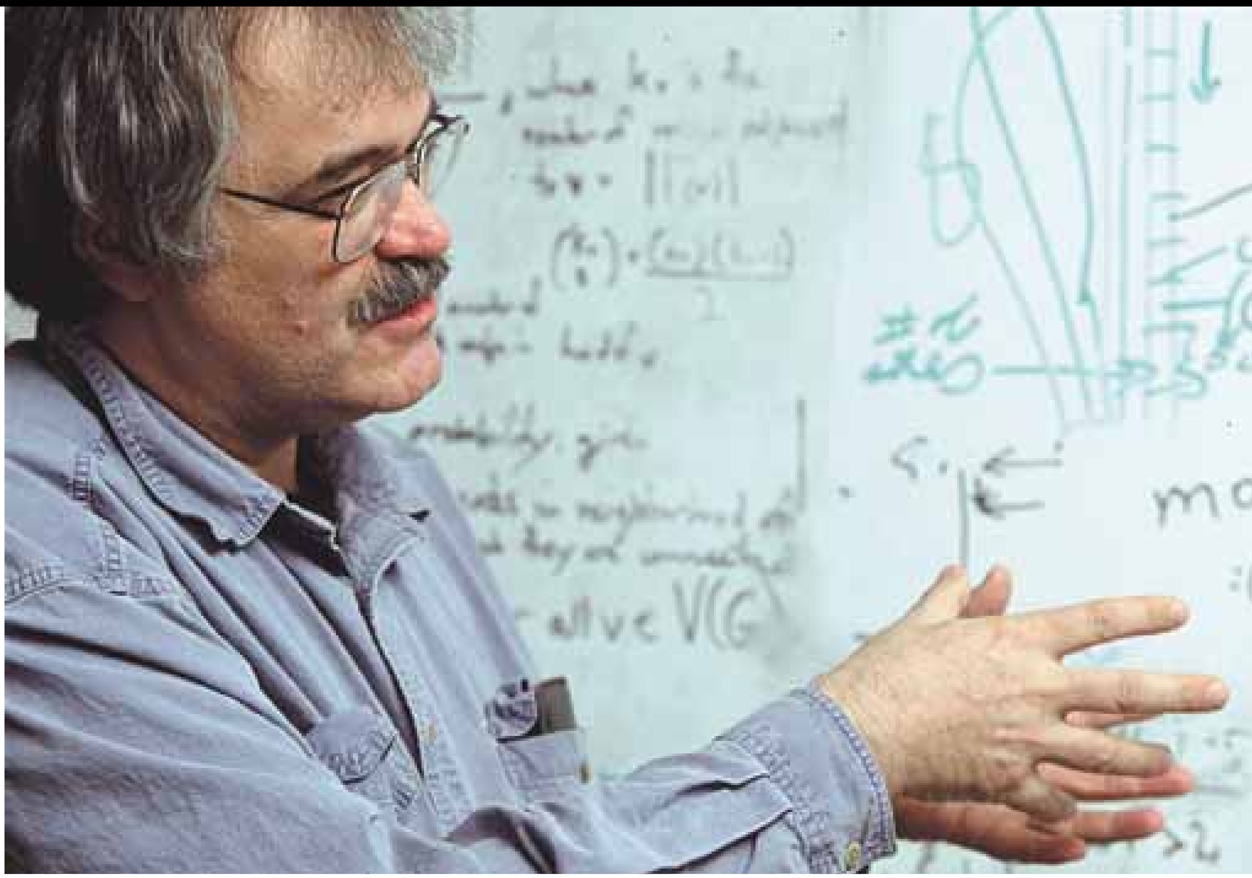
“The interface of computer technologies and biology is going to have a huge impact on society,” says Danny Chen, Rooney Associate Professor of Computer Science and Engineering. “The opportunities for medical researchers and computer engineers and scientists to work together to solve real-life problems are tremendous. For example, I have been studying robotics, more specifically mapping a path for a robot to follow, one based on the parameters of a specific environment. The same methods that allow me to determine a path for the kinds of motions a robot needs to make to maneuver in its environment, without causing harm or being damaged itself, are applicable in a variety of medical applications.”

Today when a surgeon begins planning for a specific operation, he or she might review an X-ray or other images of the body. Individually, those often prove inconclusive. “What we’re working on,” says Chen, “is a human body tissue map, a topographical image that shows tissues, organs, tumors, and their positions relative to one another.” A body tissue map allows a surgeon to evaluate all options — the costs, consequences, and benefits of a particular path he or she may follow in an actual surgical procedure.



***Danny Chen,** Rooney Associate Professor of Computer Science and Engineering, and graduate student Shuang Luan examine topographical images to determine the safest route for radioactive beams to travel through a body, bombarding a tumor with radiation but not damaging organs or healthy tissue.*

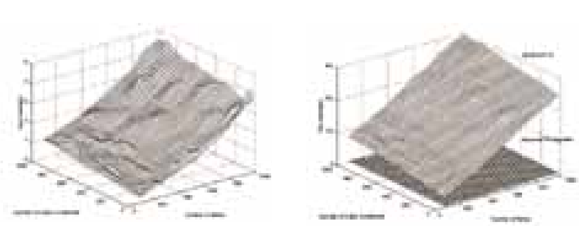
This is especially helpful when dealing with radiation therapy. When physicians identify a tumor site and want to bombard it with radiation, one of their most important tasks is to avoid damaging organs and critical tissues. Chen’s mapping paths, which identify safe routes for a number of individual radioactive beams to enter the body from different directions, have shown promise as a way to minimize the energy and amount of radiation to normal tissues while concentrating the combined power of all the beams on the

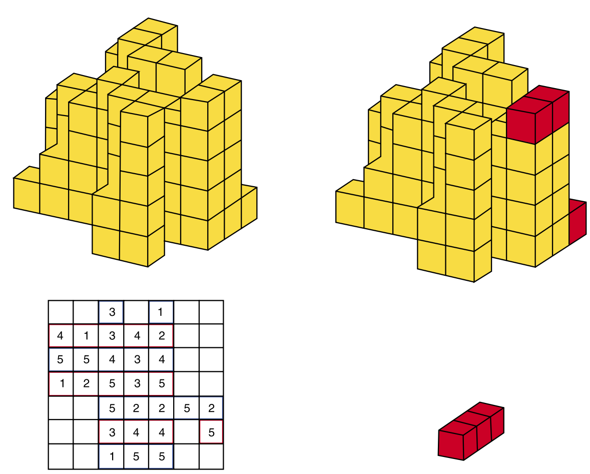


tumor. "Our studies to date have been very encouraging, but we are still evaluating this approach. If we find strong evidence that our method outperforms the current methods, then we will begin more strenuous clinical experiments in conjunction with our collaborator, Cedric Yu, the director of Medical Physics at the University of Maryland Medical Center in Baltimore."

Computational biology, biocomplexity, artificial life, agent based modeling … these are all terms defining computer simulations of complex physical phenomena, from molecules to societies to entire ecosystems. "Biocomplexity," says Gregory R. Madey, associate professor of computer science and engineering, "studies large numbers of diverse things and how they interact. Rather than developing a lot of equations and trying to predict what's going to happen — which is difficult mathematically when the items to be studied are all different — we build a model of the system and let it behave as it would in real life." One of Madey's current projects involves a

Faculty throughout the University *study biocomplexity, the unique structures and behaviors of biological entities and the interaction that arises between such entities. One of the current projects that Gregory R. Madey, associate professor of computer science and engineering, is focusing on involves the modeling of natural organic matter in ecosystems.*





New and emerging algorithms *for radiosurgical treatment planning problems will include two- and three-dimensional segmentation — such as these, developed by Xiaodong Wu, a graduate student working with Danny Chen, Rooney Associate Professor of Computer Science and Engineering — beam selection and shaping, radiation delivery, and shape approximation.*

the shapes of things to come

X-rays, CT scans, MRIs, and ultrasound scans are all imaging techniques physicians use to form their diagnoses. “Image reconstruction — developing an accurate picture from the indirect measurements created by these types of scans,” says Ken D. Sauer, associate professor of electrical engineering, “increasingly focuses on three-dimensional data. Using any of a variety of medical imaging modalities, we create the algorithms that transform non-invasive measurements into a three-dimensional map of a particular section of the body.” In the past physicians reviewing a conventional X-ray received only part of the whole picture. They were able to view structures in the body but not an accurate image of the orientation or relationship of one organ or “structure” to another.

Ken D. Sauer, *associate professor of electrical engineering, and graduate student Blanca Andia*

Sauer’s tomographic research, supported by the Indiana 21st Century Research and Technology Fund and the General Electric Corporation (GE) and in collaboration with researchers from Indiana University and Purdue University, focuses on two types of imaging: emission and transmission. In transmission imaging, such as an X-ray or CT scan, the image is constructed from the amount of radioactivity that transmits through the patient. In emission imaging, such as positron emission tomography (PET), the patient either inhales or is injected with a radioactive isotope whose subsequent emissions can be measured by medical personnel using the scanning equipment. For example, some tumors absorb certain types of glucose at higher rates than healthy tissue. When this glucose is tagged with radioactive tracers, the signals sent back during the scan can help identify the location and size of the tumor, as well as how active it is.

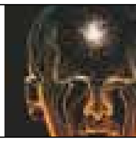
“What is different about the methods we use” says Sauer, “is that they’re based directly on the statistics of the data. We assume the data received from imaging techniques has problems. For instance, since only a limited amount of radioactive material can be injected into a patient, the signals from those isotopes can be relatively weak. So we explicitly include those limitations of quality in our inverse problem solutions to create more accurate images.”

Used as a research tool since the 1970s, in recent years PET has become particularly useful for the detection of cancer, coronary artery disease, and brain disease. The difference between PET and other imaging techniques is that PET can show the chemical functioning of organs and tissues, not just their physical structure. For example, PET can be used to measure the metabolic rate of glucose in the brain, which is helpful in locating the source of epileptic seizures and dementias. The metabolic rate of glucose in the heart can also be measured. PET scans can identify tumors, as well as disorders such as Parkinson’s disease. They can also monitor blood flow in the brain, which helps to identify which regions of the brain are responsible for performing specific tasks. One of the most recent commercial applications of tomographic imaging techniques is the combination of a CT (transmission) scanner and a PET (emission) scanner. The new scanner creates a marriage of information — based on algorithms and inverse problem solutions — that provides both structural detail and physiological function, a diagnostic tool that offers great insight to physicians while often catching diseases in their early stages.

collaboration with Patricia A. Maurice, associate professor of civil engineering and geological sciences. They are modeling natural organic matter, which plays a vital role in ecological and biogeochemical processes. Two graduate students and two undergraduates work with Madey and Maurice on the project. They are studying ecosystem function, the global carbon cycle, and the quantitative aspects of organic carbon transfer in the environment.

Jesus A. Izaguirre, assistant professor of computer science and engineering, is also part of the biocomplexity initiative at the University, which is directed by the Interdisciplinary Center for the Study of Biocomplexity. Working with James A. Glazier, associate professor of physics, and Mark S. Alber, professor of mathematics, Izaguirre is modeling the development of avian limbs. “We’re not trying to engineer a better chicken wing, although that might have interesting commercial applications,” says Izaguirre. “The purpose of the project is to determine the physical properties of cells and the tissue of a limb bud as it grows so we can develop a computer model of the process.” Izaguirre believes that the medical and scientific implications of the project are very exciting and may lead to a better understanding of malformation and other diseases associated with development.

Part of the Interdisciplinary Center for the Study of Biocomplexity, *Jesus A. Izaguirre, assistant professor of computer science and engineering, simulates the behavior of large biological molecules such as DNA, estrogen receptors, and protein. By simulating these molecules and determining how they function in relationship to a particular drug, disease, or as part of a metabolic process, Izaguirre and colleagues hope to provide information that will lead to the design and development of new and more effective drug therapies.*



BioINFORMATICS

Izaguirre also models large biological molecules such as protein, DNA, and estrogen receptors. Simulating the behavior of these types of molecules and how they interact as part of a drug, a disease process, or metabolic function can help pharmaceutical engineers design new and more effective drugs. For example, he is working with Martin P. Tenniswood, Coleman Foundation Professor of Biological Sciences, to model the effectiveness of anti-breast cancer drugs. "If you have a molecular model," he says, "you can understand the mechanisms and determine the effectiveness of a specific drug."

THE INTERDISCIPLINARY CENTER FOR THE STUDY OF BIOCOMPLEXITY

Comprised of researchers throughout the University, the Interdisciplinary Center for the Study of Biocomplexity focuses on the unique, yet complex, structures and behaviors of biological entities — such as molecules, cells, or organisms — and the variety of spatial and temporal relationships that arise from the interaction between such entities.

http://www.nd.edu/~icsb

DEPARTMENTS

Aerospace and Mechanical Engineering
- Glen L. Niebur, assistant professor

Biological Sciences
- Crislyn D'Souza-Schorey, assistant professor
- Edward H. Hinchcliffe, assistant professor
- Kevin T. Vaughan, assistant professor

Computer Science and Engineering
- Danny Chen, Rooney associate professor
- Jesus A. Izaguirre, assistant professor
- Gregory R. Madey, associate professor

Chemical Engineering
- Andre F. Palmer, assistant professor

Chemistry and Biochemistry
- Brian M. Baker, assistant professor
- Holly V. Goodson, assistant professor

Mathematics
- Mark S. Alber, professor
- Bei Hu, professor

Physics
- Albert-László Barabási, Emil T. Hofman professor
- James A. Glazier, associate professor
- Gerald L. Jones, professor

FACILITIES

- Laboratory for Computational Life Sciences

biometrics: the eye of the beholder

Simply put, biometrics is the use of physical or biological characteristics to identify people, with or without their knowledge. Fingerprinting is one of the oldest and most reliable forms of biometrics. Although research in this field has been ongoing for several years, the events of September 11 stimulated a biometrics boom. Concerns about the safety of people in public places, specifically airports, promise new life to many security consulting firms and personal identification systems manufacturers.

With the increased federal and state interest there is also increased funding of a variety of human recognition technology research projects, from radar imaging of body cavities to recognizing an individual's iris from 50 yards away.

Supported by grants from the Defense Department's Defense Advanced Research Projects Agency, Kevin W. Bowyer, Schubmehl-Prein Chair of Computer Science and Engineering, and Associate Professor Patrick J. Flynn have begun assembling a database of faces in the Computer Vision Research Laboratory in order to develop new theories and image-based identification systems.

"It's unfortunate, but true," says Flynn, "that since September 11, if you have a product that can be used to identify people or threats, it is very easy to get noticed in a security context. Some of those companies may be selling physical presence and not necessarily valid systems." Flynn suggests that it is not that all the systems are faulty but that they have not yet been thoroughly tested.

"There is also a pressing need for databases of faces, head shapes, and infrared images of people to serve in the assessment of such systems and characterization of their performance," says Flynn. To that end he and Bowyer have been recording infrared and invisible light pictures of approximately 70 students each week. They've been doing it for the past two semesters and will continue taking photos for another year.

According to Bowyer, the idea is to capture and define an individual's face mathematically using digital and infrared cameras and turning the photos into a string of numbers. The numbers could then be compared against other "strings" in the inventory and the information used by researchers to develop more reliable face-recognition systems.

The drawback in face-recognition technology has been that a person's face can change from day to day. In fact the difference between the same individual on two different days may be more prominent than the differences between two different people. So what's the answer? Bowyer and Flynn believe that an effective system will eventually rely on a combination of technologies, including infrared systems. "We may never be able to identify a specific individual, but there is every reason to believe that, using several types of images together, we will be able to identify whether a person is nervous, wearing a disguise, or otherwise suspicious."

Patrick J. Flynn, *associate professor of computer science and engineering*

the trade-offs in natural and artificial life

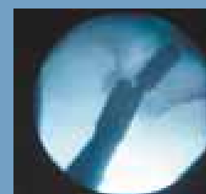
Matthias J. Scheutz, assistant professor of computer science and engineering

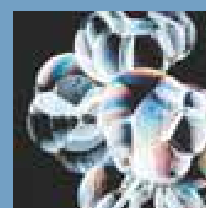
Just as with biological beings, there are trade-offs in artificial life systems. "If you want a universal, very adaptive agent," says Matthias J. Scheutz, assistant professor of computer science and engineering, "then you need a sophisticated control system that can manage the complexity of the agent, one that is able to adapt and adjust. It would require greater computational power and, hence, more physical resources. The physical implementation, for example, would consume more energy and might be heavier, which, in turn, would require a more robust body, causing it to move slower. It is very much a cause-and-effect relationship."

In his research Scheutz models control systems of artificial agents in artificial environments in order to develop an understanding of the possible evolutionary trajectories of such systems. Using an artificial life simulator to model agent behavior, Scheutz and his students hope to answer biological questions regarding the evolution of agent control systems in nature, in particular, "affective control" — behavior initiated, modulated, or interrupted by primitive emotional states like fear or anger. Why, for example are there hundreds of thousands of simple species with low-level affective control systems in nature, such as insects, and only a few species that have higher reasoning capacities? "We want to understand the circumstances in which those higher creatures evolved," says Scheutz.

The work will also assist in the development of artificial agents in the real-world — robots. "We are trying to assess the situations in which it is advantageous for a robot to have more sophisticated skills," explains Scheutz. "How much more does it cost — in terms of time, energy, and money — for a robot to be able to plan ahead, think more, reason instead of simply performing a rote function?" According to Scheutz, once the trade-offs have been worked out, it may be possible ... depending on the task the robot has to perform ... to use a less powerful, less sophisticated control system. An autonomous robot used for mowing the lawn, for instance, could be equipped with a simple biologically motivated control system that would guarantee good coverage of the lawn area while being very inexpensive in terms of initial cost and overall energy consumption.

BioENGINEERING AT NOTRE DAME





Building bridges, designing manufacturing systems, studying the aerodynamic properties of airplanes, and developing more powerful, more efficient engines … those are the types of activities traditionally considered part of the realm of engineering. "Engineers don't work with living systems. That's the job of biologists." Or is it? According to the Obligation of an Engineer pledge, similar in nature to the Hippocratic oath taken by physicians, an engineer promises to uphold the standards and dignity of the profession and to serve humanity by making the best use of his or her talents and the Earth's resources. The pledge places no limits on how an engineer can contribute.

What engineers, physicians, and biologists are finding is that, working together, they can make a greater difference in the lives of people around the world than by working separately. The unique skills and perspective offered by each group are evident in the many multidisciplinary collaborations taking place around the world.

Curricula, at Notre Dame and other universities across America, are also changing to reflect the need for engineers to better understand the life sciences and for biologists to better understand engineering and systems. Traditional mind-sets are evolving, opening a world of possibilities and collaborative opportunities.

The effort has only just begun, but the progress that has already been made is staggering. The medical advances that have occurred, and those that are on the verge of clinical studies and implementation, show that the lines between engineering and biology, between medicine and mechanics, do not run perpendicular to one another with a single intersecting point, one called bioengineering. Rather, they are intertwined and will prove more and more complementary to one another in the future, a future that offers a much higher quality of life for everyone.

Zimmer engineer *and Notre Dame graduate Sarah Thelen prepares bone cement as part of the cadaver testing procedure. A large portion of the bioengineering initiative at Notre Dame is the result of its strong partnership with Zimmer, Inc. A leader in the design, manufacture, and distribution of orthopedic implants and fracture management products, Zimmer is located less than an hour from the University.*

PASSING

Local residents huddled along one of the University of Notre Dame's main roads in January were waiting to see the Olympic torch as it swept through the South Bend area on its way to Salt Lake City for the 2002 Winter Olympic Games. Rev. Theodore M. Hesburgh, C.S.C., president emeritus of the University, and Debbie Brown, Notre Dame head volleyball coach, were two of the 34 honorary torch-bearers who carried the Olympic flame along South Bend's nearly seven-mile leg of the 13,500-mile journey. By the time it reached Salt Lake City on February 2, the torch had passed through 46 states and 11,500 pairs of hands.

In *The Republic* Plato said, "Those having torches will pass them on to others." But he wasn't talking about the Olympic flame. He was describing a process, the way ideas are conveyed from one person to another. The interaction that takes place between teacher and student and among groups of students is more dynamic than a simple hand-off. The educational process requires planning, continuity, community, excitement, and a vision for the future.

As they are developing curricula and facilities
that will address the educational needs of the 21st century,
engineering faculty at the University of Notre Dame
are shifting their focus from teaching students to helping them learn.

THE TORCH

These are the elements the College of Engineering is pursuing as it continues its plans for the development of a multidisciplinary engineering learning center. "If you look at the technical advances of the last century," says Stephen M. Batill, associate dean for educational programs and professor of aerospace and mechanical engineering, "wireless worldwide communications, the development of medical therapies and devices that enhance the length and quality of life, and the creation of materials designed to perform specialized functions — they are the kinds of activities that come about from people who not only understand engineering systems as a whole, but who also work together as a community. We expect that an engineering learning center will help students understand the necessity and benefits of collaboration. More important, we hope that the multidisciplinary perspective and environment fostered by the center will help our students become the leaders and innovators for the next great advancements."

The concept of a multidisciplinary learning center started as a seed, a glimmer of an idea, generated by the College's Curriculum Enrichment Committee in 1999 to address the changes occurring in the engineering profession and in engineering education. Over the last 15 years more and more employers have been emphasizing that a successful engineer should not only have strong technical capabilities in a specific discipline, but that he or she should also possess the knowledge of how interdependent elements function in an engineering system, exhibit solid communication skills, and have experience working as a member of a multidisciplinary team.

In its report the Curriculum Enrichment Committee recommended that these skills and experiences would be developed more effectively through interactive project-based learning — integrating the subject matter from a variety of engineering disciplines and introducing mathematical and scientific concepts in the context of actual applications — rather than through traditional, single-discipline lecture-based teaching. The committee then proposed that the best time to lay the foundation for "multidisciplinary, hands-on learning" was during the first year of a student's engineering experience. Accordingly, the college's role in the First Year of Studies program for engineering intents was significantly changed. A two-course sequence, EG111 and 112, replaced a computer programming course and includes a historical perspective on the engineering profession; exposure to engineering professionals from various disciplines; team-based design activities; and project-based analysis, modeling, and simulation exercises.

In addition to developing EG111 and 112, the committee urged the college to adopt a "learning paradigm" marked by active student participation in educational activities. The approach also focuses on developing student leadership qualities and a team mindset, as well as strong technical skills, including the ability to effectively use information technology. It also encourages increased synergy among students and between students and faculty. According to the committee, both the first-year course sequence and an emphasis on experiential learning throughout the curriculum would require a specialized facility.

If students were to have the opportunity to learn through hands-on experiences, to develop interdisciplinary projects, and to interact with other students and faculty throughout the college, regardless of discipline or class, they needed a place for this to occur. If faculty were to develop 21st-century teaching and learning activities that would stimulate and inspire students to work individually and in teams, they needed a place for this to occur. If students and faculty were to become a community, working together, and at times with industry, to explore existing and emerging technologies in a manner that would spark innovation and discovery, they needed a place for this to occur. That place, according to the committee, was an engineering learning center.

Development of a multidisciplinary learning center, as proposed by the committee, began as a two-phase process. Phase I called for the creation of a prototype facility, which would provide intermediate support for the needs of the College of Engineering and students in EG111 and 112. The prototype would also function as a working model of a much larger learning center, which would be developed as part of a new building project, Phase II.

Phase I was completed in September 2000, when a prototype facility was opened in the Cushing Hall of Engineering. Developed at a cost of approximately $950,000, the 4,000-sq.-ft. learning center is a unique combination of computer cluster, design studio, laboratory, reference center, multimedia/presentation area, and study space. Its mission is to nurture a community environment where students and faculty are connected through their search for knowledge and quest to engineer better products and processes.

The prototype center is multifunctional, providing flexible work areas for a variety of activities. Although created with first-year students in mind, it can be, and is being, used by students at all levels and in every department of the college to explore, experiment, and experience the many facets and disciplines of engineering. For example, students in the learning center can work individually or in teams on discipline-specific projects. They can also pool their skills, using group work areas with networked computer support and multiple screen audio-visual capabilities, to complete a multidisciplinary class assignment.

Although there are similar centers at a handful of universities across the country, the college's facility is unique in two very important ways. First, it offers a wide variety of tools and resources to students and faculty in the college, many of which are not easily accessible to students at other institutions. Also, while it functions primarily as a student learning center, the prototype facility provides faculty the opportunity to develop and test novel teaching and learning techniques.

"The real beauty of the learning center is that the space is so dynamic," says Batill. "Different people can use it in a multitude of ways at the same time." And, that's exactly what's happening. Junior chemical engineering students are completing work for a fluid mechanics course at the same time first-year students are reviewing their notes for the next day's truss project.

When the prototype was opened, there was plenty of room for anyone wanting to use the center. Original operating hours were set from 9:00 a.m. to 10:00 p.m., Monday through Friday, and 10:00 a.m. to 10:00 p.m., Saturday and Sunday. The College has expanded hours once and is currently considering adding more hours during the evenings and on weekends.

"What's been very exciting for me," says Natalie Gedde, the learning center manager, "is being able to see how many students not involved in EG111 and 112 are using the learning center. Watching them get excited about the resources available here confirms that we're on the right track." Gedde also notes the number of students who gather in the center for group projects has increased dramatically since the beginning of the year.

In fact, several courses from each department now require that specific projects be conducted in the learning center. Some courses have held oral presentations in the center, making use of the facility's

The First-Year Experience

Although most engineering programs are rigorous, not all of them provide a good "learning" environment, especially for first-year students. In addition to selecting an institution that has excellent library facilities, top-notch laboratory equipment, a world-class faculty, and solid advising, counseling, and tutoring services, many prospective students are comparing how different engineering schools "teach" engineering. Increasingly, instead of choosing traditional lecture-based programs, they are selecting institutions with interactive programs and courses like the College of Engineering's first-year sequence, EG111 and 112. Based largely in the Engineering Learning Center, EG111 and 112 is a hands-on, interactive sequence that supports the premise that the best "learning" is achieved through "doing." The courses are designed to help students begin to understand the nature of engineering, develop and apply fundamental engineering skills, and gain practical design experience.

Students are assigned two projects during each course which focus on multidisciplinary systems, their behavior, and their interdependent parts. They work in teams using engineering models to analyze, build, test, and demonstrate their designs, while documenting their rationale and design decisions. They function as engineers, which helps them become independent thinkers who can creatively solve technical problems.

Through Students' Eyes

Students throughout the college have been weighing in about their experiences in the Engineering Learning Center. Some sit on the Engineering Learning Center Steering Committee and are involved in the planning of the new facilities. Some are peer mentors in the current center and help other students explore and experience engineering. And, some simply appreciate the resources the learning center provides:

Rebecca Camus

The first experience Rebecca Camus, a sophomore in the Department of Computer Science and Engineering, had with engineering at Notre Dame was through the Introduction to Engineering Program (IEP), a summer program for high school students. She had been considering chemistry or biology as a career, but the IEP gave her a glimpse of the options engineering offers and she applied to the University.

Camus was a member of the first full class of freshmen to participate in EG111 and 112. Last semester she was a learning center monitor, and this semester she is a peer mentor, working with EG112 students.

From a student perspective, Camus appreciates the learning center. "When you go to computer clusters around campus," she says, "there is no place to spread out your project information and work, as an individual or with a group. The learning center gives you plenty of room to work, and different people in your group can be on different computers at the same time."

Camus also likes the fact that the center is used by students throughout the College. "Seniors work there, but freshmen also feel free to go to the center, and there is usually a teaching assistant or a peer mentor there to help."

On average Scott Turner, a junior in the Department of Electrical Engineering, is in the Engineering Learning Center four nights a week. Three of those nights he's working on his own projects, but on Sunday night he's serving as a peer mentor to other engineering students.

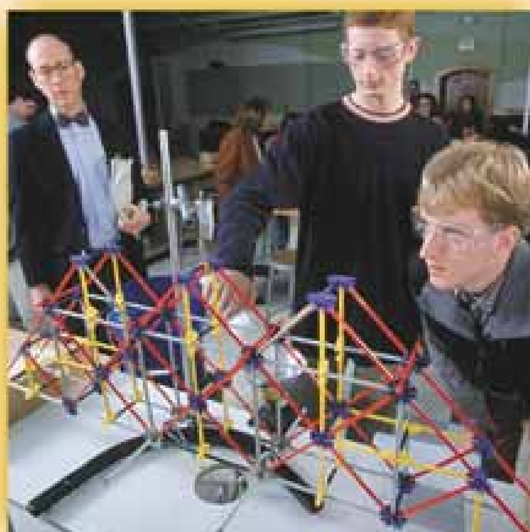
During his freshman year Turner was one of the 25 engineering students in the pilot sequence for EG111 and 112. He has worked as a peer mentor in the learning center ever since. He believes that the learning center is a wonderful resource for students at all levels. "I can go there and use a soldering iron, an oscilloscope, or any number of power tools," he says. "There are so many resources available there, and it's an easy environment in which to get together and work on group projects."

Turner says the interaction he sees in the center among his fellow students is almost as exciting as what he sees happening among the freshmen he mentors as part of EG111 and 112. "The learning center gives them [the first-year students] hands-on opportunities to explore engineering and really get involved. It's a great place."

Scott Turner

audio-visual capabilities and presentation area. Other classes use the center for software tutorials.

Individually, students can check out portable learning modules. These multidisciplinary modules, supported by a grant from the General Electric Fund, complement classroom activities by helping students explore the interfaces between disciplines in devices such as an embedded microcontroller or processes like the flow of chemicals and contaminants in groundwater. Students using the modules can work at their own pace while expanding their educational experiences.



"What we're seeing in the learning center," says Batill, "is an increased use of the facility, by students and faculty, as a learning tool. There is an excitement and a spirit of cooperation and communication in the learning center that is beginning to echo throughout the college."

And, of course, the Introduction to Engineering Program uses the center during the summer for its bridge and robotics projects. The high schoolers in this program enjoy the center almost as much as their parents enjoy the center's web cam. Parents, school friends, and others are able to watch activities in the center by logging onto the center's live camera at *http://www.nd.edu/~englearn/webcam/webcam.htm.*

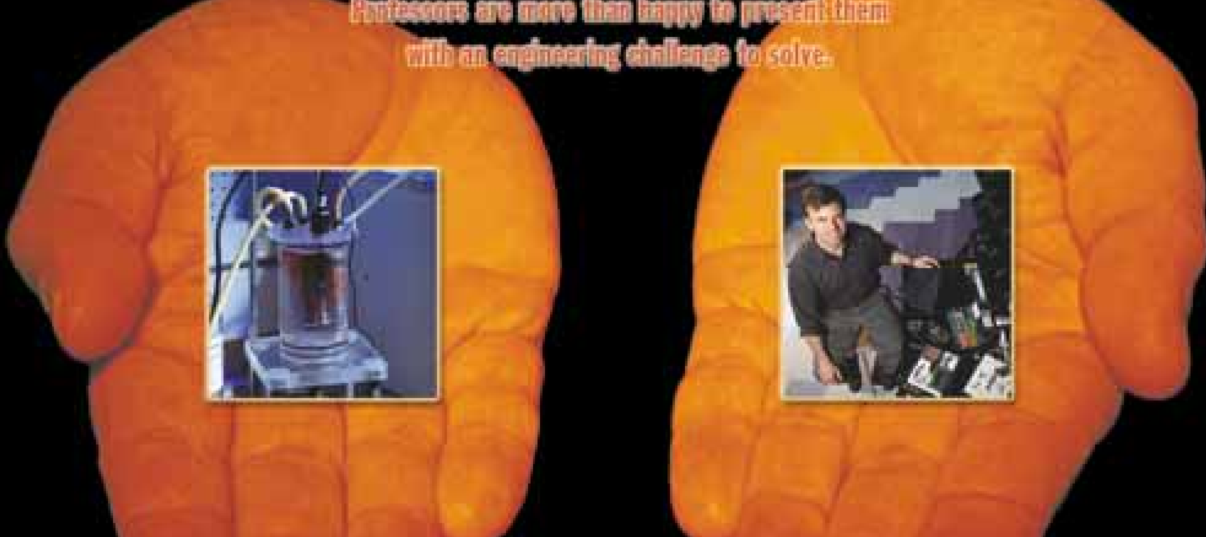
As successful as the prototype has been in launching EG111 and 112 and the new learning paradigm, there is more to be done. Engineering problems and technologies have become extremely complex and multifaceted. "Students who have participated in multidisciplinary, experiential, interactive, and team-based learning activities are those we believe," says Batill, "who are better prepared, have a better understanding of what engineering is as an academic discipline and profession, and are more committed not only to the major, but also to building teams that address societal needs."

Unfortunately, measuring if students are better prepared for careers in engineering or more successful in their careers because of the "learning by doing" focus is not an easy task. As Batill and

Learning and Doing Go

Hand in Hand

Students looking to apply what they've learned in class through hands-on projects in the learning center don't have to go very far. Professors are more than happy to present them with an engineering challenge to solve.



A Lesson in Control

Most of the "challenges" come from departmental course-work like the control experiment Hsueh-Chia Chang, Bayer Professor of Chemical Engineering, developed for his students. Seniors in Chang's class on chemical process and control were asked to design a controller for a pH control project and then tune and monitor its functions. The learning center helped Chang and his students test controller tuning theories on a real system. "My students really appreciated being able to put the theories they were learning into action," he says. "Many of them commented that working with a real system — seeing the fluctuations, monitoring gains, and learning not to over adjust the control mechanism — was invaluable."

A Session on Microcontroller Interfacing

One of six learning center modules funded by the General Electric Fund, the project designed by J. William Goodwine Jr., assistant professor of aerospace and mechanical engineering, and Michael D. Lemmon, associate professor of electrical engineering, works like a "mini course." Students, even faculty, can teach themselves about interfacing microcontrollers. All Notre Dame engineering students are exposed to microcontroller concepts in EG111 and 112, but the first-year course sequence doesn't cover a number of advanced topics essential for the successful design and development of real-life embedded systems. Nor does it address the costs, benefits, and risks associated with integrating microcontrollers into a variety of systems. The multidisciplinary module takes about four hours to complete and covers methods from electrical, computer, and mechanical engineering. Topics include analog interfacing, interrupt synchronization, and embedded system applications. In addition to being a unique individual course, the module augments undergraduate control courses in both the electrical engineering and aerospace and mechanical engineering departments.

A Variety of Experiences

Multidisciplinary in nature, the GE Learning Modules have been integrated into the course activities of several departments. The six modules developed for the learning center include:

- Autonomous robots
- Embedded microcontrollers and microcontroller interfacing
- Remote sensing and data acquisition in microprocessor-based systems
- Degradation of organic contaminants in groundwater
- Microelectromechanical systems (MEMS)
- Satellite communications

researchers from the University's Kaneb Center for Teaching and Learning work to create meaningful devices for measurement, the college is continuing to develop plans for a 15,000-sq.-ft. learning center, which will be housed in a new engineering facility, the Multidisciplinary Engineering Education and Research Building.

"The purpose of the new building," says Frank P. Incropera, McCloskey Dean of Engineering, "is much broader in scope than simply the need for space. It's about developing innovative and effective learning environments and communities. It's also about creating a seamless transition between education and research, one that will benefit our students, faculty, industry partners, and society." It is this vision for the future that is driving plans for the new building.

The learning center in the new building will provide cutting-edge design, fabrication, and presentation facilities; interactive learning modules; and even more hands-on engineering experiences than those available in the current center. As in the prototype, students in the new learning center will be able to work individually and in teams on a variety of cross-disciplinary projects. The fact that there will be no "walls" between disciplines in the center will foster the development of an engineering community among undergraduates, graduate students, and faculty throughout the college, encouraging interaction and collaboration.

Facilities in the new center will include computer clusters for simulation and design activities, equipment for fabricating and testing prototypes, facilities for conducting experiments, a multimedia presentation area, demonstration areas, and group project work and study space. Although plans are not finalized, preliminary requirements for the new facility have been drafted by the Engineering Learning Center Steering Committee — a group comprised of faculty, graduate students, and undergraduates from each department. Proposed elements of the center include:





❑ Workstations in open areas supporting individual and small-group activities using a wireless computer network.

❑ Shelf and table space allowing for use of instrumentation, data acquisition systems, and other equipment needed for student projects.

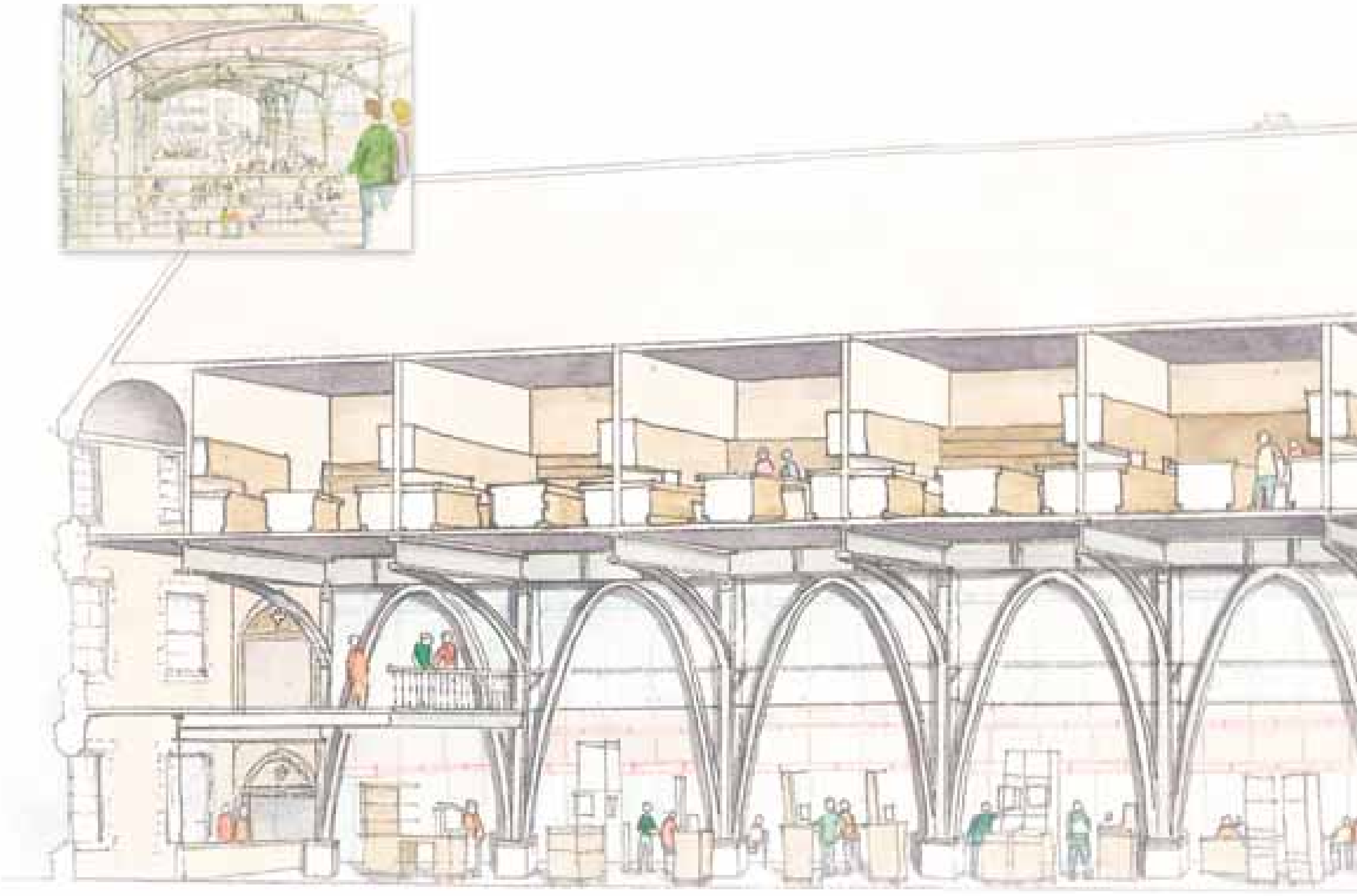
❑ Fume hoods, chemical disposal sinks, vacuum and pressurized air, gas, and other chemicals for specialized activities.

❑ A flexible multimedia presentation area offering teleconferencing and distance-learning capabilities for groups of up to 50 people.

❑ Small group work areas, for up to eight students, offering network access, white boards, and conference tables.

❑ A student shop supporting machining, computer-aided machining and rapid prototyping, and electronic assembly and testing equipment.

❑ Computer clusters/classrooms supporting computer-aided design simulations, virtual prototyping, and information retrieval for small groups or individuals.







- A multimedia resource area with preparation and practice rooms, as well as viewing capabilities for videos, CDs, etc.

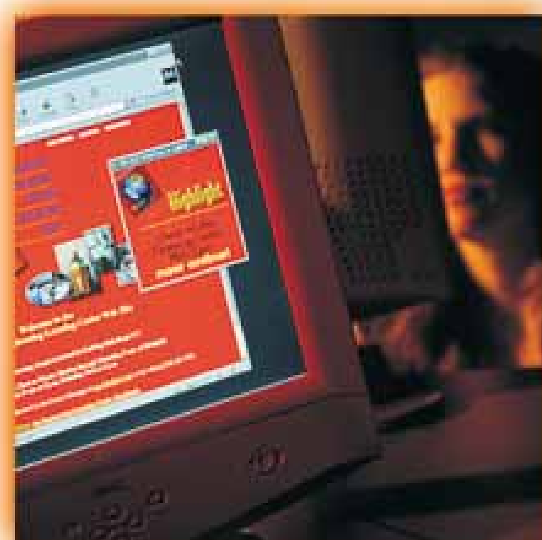
- Student storage space for completed projects, equipment, and other engineering artifacts.

- Precision electronic and optical instruments for student projects.

As an important extension of the learning center, the Multidisciplinary Engineering Education and Research Building will also house a commons area. Plans for the commons include a large atrium, coffee house, internet access ports, modern audio-visual equipment, and white boards, all of which will foster dialogue and the development of an educational and research community, one that is truly multidisciplinary in nature. The commons will encourage collaboration as faculty and students gather there to discuss specific projects or engineering concepts, interacting on a social level while connecting on a professional one. The commons and the learning center will be two vital parts of an active and productive engineering community.

Sharing the new building will be two University centers: the Center for Nano Science and Technology and the Center for Molecularly Engineered Materials, which will also house the College of Engineering's Materials Characterization Facility. The location of these two research centers within the new building and in such close proximity to the learning center will further strengthen the ties between teaching and research.

In fact, one of the most exciting aspects of the new building is that state-of-the-art laboratories and research facilities will be fully integrated with state-of-the-art teaching and learning facilities. Students at all levels and across all disciplines will benefit from the exchange of ideas that will occur in a building where traditional boundaries have no meaning. They will experience firsthand the excitement of what it means to be part of an engineering community.



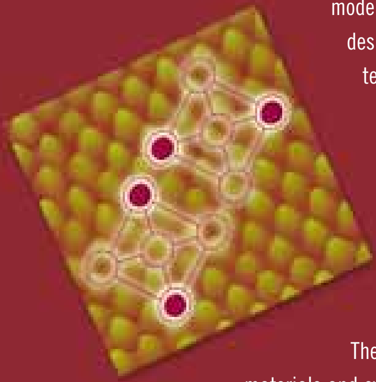
Most important, at the end of each undergraduate's time at this University, he or she will not say, "I've been studying to be an engineer." No ... as a Notre Dame engineering student each graduate will have served as a vital member of a multidisciplinary team on a classroom project, as an undergraduate research assistant, or through an engineering internship. Each will have made multiple presentations to classmates, faculty, and even industry representatives. Each student will, in essence, be able to lift his or her torch very high and say, "I am an engineer."

For more information about the Engineering Learning Center, visit **http://www.nd.edu/~englearn.**

THE CONNECTION BETWEEN EDUCATION & RESEARCH

Research laboratories and teaching-learning facilities rarely share the same space, which is ironic considering that they are interdependent in nature.

The University's new **Multidisciplinary Engineering Education and Research Building,** however, will not only provide unique learning areas for all engineering students, but it will also house two unique research centers. An important benefit of locating the learning center as a central element in the new engineering building is the exposure it will provide for all engineering undergraduates to two highly visible emerging technologies: nanoscience and molecularly based materials synthesis.



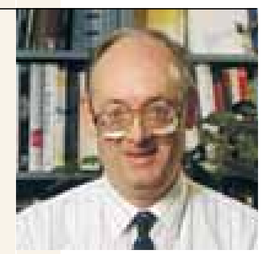
The **Center for Nano Science and Technology** explores a wide variety of fundamental concepts in nanoscience and engineering with emphasis on molecular-based nanostructures, device concepts and modeling, nanofabrication characterization, image and information processing, and functional systems design, including the development of future generations of computing, optical, and information storage technologies. The center is the only research facility in the country addressing nano-computing capabilities using Quantum-dot Cellular Automata (QCA), which was pioneered at Notre Dame. The multidisciplinary center is comprised of researchers from the departments of electrical engineering, computer science and engineering, chemistry and biochemistry, and physics. Facilities in the new building will include Class 100 clean rooms for nanodevice and circuit fabrication, nanolithography, and scanning tunneling microscopy. Wolfgang Porod, Frank M. Freimann Professor of Electrical Engineering, is the center's director. For more information on the center, visit *http://www.nd.edu/~ndnano.*

The main function of the **Center for Molecularly Engineered Materials** (CMEM) is two-fold: to develop materials and systems whose structure and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processing, and to train students in emerging materials technologies. According to Arthur J. Schmitt Professor of Chemical Engineering Arvind Varma, the center's director, "The fact that we're focusing on materials — such as fuel cells, catalysts, biomaterials, and sensors — and changing them at the molecular level to obtain desired properties and performance is what makes the center unique." CMEM draws researchers from the departments of chemical engineering, aerospace and mechanical engineering, chemistry and biochemistry, physics, and the University's Radiation Laboratory. For additional information, visit *http://www.nd.edu/~cmem.*

Working in tandem with researchers in the Center for Nano Science and Technology and CMEM, faculty and staff in the **Materials Characterization Facility** will provide extensive characterization of materials from one angstrom to several centimeters in length. The facility will assist the identification of atomic/electronic structure and species concentrations of materials to parts-per-billion levels. Microstructural features as observed on polished, etched, fractured, and other degraded surfaces will be photographed and stored for analysis and application by University researchers. For more information, visit *http://www.nd.edu/~cmem.*

C O L L E G E   N E W S

Kogge Named Associate Dean



Peter M. Kogge

Peter M. Kogge, Ted H. McCourtney Professor of Computer Science and Engineering, has been named the associate dean for research within the college. In his new role Kogge's main responsibility will be to identify strategic issues and directions in research. He will also coordinate external partnerships and assist faculty in the college in the development of industry relations, while targeting federal funding opportunities for multidisciplinary research projects.

A world-renowned researcher, Kogge's work focuses on advanced computer architectures. He has written two books and holds 20 patents. In addition, he is a fellow of the Institute of Electrical and Electronics Engineers and an IBM fellow.

Kogge joined the University in 1994 from the Federal Systems Division of IBM to become the first holder of the McCourtney chair in computer science and engineering. He graduated from Notre Dame in 1968 with a bachelor's degree in electrical engineering. In 1970 he received his master's degree in systems and engineering sciences from Syracuse University, and in 1973 he received his doctorate in electrical engineering from Stanford University.

EG111/112 Coordinator Named

Leo H. McWilliams

Leo H. McWilliams has been named coordinator for EG111/112, the two-course sequence required of all first-year engineering intents. Assisting course director Jay B. Brockman, associate professor of computer science and engineering in the development and implementation of curriculum content, McWilliams is responsible for course logistics and execution, including the coordination of approximately 400 first-year students and eight faculty members, who teach the 14 sections of the course. He also manages the course's web page, equipment, and materials needs.

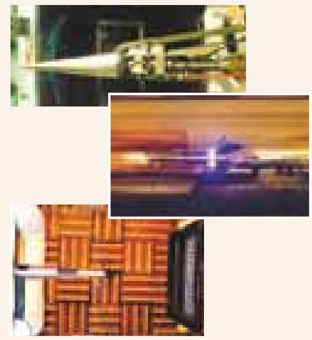
Previously, McWilliams served as a lead engineer at Honeywell International in South Bend, Ind. A "quadruple Domer," he holds bachelor's degrees in both economics and electrical engineering, which he earned in 1981 and 1982, respectively. In 1985 he received a master's degree in electrical engineering and was awarded a doctorate in electrical engineering in 1993.

Engineering Student Magazine Receives Top Honors

Technical Review, the student-run engineering magazine, received top honors again this year from the Engineering College Magazines Association. According to Justin Burt, the magazine's editor-in-chief, the publication received a first-place award for "Best Editorial/All Issues" and second-place honors for "Best Editorial/Single Issue." Technical Review was also honored for its web site, receiving second place overall. For more information on Technical Review or to check out the latest issue, visit *http://www.nd.edu/~techrev.*

Notre Dame Creates Center for Flow Physics and Control

Building on a tradition of achievement in aerodynamics that dates back to 1882, the University of Notre Dame has formed the **Center for Flow Physics and Control.** The mission of the center is to foster the efforts of individual investigators, as well as multidisciplinary research teams, in the fields of flow diagnostics, prediction, and control. Research within the center will address five main areas: aero-optics, aero-acoustics, fluid-structure interactions, multiphase flows, and flow control.



Facilities of the center are located in the Hessert Center for Aerospace Research, a 40,000-sq.-ft. building that houses numerous specialized laboratories and equipment, including high-quality subsonic, transonic, and supersonic wind tunnels; a high-speed heated anechoic jet facility; an anechoic open-jet wind tunnel; and an atmospheric boundary layer wind tunnel.

The center is comprised of faculty from five departments across the University — aerospace and mechanical engineering, civil engineering and geological sciences, computer science and engineering, electrical engineering, and physics. Thomas C. Corke, Clark Equipment Professor of Aerospace and Mechanical Engineering, serves as center director.

For more information on the Center for Flow Physics and Control, visit *http://www.nd.edu/~flowpac*.

Engineering Programs Gear up for Summer

The College of Engineering and the University are offering three separate summer experiences for high school students this summer. Plans are under way for the largest summer sessions ever.

Introduction to Engineering Program

The College's Introduction to Engineering Program (IEP) is a three-week, interactive course designed to give students a taste of college life while also answering some very important questions about engineering: What is engineering? What does an engineer do? What are the different disciplines of engineering? And, what kinds of jobs are available for engineers?

On a daily basis students in the IEP engage in hands-on projects involving technical issues drawn from a variety of engineering disciplines. They also interact with professional engineers working in industry. At the end of the session, students may leave with a keen interest in a specific discipline. More important, over the course of the program, they will have gained an overview of the opportunities and disciplines available in engineering today.

For details about the IEP, visit *http://www.nd.edu/~iep*.

University Summer Experience 2002

Notre Dame also provides a summer session focusing on computer science and engineering. Offering a broad introduction to the field of computing, hands-on projects will introduce students to web development, artificial intelligence, computer design and architecture, information technology, software engineering, and computer theory.

For details about the University Summer Experience, visit *http://www.nd.edu/~precoll*.

AEROSPACE AND MECHANICAL ENGINEERING

New Master's Program in Mechanical Engineering Introduced

The new master's program in mechanical engineering employs a sequence of design and manufacturing courses and electives to allow students to address specific needs and interests. Students work with one another and with engineers from industry to complete a design project, which replaces the traditional research thesis.

The Department of Aerospace and Mechanical Engineering has developed a new **master's program in mechanical engineering.** While it focuses on traditional aspects of the design and development of a product, the new program also provides a unique business perspective that helps prepare students for the requirements and expectations of industry. Understanding the potential of technology is not enough. An engineer must be able to determine how to best integrate new and existing technologies.

There are four main aspects to the new program: a design and manufacturing core, business electives from the college's new business practices curriculum and the University's Mendoza College of Business, general engineering electives, and a team-based design project.

Students can choose from a variety of electives to tailor the program to his or her specific needs. For example, a student may take courses on autonomous electromechanical systems, vision-based control of electromechanical systems, advanced rapid prototyping and rapid production manufacturing processes, biomedical engineering, or microelectrical mechanical systems.

The degree requires 24 credits of coursework and six credits for work on the project. When taken full-time, it is a one-year endeavor. However, this program is also well-suited for part-time students, such as engineers currently working in industry who wish to expand their educational background.

Notre Dame Hosts Supersonic Tunnel Association Meeting

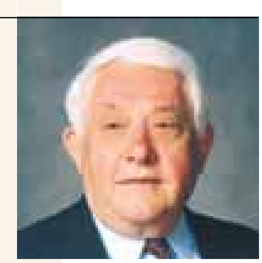
In April 2002 the University of Notre Dame hosted the 97th meeting of the **Supersonic Tunnel Association International** (STAI), the third such meeting held on campus since 1978.

STAI was formed in 1954 to convene engineers and scientists working in the then-new technology of high-speed wind tunnel testing. The purpose of the organization is to share information concerning facility operation, instrumentation, and testing techniques.

According to **Thomas J. Mueller,** Roth-Gibson Professor of Aerospace and Mechanical Engineering and organizing chair of the three STAI meetings held at Notre Dame, STAI members meet twice a year in order to maintain the vibrancy of the technical contributions and their close personal and professional ties. "From the beginning," says Mueller, "STAI members have believed that sound personal relationships are a valuable foundation for technical communication.The free and open exchange of information benefits us all."

CHEMICAL ENGINEERING

Manly Establishes Endowment for Excellence



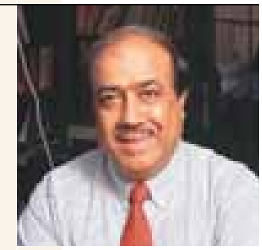
William D. Manly

A consultant for the Department of Energy's Oak Ridge National Laboratory, **William D. Manly,** Ph.D., of Oak Ridge, Tenn., has donated approximately $350,000 to the University of Notre Dame to establish two endowments for materials research within the College of Engineering. The first endowment of $100,000 is for the William D. Manly Award for Excellence in Materials Research. This award recognizes one undergraduate and one graduate student annually for the quality and significance of his or her work in materials science and engineering. Recipients of the first two Manly awards will be announced later this year.

The second and larger portion of Manly's gift, approximately $250,000, creates the William D. Manly Endowment for Excellence in Materials Research, and income from the endowment will be used to help defray recurring costs associated with the materials characterization facility of the new engineering building.

Manly received a bachelor's degree in metallurgy from Notre Dame in 1947, a master's degree in 1949 — also in metallurgy — and was presented with an honorary doctor of engineering degree from the University in 2000.

Kareem Receives Cermak Award



Ahsan Kareem

"For his long-term leadership in wind engineering and industrial aerodynamics applications to structural systems," **Ahsan Kareem,** Robert Moran Professor and Chair of the Department of Civil Engineering and Geological Sciences, has been named the recipient of the 2002 Jack E. Cermak Medal.

Bestowed annually on one individual for outstanding contributions to research or practice in wind engineering, the Cermak Award was established by the Engineering Mechanics Division of the American Society of Civil Engineers (ASCE) and the Structural Engineering Institute to recognize Jack E. Cermak's lifetime of achievements in wind engineering and industrial aerodynamics. It will be presented to Kareem at the ASCE Annual Convention in November.

A leading researcher in probabilistic structural dynamics, fluid-structure interactions, structural safety, and the mitigation of natural hazards, Kareem has been a member of the Notre Dame faculty since 1990.

Students Drive Engineering Outreach Projects

According to its 2001-02 annual report, one of the goals of the student chapter of the **Earthquake Engineering Research Institute at Notre Dame** (EERI@UND) is to "provide the next generation of practicing engineers with a venue to discuss the latest developments in the areas of earthquake engineering and to better prepare them for the challenges which will await them in their careers." Tracy Kijewski-Correa, president of the student chapter, emphasizes that the graduate and undergraduate students of Notre Dame's EERI hope to make a difference in the lives of area youngsters through two specific and very special outreach programs: Shakes & Quakes and Ms. Wizard Day.

The Shakes & Quakes program is designed to help elementary and middle school students grasp the ways in which structures such as buildings and bridges respond to earthquakes. Often used as a supplement to textbook units, the program runs for approximately three weeks.

The first week EERI@UND members visit a classroom they discuss the damage earthquakes cause and the importance of understanding how structures respond. They describe concepts such as energy dissipation and base isolation and highlight new life-saving technologies.

Then, they divide the class into groups of four students. Each of the groups of youngsters is asked to build an "earthquake-proof" building out of Lego® blocks and K'nex® pieces, using a project handout and guidelines developed by EERI@UND. For example, one person plays the owner of the building, one is the architect, one is the engineer, and the fourth is the builder. Each is responsible for specific aspects of the project, including the cost, strength, appearance, and constructability of the structure.

At the end of two weeks, EERI@UND members visit the class again to test the students' buildings with a portable shaking table. In addition to testing their buildings, the student groups prepare presentations about their design, discussing the process and some of the obstacles they encountered as they worked together to meet the goals of the project.

A one-hour adaptation of the Shakes & Quakes project has also been used for the Ms. Wizard Day program, an annual career fair targeting fourth to sixth-grade girls. Held on campus, Ms. Wizard Day helps girls "take the mystery out of math and science." Participants spend the day engaged in a variety of hands-on activities that encourage teamwork while introducing them to engineering, science, and math concepts. The 2002 Ms. Wizard Day was sponsored by the University's colleges of engineering, science, and business, along with Honeywell, Inc. Approximately 75 girls from several area schools attended.

For more information on the student chapter of the Earthquake Engineering Research Institute at Notre Dame, visit *http://www.nd.edu/~eeriund.*

Computer Science and Engineering Names New Chairman

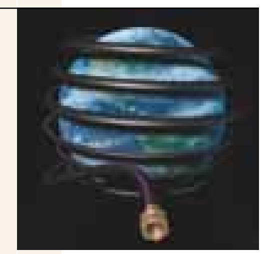
Kevin W. Bowyer

Kevin W. Bowyer joined the Department of Computer Science and Engineering in August 2001 as the Schubmehl-Prein Professor and Chair. Specializing in computer vision, image analysis, pattern recognition, data mining, and applications to medical imaging, Bowyer is also involved in the study of ethics and computing. The second edition of his textbook, "Ethics and Computing — Living Responsibly in a Computerized World," was published in 2001. In addition he has organized a series of National Science Foundation workshops for undergraduate faculty from across the United States on the topic of teaching ethics and computing.

Prior to joining the Notre Dame faculty, Bowyer served as a professor of computer science and engineering at the University of South Florida. He is the author and co-author of nine books and numerous journal articles.

Bowyer received a bachelor's degree in economics from George Mason University in 1976 and a doctorate in computer science from Duke University in 1980.

On-line Piracy and Parasitic Computing Studied



Researchers at the University of Notre Dame have uncovered a new Internet vulnerability, parasitic computing. According to **Vincent W. Freeh,** assistant professor of computer science and engineering; **Jay B. Brockman,** associate professor of computer science and engineering; Albert-Lázló Barabási, Emil T. Hofman Professor of Physics; and Hawoong Jeong, assistant professor of physics, parasitic computing is enabled by the way in which communication occurs across the Internet. Since a standard set of protocols is used by all computers, one can "force" others to solve a piece of a complex computational problem by merely engaging them in standard communications.

In order to prove their theory, the researchers used web servers around the world to solve math problems without their owner's permission. The parasitic computing technique they utilized to harness the power of the other computers resembles distributed computing, which takes advantage of the fact that complex tasks can be split into small parallel processes and run simultaneously on a large number of individual computers.

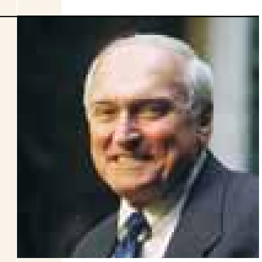
Their "usage," although an academic exercise in this case, raises some interesting questions: "Is it legal to use a computer without the owner's consent, even if calculations are being done in the background?" "How much access does parasitic computing allow?" According to the Notre Dame team, parasitic computing cannot violate the security of unwitting servers. At this point in time, it uses only those areas earmarked for public access. However, with faster, cheaper, and more sophisticated communications technology, variations could be engineered to make on-line piracy of computer time more efficient.

Parasitic computing also highlights some interesting ethical issues regarding the ownership of the resources available on the Internet as well as the "theft" of time — keeping each host computer from its intended purpose.

For more information on parasitic computing at Notre Dame, visit *http://www.nd.edu/~parasite.*

ELECTRICAL ENGINEERING

Merz Receives Humboldt Award



James L. Merz

James L. Merz, Frank M. Freimann Professor of Electrical Engineering, has been selected to receive the Alexander von Humboldt Research Award for senior U.S. scientists. A Notre Dame graduate, Merz is the fourth member of the Department of Electrical Engineering to receive a Humboldt award, joining Frank M. Freimann Professors Ruey-Wen Liu and Anthony N. Michel and Leonard C. Bettex Professor Daniel J. Costello Jr.

An international leader in investigations of II-VI and other III-V compound semiconductor systems, Merz is a fellow of the American Physical Society and the Institute of Electrical and Electronic Engineers. He currently serves on the Electronic Materials Committee of the Minerals, Metals, and Materials Society and is a member of the Association for the Advancement of Science, the Materials Research Society, and the Society for Values in Higher Education. A recipient of an honorary doctorate from Linköping University in Sweden, Merz is the former vice president for graduate studies and research at Notre Dame.

Humboldt honorees collaborate with German colleagues in universities and laboratories throughout the Federal Republic of Germany. In spring 2002 Merz began working with Klaus H. Ploog at the Paul Drude Institute for Solid State Electronics in Berlin. They are investigating wideband gap semiconductor materials based on the compound gallium nitride.

Schlafly Dedicates Circuits Laboratory

When **Hubert J. "Hub" Schlafly** graduated from Notre Dame in 1941 with a degree in electrical engineering, he had high hopes and dreams for the future. Still, he probably never imagined that he would become part of satellite communications history, the recipient of two Emmy Awards, and the holder of 16 patents.

Upon graduation Schlafly joined the General Electric Company where he worked on war-time projects such as anti-aircraft searchlights and radar-directed gunfire control systems. Later he joined Twentieth Century Fox as director of TV research. In 1951 he joined Fred Barton and Irving Kahn to form the TelePrompTer Corporation. Together they created a prompting device for actors and on-air commentators/reporters that forever changed the scope of television. Schlafly and his colleagues pursued their interest in television, developing an early version of a pay TV system and eventually working with Dr. Hal Rosen at Hughes Aircraft to use satellite technology for national distribution of cable signals.

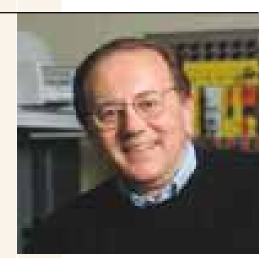
Hubert J. and Leona Schlafly were present on October 11, 2001, as the Schlafly Electronic Circuits Laboratory was dedicated.

In June 1973 at a convention of 3,000 cable operators, Schlafly and TelePrompTer sent a program from Washington, D.C., via satellite to the convention floor in Anaheim, Calif. It was the first domestically transmitted national cable program.

Schlafly, the chairman emeritus of Portel Services Network, has returned to Notre Dame many times since graduation as an alum and member of the College of Engineering Advisory Council. During his most recent visit, he and his wife dedicated the Schlafly Electronic Circuits Laboratory. Recurring income from an endowment provided by the Schlaflys will be used to maintain and periodically upgrade equipment in the laboratory which serves three undergraduate courses — EE224: Introduction to Electrical Networks, EE242: Electronic Circuits I, and EE342: Electronic Circuits II. Both electrical engineering and computer science and engineering students will benefit from the state-of-the-art facilities afforded by the Schlafly gift.

Endowed Professorships in Electrical Engineering Announced

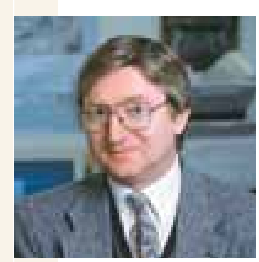
Two faculty members from the Department of Electrical Engineering have been awarded endowed professorships. **Panos J. Antsaklis** has been appointed the H.C. and E.A. Brosey Professor of Electrical Engineering, and **Wolfgang Porod** has been appointed the Frank M. Freimann Professor of Electrical Engineering.



Panos J. Antsaklis

Antsaklis, a faculty member since 1980, serves as director for the Center for Applied Mathematics. His research addresses problems of control and automation and examines ways to design engineering systems that will exhibit a high degree of autonomy in performing useful tasks, as well as networked embedded systems. He also investigates problems in the interdisciplinary research areas of control, computing and communication networks, and hybrid and discrete event dynamical systems. He has more than 240 technical publications to his credit and is author of "Linear Systems," a graduate textbook.

The director of the Center for Nano Science and Technology, Porod is the co-inventor of Quantum-dot Cellular Automata, a transistorless approach to computing that was developed at Notre Dame. His research focuses on the area of nanoelectronics and the physical limits of computation. Specifically, he studies new ways of representing information in nano-scale structures and how to use these devices to implement computational functions in novel circuits. He also addresses the implications of these basic issues for the engineering design of physical systems which perform computational tasks. Porod joined the Notre Dame faculty in 1986. He has authored 270 publications and presentations.



Wolfgang Porod

Both Antsaklis and Porod are fellows of the Institute of Electrical and Electronic Engineers.

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