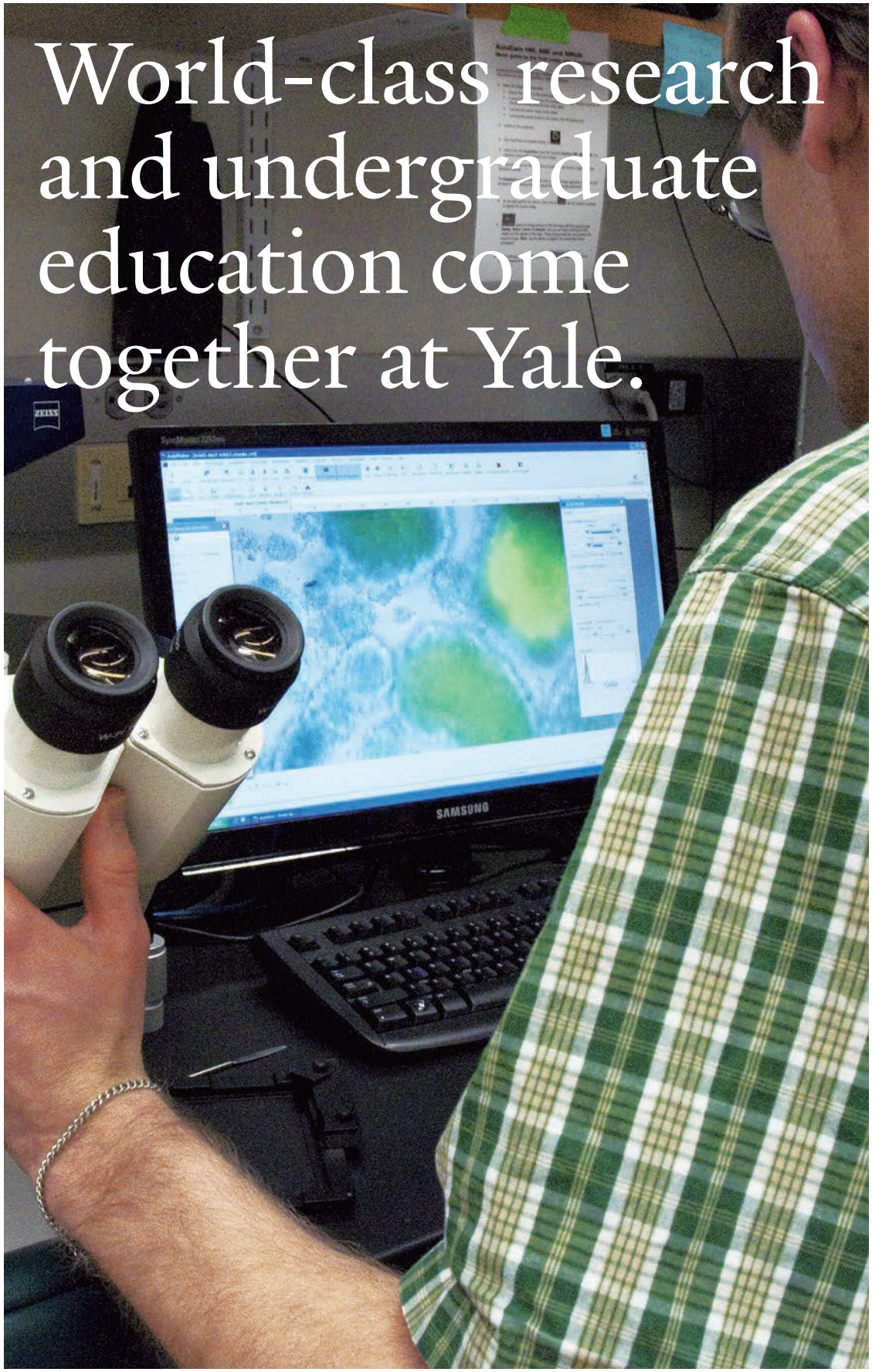
Science and Engineering at Yale.*

* A Guide to Undergraduate Research, Teaching, and Resources

World-class research and undergraduate education come together at Yale.



Science and Engineering Leadership in an Age of Opportunity

Yale scientists and engineers are changing the world with breakthrough research in astrophysics, medicine, nanotechnology, and many other fields. Undergraduates at Yale have extraordinary access to this groundbreaking work through research opportunities and mentorships with senior faculty in tandem with the focus on undergraduate education that has long been the hallmark of the Yale College experience.

We seek students who are ambitious, who desire to serve society through scientific achievement, and who will make the most of the incredible opportunities here. As an aspiring engineer, mathematician, or scientist, you owe it to yourself to consider applying to Yale.

Peter Salovey, *President of Yale University*

Capital "R" Research.

(Pioneering discoveries by students)

Research with a capital "R" is about discovering something that nobody else has ever known. Yale undergraduates have that opportunity, since so many are doing their own research as early as the summer after their freshman year. The process of doing real science here is a bit like an apprenticeship, where students learn by doing, from professors, other students, and other scientists. While working with and learning from scientists at the forefront of some of today's most exciting research, they become part of the world's scientific community.

Atomic Sweat

"Science is fundamentally about research. Regardless of how many classes you take or how much math you learn, you haven't really done science unless you've poured sweat into your own lab project, computer program, or solar-powered robot. I had the tremendous opportunity to start working in a laboratory the summer after my freshman year, and in that time, I found that I love doing science. Research wasn't about grinding out problem sets, but getting to tackle puzzles that nobody had ever seen or thought about before. It was about getting to ask the questions that I thought were interesting and important. On top of that, in classes from then on, I started thinking about questions like 'How would one measure that in the lab?' Or 'What kinds of experiments make use of this principle?'

"My research explores the structure of atomic nuclei. I am hoping to explain how removing neutrons from a heavy nucleus changes its structure from largely spherical and stable, to deformed and unstable. In my experiments, I measure the gamma rays emitted from nuclei created in Yale's particle accelerator, and then use these measurements to recover the excited states of these nuclei.

"In my sophomore fall, I went with the rest of my lab to a conference and presented my research from the previous summer. Here I was, a sophomore, being asked questions by leaders in the field from all over the country. It was an amazing experience, and I made sure I went back to that conference every year after that. If I hadn't done research, I never would have glimpsed the larger scientific community, and where I fit in."
Axel

Axel Schmidt

Hometown Pittsburgh, PA

Major Physics Intensive. (The Physics major has two tracks: B.S. and B.S. Intensive. The latter is designed for students who want to continue on to graduate school, while the former offers more flexibility for students who want to complete the pre-med curriculum, double-major, or combine physics with another field like philosophy or astronomy.)

Extracurriculars Purple Crayon improv comedy, intramural sports, Peer Health Education

Why Yale "I chose Yale over a more technical university because I wanted a peer group that had a broader range of academic interests. I also wanted to be taught English, history, and music by professors who were leaders in those fields as well. If I were to make that choice again knowing what I know now, I would choose Yale for those reasons but also because at Yale, science majors are a little less common. We get special treatment for it. I was given a huge amount of support—academic and financial—to pursue research from the moment I got here. That has been the most valuable thing that Yale has offered."

Post-Yale Plan "I'm headed to graduate school next year, to get a Ph.D. in physics. I haven't made up my mind about where I'm headed, but I did get into MIT, Duke, Columbia, and Yale, so I have terrific options."

Engineering Solutions

"I came to Yale with a background in robotics but wanted to explore other areas of science and engineering, too. My freshman- and sophomore-year summers took me to CERN in Switzerland, site of the world's largest and highest-energy particle accelerator. While conducting data-processing research there, I realized that my true interest lay in the *engineering* of the particle detector. Back at Yale, I began work in the Center for Systems Science, researching pattern recognition.

"These experiences taught me that I still wanted to build physical systems, and my senior project led me back to robotics when my team decided to construct a device that could retrieve objects dropped off a boat or dock into the water. We produced a cost-effective, practical solution: a tele-operated robotic arm. We mounted a miniaturized version of the arm on a control box outfitted with a video feed of the underwater scene to allow the user to steer the submerged arm while watching its movements in real time. None of us had designed anything for underwater use, which made for a challenge as we researched waterproof materials and considered factors such as the buoyancy of the arm.

"For me, engineering demands an energizing combination of the creative and the concrete. We took theory that we'd learned through course work, made it our own by applying it to design development, and saw it all come to fruition as a working device—one that could improve someone's quality of life. This is a great feeling."
Brigid

Bio-Prospecting

"Yale without my rain forest research would have been a very different place. Almost no one goes bio-prospecting for endophytes in the Amazon rain forest. So my mentor, Professor Scott Strobel, a world leader in understanding catalytic reactions triggered by RNA, knew the students in his Amazon Rain Forest Expedition and Laboratory were likely to find things no one else had seen.

"What we discovered blew us away. We returned with ten species of fungal endophytes that we have been able to classify as an entirely new genus. Even more exciting for me was that, once we got back to the lab, I discovered that an extract from one of these fungal endophtyes reduces inflammation in human tissue. A subsequent analysis of the molecule revealed it to be an inhibitor of apoptosis, or programmed cell death. It may also lead to drugs that could prevent preterm birth—something we're continuing to investigate both in the lab and with further prospecting in Ecuador.

"I've had multitudes of opportunities to present this research in all sorts of settings, including informal lab meetings, undergraduate symposia, professional conferences, general public and classroom talks, and even a talk for the president of the University and his council on international affairs. In addition, I have been working on publishing my results in scientific journals. In all of these endeavors, I have had support and encouragement from my faculty advisers.

"My research experience has absolutely been an invaluable and integral part of my undergraduate education here. It's also had a direct impact in defining my future goals."
Sunjin

Sunjin Lee

Hometown Vancouver, WA

Major Molecular Biophysics and Biochemistry

Extracurriculars "Aside from scientific research, I love to pursue my interests in classical music. I play oboe with a couple of different chamber groups and orchestras, and also enjoy playing in pit orchestras for operas."

Why Yale "Beautiful campus, amazing people, and countless opportunities for anything and everything you could possibly be interested in. Yale also had one of the best financial aid packages among all of the schools I had to choose from."

Post-Yale Plan "I will be pursuing a career in translational research, which bridges gaps between basic science and clinical medicine."

Opposite page:

Brigid Blakeslee

Hometown Oradell, NJ

Major Electrical Engineering

Extracurriculars Student researcher, head science and engineering tour guide, president of Yale's Institute of Electrical and Electronics Engineers, cofounder of Yale's Society of Women Engineers, bagpiper, Scottish Highland dancer

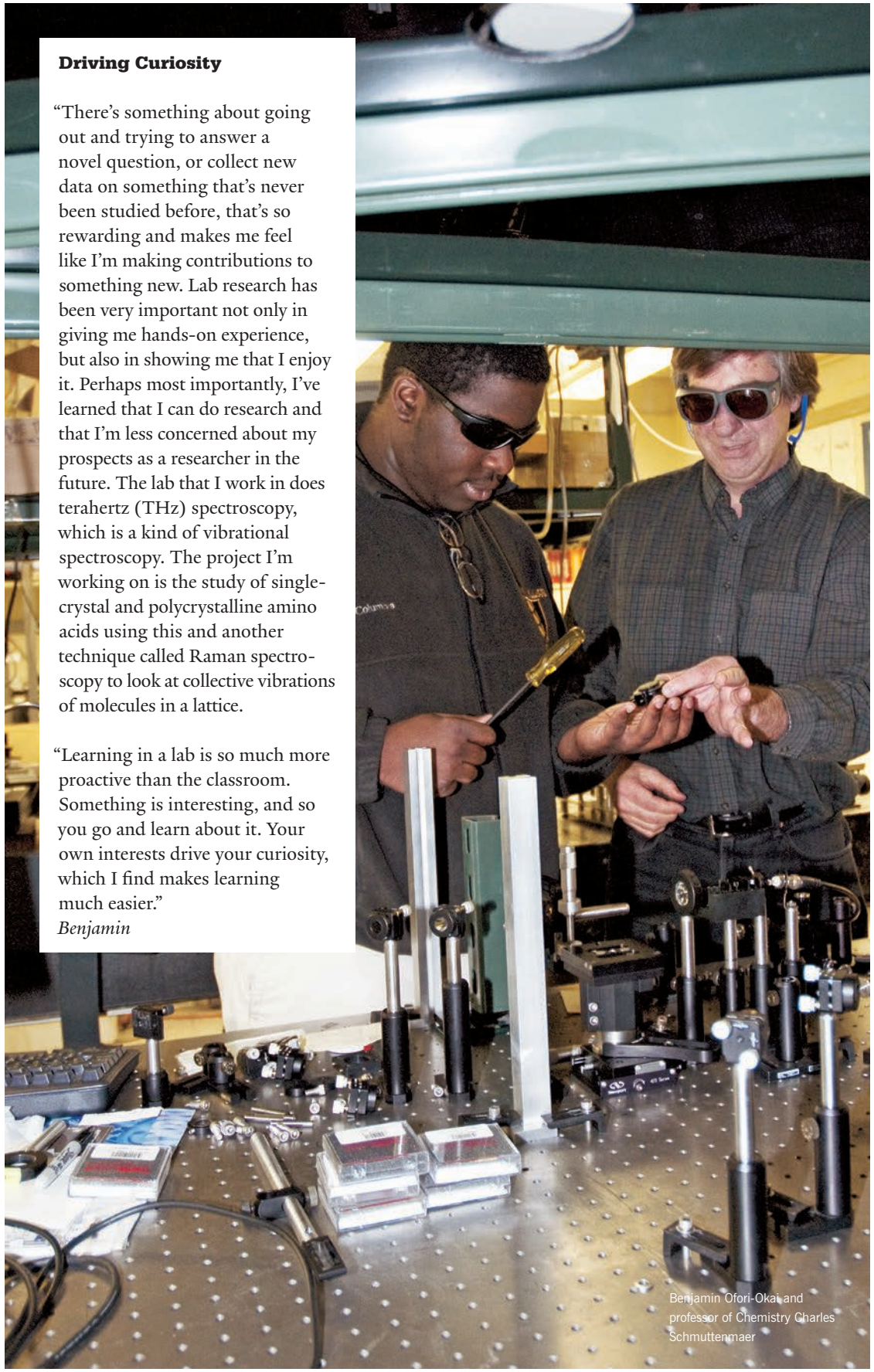
Why Yale "I chose Yale over a technical school because its relatively small engineering program provides remarkable resources to undergraduates. From freshman year on, I gained access to high-level research opportunities and worked closely with supportive faculty. The seminar-style courses are also a bonus because professors can tailor material to students' individual interests. Plus, I love Yale's student community and the way people interact with one another here."

Post-Yale Plan I will pursue a Ph.D. in robotics, with the hope of one day combining engineering research with the opportunity to teach.

Driving Curiosity

"There's something about going out and trying to answer a novel question, or collect new data on something that's never been studied before, that's so rewarding and makes me feel like I'm making contributions to something new. Lab research has been very important not only in giving me hands-on experience, but also in showing me that I enjoy it. Perhaps most importantly, I've learned that I can do research and that I'm less concerned about my prospects as a researcher in the future. The lab that I work in does terahertz (THz) spectroscopy, which is a kind of vibrational spectroscopy. The project I'm working on is the study of single-crystal and polycrystalline amino acids using this and another technique called Raman spectroscopy to look at collective vibrations of molecules in a lattice.

"Learning in a lab is so much more proactive than the classroom. Something is interesting, and so you go and learn about it. Your own interests drive your curiosity, which I find makes learning much easier."
Benjamin



Benjamin Ofori-Okai and professor of Chemistry Charles Schmuttenmaer

Lee Christoffersen

Hometown Littleton, CO

Major Environmental Engineering Intensive and Geology and Natural Resources

Extracurriculars Research assistant, science and engineering tour guide, sustainability coordinator, Engineers Without Borders, founding member of Yale's Society of Women Engineers

Why Yale "I thought I wanted to study astrophysics. When I visited Yale, the college set up a personal meeting with Professor Meg Urry. This renowned scientist took me out to lunch! I've had the opportunity to take classes in the humanities and social sciences—classes taught by really incredible professors. Scientific fields are inextricably tied to politics, the economy, and social values. It's vital to understand these other factors."

Post-Yale Plan "I am interested in the environmental aspect of the mining industry. I've had three summer internships focused on the topic. I've worked on the design of a tailing storage facility, environmental and social impact assessments, closure plans, and acid rock drainage treatment."

Getting Your Hands Dirty

"When I was a sophomore, I was looking for a campus job. I went to the chair of the Chemical Engineering department and asked what was available. He told me that the policy of the department was to give a research position to every student who wanted to participate. That's a pretty incredible thought—that Yale has the resources and the faculty support to encourage every undergrad to do research.

"I worked with Robert McGinnis on forward osmosis desalination for two years. Rob, who earned a doctorate in Environmental Engineering, is revolutionizing the industry. While at Yale he started a company that uses the new technology he's developed. I feel lucky to have been a part of that. Beyond the intellectual benefits of participating in a working laboratory, I learned about the importance of humility in research. Rob and I were doing important work that I truly believe will be a viable technology within the decade. It has the potential to change the way we think about potable water. However, our experiments could be thwarted by a simple leak. I spent so many hours clambering over our prototype, tightening bolts.

"That's what research is all about—having the intellectual prowess to problem-solve in an efficient and innovative way, but also having common sense and a willingness to get your hands dirty. Persistence is important."
Lee

Opposite page:

Benjamin K. Ofori-Okai

Hometown Albany, NY

Major Chemistry

Extracurriculars Yale Anti-Gravity Society, Pierson College Master's Aide, Pierson College Buttery, Association of Undergraduate Chemistry Students, Society of Physics Students

Why Yale "I chose Yale because I can dedicate the rest of my life to science, but not necessarily to all the other things I am interested in. Some of my greatest learning has come from the conversations with my friends who major in history, philosophy, and classics."

Post-Yale Plan "I am going to graduate school to earn my Ph.D. with the goal of becoming a professor."

Breaking News.

(A few of the year's top undergraduate science and engineering stories)

Solar Decathlon

A team of eight Yale College students, led by sophomore Architecture majors Katherine McMilland and Juan Pablo Ponce de Leon, was selected by the U.S. Department of Energy to be one of twenty collegiate teams competing in the next Solar Decathlon—the first Yale team to participate in the prestigious contest. The team, which includes students majoring in Electrical, Environmental, and Mechanical Engineering and in Geology and Geophysics, will spend almost two years building an affordable and energy-efficient solar-powered house for the Decathlon, which takes place in California in October 2015.

Undergraduate Entrepreneurs

Yale undergraduates head three of the eight business ventures that earned summer fellowships from the Yale Entrepreneurial Institute in 2014. The program is geared toward scalable ideas with high-growth potential. This year's projects include development of an organic, non-GMO sports drink; a mobile mesh network that offloads cellular data demand from overloaded cell towers; and a medical device to improve treatment of scoliosis by tracking how long and how tightly the braces are worn over time.

Social Innovation

The inaugural Thorne Prize for Social Innovation in Health, sponsored by the School of Public Health, was won by a team of four Yale students—including undergraduates Ruchit Nagar, Ifedolapo Omiwole, and Leen van Besien—for Khushi Baby, a bracelet for infants that is embedded with a silicone chip that records their vaccination history. The students, who developed the bracelet in the course Appropriate Technology and the Developing World, will use the $25,000 prize to begin work on implementing their health innovation in India. Other projects in the course, which focused this year on vaccine delivery issues, included a real-time temperature monitoring system that fits into portable vaccine storage containers; a modular packaging design that keeps vaccines at the ideal temperature longer; and a pre-dosed, single-use vaccine administrator.

24 Hours

Yale College teams won both the first and second prizes at Y-Hack, a national twenty-four-hour hackathon held at Yale. Seniors Geoffrey Litt and Seth Thompson earned top honors for "Rainman," a Chrome extension that identifies key phrases in an online article and creates sidenotes with contextual information and images. Senior Sean Haufler and sophomore Matthew Rajcok won second prize for "Lux," an app that varies the brightness and hue of the lights in your home according to the time of day. Y-Hack, which was founded by three Yale College classmates in 2012, drew more than 1,000 coders from about seventy-five schools across the country and Canada.

Post-Yale Fellowships

Four Yale seniors majoring in STEM disciplines have been awarded some of the country's most prestigious fellowships for postgraduate study next year. Isabel Beshar, a double major in Molecular, Cellular, and Developmental Biology and History of Science and Medicine, will study medical anthropology at Oxford and plans to go on to medical school and a career in global health. Benjamin Horowitz, Katherine Lawrence, and Colin Pawlowski—and twenty-one recent Yale College alumni/ae—earned National Science Foundation Graduate Research Fellowships. Horowitz, a Mathematics and Physics major, is off to study astrophysics and particle physics at UC Berkeley. Lawrence, a Physics Intensive major, also earned a Hertz Fellowship; she will be studying experimental atomic molecular and optical physics at MIT. Mathematics Intensive major Pawlowski will also be at MIT, pursuing a doctorate in Operations Research.

Class Kudos

Seniors Andrew Crouch, Brian Loeb, Raja Narayan, Natalie Pancer, and Kristi Oki—all students in the new Yale College course Medical Device Design and Innovation—designed an intestinal transport system that could significantly improve the success rate of intestinal transplants. The group, which plans to work with Connecticut-based organ banks to conduct a trial with human tissue, presented its project at the annual meeting of the Society for Surgery of the Alimentary Tract in May. Other projects in the course included a portable device to record epileptic seizures, a surgical tool for ENT procedures, and a drug-delivery system for pediatric hemophilia patients.

Rookie of the Year

Competing against more than forty international teams at the 2014 Intelligent Ground Vehicle Competition (IGVC) in Rochester, Michigan, in June, the Yale Undergraduate Intelligent Vehicles team earned both the Rookie-of-the-Year Award and fourth place in the Design competition. Each team's autonomous robotic vehicle had to navigate a flagged course, driving to a series of GPS waypoints without running into any traffic barrels or crossing any painted lines.

Artistry Meets Technology

For his senior project, Computing and the Arts major Sho Matsuzaki wrote computer programs to produce a 23,000-node LED display on the walls and ceiling of the Ground café in Becton Engineering Center that combined music, dance, and technology. As members of the Yale dance team Rhythmic Blue performed in the middle of the café, an audience member used simple hand gestures to control the texture and speed of the music, and the color and intensity of the lights. Matsuzaki described the result as "a call and response between the manipulator and the dancer" that celebrates the beauty of human gesture and movement.

Lab Wear

Olivia Pavco-Giaccia, a sophomore Cognitive Science major, is helping to promote the sciences among young girls by producing and selling fashionable lab wear that disproves stereotypes about how scientists look. Her start-up, LabCandy, has earned backing from the Yale Entrepreneurial Institute and was featured in March in an article on NationSwell, a new digital media company focused on stories about innovation and renewal in America.

Tech Bootcamp

Twenty-six Yale undergraduates, majoring in fields from Chemistry to Environmental Studies, were among the thirty applicants chosen to participate in Yale's second summer Tech Bootcamp. A partnership between the Yale Entrepreneurial Institute and the Yale Student Tech Collaborative, the ten-week, immersive, full-stack programming bootcamp provides students with coding experience that could be used to build their own start-ups or join an early-stage tech company. Project ideas that won over the selection committee include an app to translate medical questions into different languages, a taxi-sharing app, and a rhyming app for children.

Freshman Summer Research Fellowships

Research and design projects are a critical part of undergraduate science and engineering education, and opportunities need to be available when students are making decisions about majors and potential careers. To that end, Yale has established a Freshman Summer Research Fellowship program that in its inaugural year, 2013, provided nearly $500,000 in support for more than 100 science and engineering freshmen, with funds for full-time research; summer programming; and enhanced guidance and support for finding mentors, developing proposals, and making a successful entry into research.

Undergraduate Research Fellowships

In addition to the summer fellowship program, more than fifteen individual fellowship programs are available for the support of undergraduate science and engineering research. Many student research projects are also supported by individual faculty research grants. Fellowships are available for study in specific areas such as environmental issues, cancer-related research, biomedical engineering, and international research in applied science.

Student Groups (sampling)

American Indian Science and Engineering Society

American Institute of Chemical Engineers

American Society of Mechanical Engineers

Bioethics Society

Biomedical Engineering Society

Bulldogs Racing

Club Geo

Design for America

Engineers Without Borders

Institute of Electrical and Electronics Engineers (Y-IEEE)

Math Society

Mathcounts Outreach

Medical Professions Outreach

Minorities in Medicine

Minority Association of Pre-Medical Students

National Society of Black Engineers

Peer Health Educators

Public Health Coalition

Science and Engineering Association (YSEA)

SMArT (Science and Math Achiever Teams)

Society of Physics Students

Society of Women Engineers

Student Emergency Medical Services

Student Environmental Coalition

Student Task Force for Environmental Partnership (STEP)

Students for Environmental Engineering and Sustainability

Tau Beta Pi

Undergraduate Chemistry Students

Undergraduate Energy Club

Undergraduate Society for the Biological Sciences

Undergraduate Women in Science

Women in Physics

Yale Drop Team

Yale Entrepreneurial Society

Yale iGEM Team

Yale Scientific Magazine

Top 10

Among university faculties in National Academy of Sciences membership, in fields ranging from evolutionary biology to biochemistry to physics.

95%

Undergraduate science and engineering majors who do research with faculty members.

40%+

Percentage of Yale College students graduating with a STEM major who are women.

$1 Billion

In new monies for science, engineering, and medical research facilities since 2001.

93%

Undergraduate courses taught by professors or lecturers (the remaining 7% are chiefly in foreign languages and freshman English).

80+

Yale College graduates awarded National Science Foundation Graduate Research Fellowships in the past three years, recognizing their potential for significant achievement in science and engineering research.

$1 Million

Funding for undergraduate science research fellowships in the most recent year.

100+

More than 100 science program alumni who graduated in the mid-80s and early 90s are now science faculty members at top universities.

1:1

Yale's School of Engineering & Applied Science has approximately 60 professors and graduates approximately 60 engineering majors a year.

800+

Science, math, and engineering labs at Yale College and the graduate and professional schools.

88%

Admission rate for Yale College graduates to medical schools (national average 43%).

200+

Summer fellowships for undergraduate science and engineering students per year.

2,000+

Courses offered each year in 80 academic programs and departments.

Major Departments and Programs

Science and engineering majors are highlighted

African American Studies
African Studies
American Studies
Anthropology
Applied Mathematics
Applied Physics
Archaeological Studies
Architecture
Art
Astronomy
Astrophysics
Biomedical Engineering
Chemical Engineering
Chemistry
Classical Civilization
Classics (Greek, Latin, or Greek & Latin)
Cognitive Science
Computer Science
Computer Science & Mathematics
Computer Science & Psychology
Computing & the Arts
East Asian Languages & Literatures (Chinese or Japanese)
East Asian Studies
Ecology & Evolutionary Biology
Economics
Economics & Mathematics
Electrical Engineering
Electrical Engineering & Computer Science
Engineering Sciences
English
Environmental Engineering
Environmental Studies
Ethics, Politics, & Economics
Ethnicity, Race, & Migration
Film Studies
French
Geology & Geophysics
Geology & Natural Resources
German
German Studies
Global Affairs
Greek, Ancient & Modern
History
History of Art
History of Science, Medicine, & Public Health
Humanities
Italian
Judaic Studies
Latin American Studies
Linguistics
Literature
Mathematics
Mathematics & Philosophy
Mathematics & Physics
Mechanical Engineering
Modern Middle East Studies
Molecular Biophysics & Biochemistry (MB+B)
Molecular, Cellular, & Developmental Biology (MCDB)
Music
Near Eastern Languages & Civilizations
Philosophy
Physics
Physics & Geosciences
Physics & Philosophy
Political Science
Portuguese
Psychology
Religious Studies
Russian
Russian & East European Studies
Sociology
South Asian Studies*
Spanish
Special Divisional Major
Statistics
Theater Studies
Women's, Gender, & Sexuality Studies

Special Programs

Perspectives on Science and Engineering is a yearlong interdepartmental course that introduces selected first-year students with exceptional math and science backgrounds to faculty and their research disciplines.

STARS (Science, Technology, and Research Scholars) Since 1995, Yale's nationally recognized STARS Program has promoted diversity in the sciences through mentoring, academic year study groups, and an original research-based summer program for freshmen and sophomores. Juniors and seniors have the opportunity to continue their research through the STARS II Program.

Graduate and Professional Schools

Graduate School of Arts & Sciences
School of Engineering & Applied Science
School of Forestry & Environmental Studies
School of Medicine
School of Nursing
School of Public Health
Plus
School of Architecture
School of Art
Divinity School
School of Drama
Law School
School of Management
School of Music
Institute of Sacred Music

**May be taken only as second major*

Innovation Incubator.

(Yale scientists changing the world)

Translating basic research into new technologies that advance health and welfare has been part of Yale's "DNA" for centuries, and the pace of innovation here continues to accelerate dramatically. Today's Yale inventors are leading the way in science, medicine, and engineering through breakthrough research in nanomaterials, genetics, computational biology, biomedical engineering, and sustainable energy production. While "interdisciplinary" is a buzzword these days, the concept of bridging traditionally disparate fields, including biology and the life sciences, physics, chemistry, geology, mathematics, and engineering, is at the heart of this university's scientific endeavors. Here are just a few of our faculty and projects at the frontiers of discovery and making a real-world difference.

Associate professor Tarek Fahmy (right) and graduate student Erin Steenblock

Portable Disease Detectors

Yale scientists have created nanowire sensors coupled with simple microprocessor electronics that are both sensitive and specific enough to be used for point-of-care disease detection. Using such detectors, says Tarek Fahmy, Yale associate professor of Biomedical Engineering, doctors could immediately determine which strain of flu a patient has, whether or not there is an HIV infection, or what strain of tuberculosis or *E. coli* bacteria is present. Currently, there are no electronic point-of-care diagnostic devices available for disease detection.

Fahmy and his colleagues see a huge potential for the system in point-of-care diagnostic centers in the United States and in developing countries where health care facilities and clinics are lacking. He says it could be as simple as an iPod-like device with changeable cards to detect or diagnose disease. Importantly, the system produces no false positives—a necessity for point-of-care testing. "Instruments this sensitive could also play a role in detection of residual disease after antiviral treatments or chemotherapy," said Fahmy. "They will help with one of the greatest challenges we face in treatment of disease—knowing if we got rid of all of it."

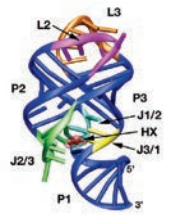
Creating a Quantum Computer—One Artificial Atom at a Time

Robert Schoelkopf and Michel Devoret are creating basic building blocks for a future quantum computer. These computers of tomorrow, researchers say, will store, process, and transfer huge amounts of information unimaginably quickly and in spaces that are almost inconceivably small—visible only with an electron microscope. The two Applied Physics professors are among an elite group of experimentalists, working at the level of single microwave photons, tiny packets of light energy. The Schoelkopf lab has recently created the world's largest "Schrödinger Cat" consisting of a simultaneous quantum superposition of zero and 111 photons.

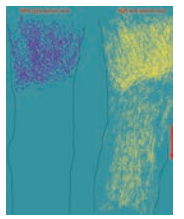
Schoelkopf is a former NASA engineer and Devoret was a director of research at the French Atomic Energy Commission before moving to Yale. At Yale, they are combining novel new designs for superconducting "artificial atoms" with tiny superconducting cavities to create electrical circuits that realize "microwave quantum optics on a chip," said Steven Girvin, a Yale theoretical physicist who collaborates on their project. The two scientists have managed to squeeze the tiny photons into ultra-small cavities on a chip, akin to a regular computer microchip. They've also squeezed "artificial atoms" that can act as quantum bits—units to process and store quantum information—into the ultra-small cavities. The tiny packets of energy from the microwaves interact with these small atoms a million times more strongly than if the atoms had been in a standard bigger cavity.

The cavity acts as a "quantum bus" allowing quantum information to be sent from one atom to another, forming the basis of a new architecture, the beginnings of what someday the researchers expect will be a huge integrated circuit of quantum bits. One practical application for quantum computers is cryptanalysis. "If quantum computers can be built," Girvin said, "they can very efficiently break certain types of codes."

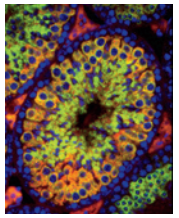
Professors Michel Devoret (left) and Robert Schoelkopf



New Class of Antibiotics
After imagining and "inventing" riboswitches, RNA sequences that can bind and act as sensors of various molecules, Ronald Breaker, Henry Ford II Professor of Molecular, Cellular, and Developmental Biology and professor of Molecular Biophysics and Biochemistry, discovered natural riboswitches in the genomes of microorganisms. Riboswitches act as major control elements for gene expression. Yale start-up BioRelix was established to target these genetic elements by designing new classes of antibiotics.



Spinal Cord Injury Treatment
Stephen Strittmatter, Vincent Coates Professor of Neurology, helped discover the existence of a molecule, called Nogo, that shows remarkable promise in animal models for treating spinal cord injury, for which there is no current effective treatment.



RNA Snippets and Stem Cells
Professor Haifan Lin, director of Yale's Stem Cell Center, is among the world's leading investigators of how tiny snippets of RNA can have profound effects on physiological activity in organisms. His lab has studied how stem cells renew themselves in the reproductive system and other tissues, and his work on various so-called small RNAs has many medical applications.

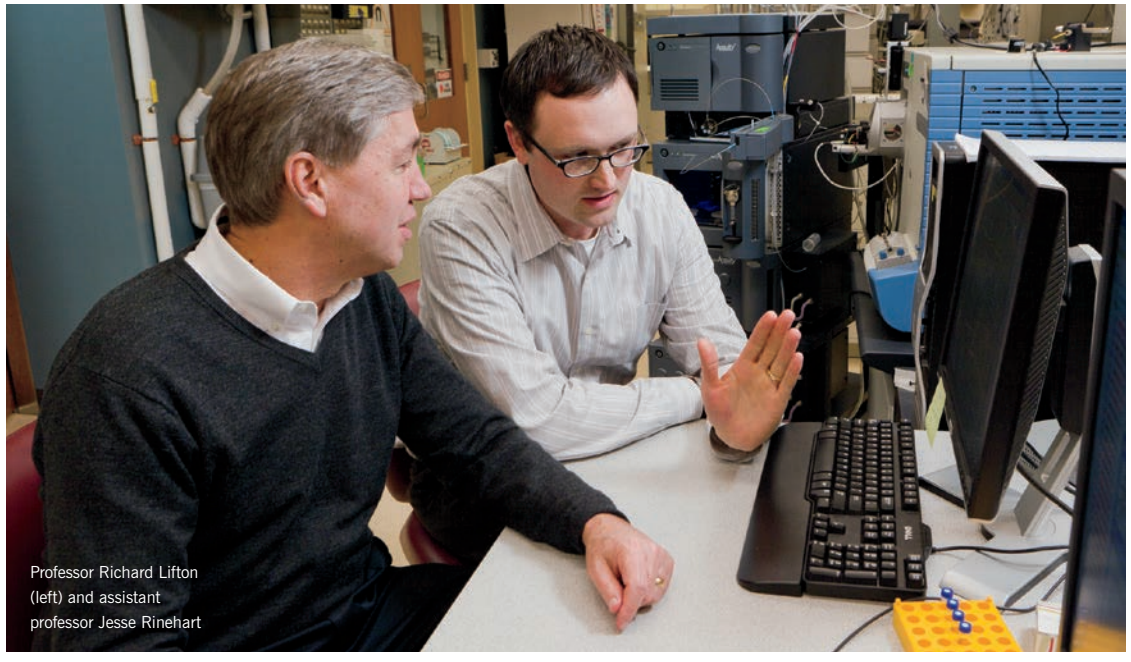
Saving Lives through Genetics

An amazing revolution is under way as it becomes possible to rapidly and cheaply sequence large portions of the human genome. The most common fatal diseases have underlying inherited components. Rapid advances in molecular genetics now make it possible to quickly and easily identify the genetic variants underlying these diseases, promising to transform the diagnostic and therapeutic approaches to these disorders.

Dr. Richard Lifton, Sterling Professor of Genetics, chair of the Department of Genetics at the Yale School of Medicine, and professor of Medicine, is one of the world's leading experts and advocates of genome-wide analysis of human populations to find genetic links to diseases. He and Yale neurobiologist Dr. Murat Gunel recently discovered a genetic link to brain aneurysms, and their findings could lead to new tests to spot those at greatest risk. In addition, a postdoctoral fellow in Lifton's lab, investigating the genetic causes of blood pressure variation, recently identified a previously undescribed syndrome associated with seizures, a lack of coordination, developmental delay, and hearing loss. The work illustrates the power of genetic studies not only to find causes of chronic ailments, but also to identify a common cause in a seemingly unrelated set of symptoms in different parts of the body.

"Our ability to unequivocally and rapidly define new syndromes and their underlying disease genes has progressed dramatically in recent years," says Lifton. "A study like [the one identifying the new syndrome] would have taken years in the past, but was accomplished in a few weeks by a single fellow in the lab." He says he hopes the research will not only help doctors identify people with the new syndrome but also lead to greater recognition that patients with apparently complicated syndromes may often have simple underlying defects that can be understood.

Ultimately, the ability to identify genes associated with human disease paves the way for "personalized medicine" in which treatments can be tailored to an individual's specific genetic makeup.

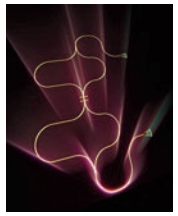


Professor Richard Lifton (left) and assistant professor Jesse Rinehart

"Free-Style" Geophysics and a Habitable Planet

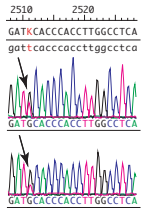
"The links among plate tectonics, the geomagnetic field, the existence of oceans, and the composition of the air have profound implications for the habitability of a planet and the evolution of life," says Jun Korenaga, professor of Geology and Geophysics. In 2008 his project "How to Build a Habitable Planet: Estimating the Physics of Plate-Tectonic Convection on Earth" received Microsoft's breakthrough research award given to encourage academic research that helps solve some of today's most challenging societal problems.

"Understanding the physics of plate-tectonic convection in Earth's mantle is one of the outstanding and most puzzling challenges in geosciences and planetary sciences," says Korenaga. The self-described "free-style" geophysicist's research spans mantle and core dynamics, theoretical geochemistry, and marine geophysics. He uses computer simulation to study the balance between the physical forces that cause movement in the surface plates of Earth. Korenaga's work exemplifies how this long-standing mystery can be approached by addressing the fundamental physics question and formulating it as a quantitative mathematical problem.



Light-driven Semiconductor Chips
While the force of light is too weak to be used to power devices in everyday use, Hong Tang, associate professor of Electrical Engineering, and his engineering team have found that it can be harnessed to drive machines—when scaled to nano-proportions. This research is opening the door to a future new class of semiconductor devices operated by the force of light. In 2009 Professor Tang won a Packard Fellowship in Science and Engineering, one of the highest honors for young faculty members.

Wireless Electrodes to Locate the Seizure Focus
Hitten Zaveri, associate research scientist in Neurology, and Dr. Dennis Spencer, chair and Harvey and Kate Cushing Professor of Neurosurgery, have created a small, battery-free, low-power, brain-implantable, 64-channel wireless device to measure cortical activity and accurately define the seizure onset area in patients with epilepsy. Spencer pioneered new surgical treatments for the disorder that have been adopted by medical centers worldwide.



Biomarkers for Disease Risk
Cancer researchers Frank Slack and Joanne Weidhaas discovered a potential diagnostic test to pinpoint genetic biomarkers to help identify those individuals who are most predisposed to lung cancer, ovarian cancer, and other types of the disease. Weidhaas is associate professor of Therapeutic Radiology at the School of Medicine; and Slack was professor of Molecular, Cellular, and Developmental Biology until his appointment in July 2014 to the directorship of the new Institute for RNA Medicine at Beth Israel Deaconess Medical Center in Boston.

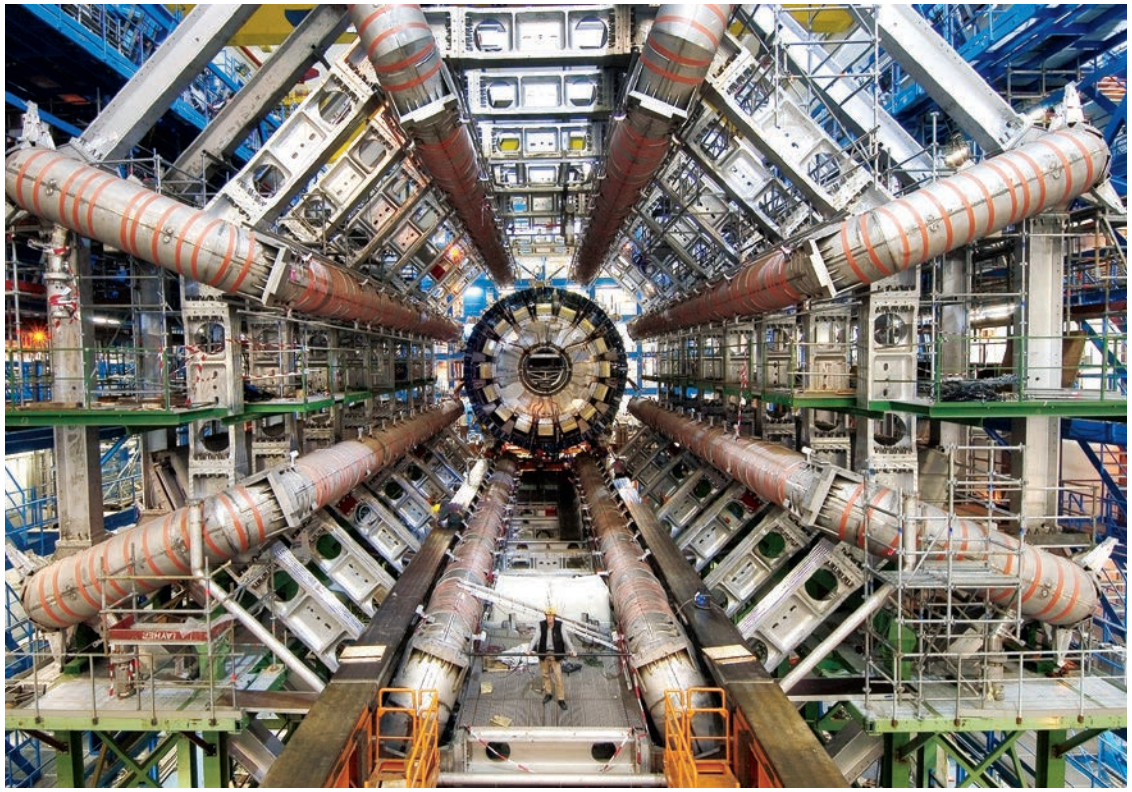
Green Chemistry in Policy and Practice

Yale is easily one of the foremost centers in the world for green chemistry and green engineering. Indeed, "the father of green chemistry" is Yale chemist Paul Anastas. In 1991, when Anastas served as chief of the Environmental Protection Agency's chemistry branch, he coined the term "green chemistry" to describe the design of safer chemicals and chemical processes to replace the use of hazardous substances. Today he leads Yale's Center for Green Chemistry & Green Engineering.

One of Yale's next generation of innovators in green chemistry and engineering is Julie Zimmerman, jointly appointed to the Department of Chemical and Environmental Engineering, where she is Donna L. Dubinsky Associate Professor of Environmental Engineering, and the School of Forestry & Environmental Studies, where she is Professor of Green Engineering. Through her engineering research, Zimmerman is working toward the next generation of products, processes, and systems based on efficient and effective use of benign materials and energy to advance sustainability. To enhance the likelihood of successful implementation of these next-generation designs, she also studies the effectiveness of and barriers to current and potential policies developed to advance sustainability. Together these efforts represent a systematic and holistic approach to addressing the challenges of sustainability to enhance water and resource quality and quantity, to improve environmental protection, and to provide for a higher quality of life.

Zimmerman and her colleagues proved that certain countries and some U.S. states stand to benefit from the use of compact fluorescent lighting in the fight against global warming, while the use of such lighting in some areas could actually be more harmful to the environment. Zimmerman is also part of an interdisciplinary team developing design guidelines for safer chemicals to minimize or eliminate toxicity concerns from new molecules being developed and introduced to the market.

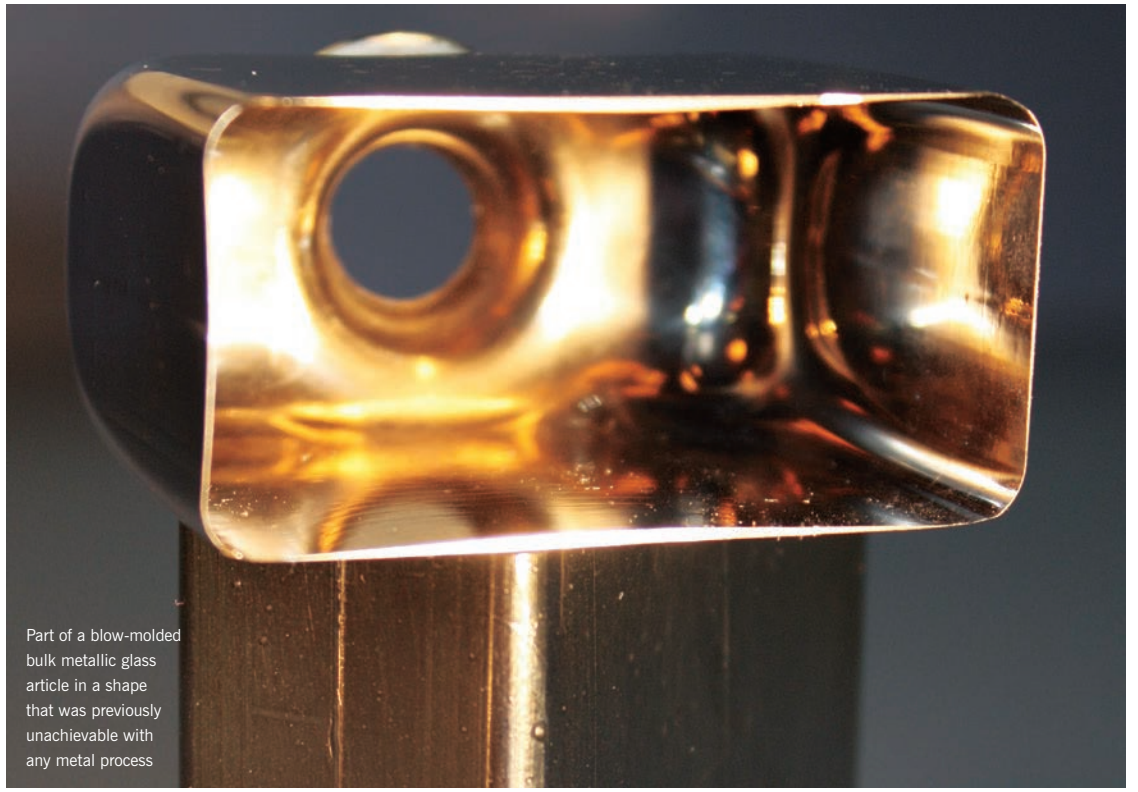
Associate professor Julie Zimmerman and associate professor Jordan Peccia, director of undergraduate studies in Environmental Engineering



Hunting for New Phenomena with the World's Largest Atom Smasher

The Large Hadron Collider—the world's largest atom smasher—was built in collaboration with thousands of scientists from hundreds of universities across the globe, including Yale. Keith Baker, Sarah Demers, Tobias Golling, and Paul Tipton, professors of Physics at Yale, use the Large Hadron Collider to investigate a number of current mysteries in the present theory of particle physics. Baker participated in the recent discovery of what is likely the elusive Higgs boson. Dubbed the "God particle," the Higgs boson explains why every other particle has mass and would provide the missing link in the Standard Model—our current theoretical understanding of particle physics. Many of the Yale team will be working to understand the properties of this new particle, including Demers, who will be searching for rare Higgs decays. Golling and Tipton are searching for new discoveries, motivated by, among other things, dark matter, that elusive substance which neither emits nor absorbs light but accounts for approximately 25 percent of the universe's mass. The four particle physicists carry out their experiments using ATLAS, one of two general-purpose detectors at the Large Hadron Collider located at the CERN laboratory near Geneva, Switzerland. The Large Hadron Collider, which took nearly fifteen years to complete, was commissioned in 2008.

Improved Vaccines
The focus of professor of Immunobiology Ruslan Medzhitov's research is the innate immune system, which alerts the host to infectious assaults and triggers a cascade of responses—known as the adaptive immune response—that is the basis for vaccine activity. Improved vaccines could be developed by injecting the immune system with disease antigens that are physically linked to particular polypeptide activators of the innate immune response. A Yale start-up, VaxInnate, is developing a high-throughput screening platform to identify these activators.



Part of a blow-molded bulk metallic glass article in a shape that was previously unachievable with any metal process

A New Class of Metals

Jan Schroers, professor of Mechanical Engineering, and his team have been exploring a class of materials called amorphous metals or bulk metallic glasses, BMGs, which can be molded like plastics and are more durable than silicon or steel. The team has created a process for making computer chips at the nano-scale that may revolutionize the industry. More recently Schroers has determined that BMGs have important biomedical applications—from stents to bone replacement. He and Themis Kyriakides, associate professor of Pathology and Biomedical Engineering, are working together to put the unique processibility of BMGs and their outstanding properties to the test. Their work targets three applications: bone replacement, soft tissue implants like stents, and surface patterning to program cellular response (synthetic membranes such as artificial kidneys).

Unlike most metals, BMGs have a tendency to avoid crystallization when solidified. It is their "amorphous" structure that yields many advantages including remarkable properties of high strength (three times that of steel), elasticity, corrosion resistance, and durability—all of which exceed the properties of currently used biomaterials. Most notable, however, is their unique processibility that allows them to be molded like plastics with nano-scale precision and complex geometries. This processing capability has only come with the recent emergence of thermoplastic forming, which decouples the fast-cooling process from the molding process, allowing the time needed for precision net-shaping.

Of course, the selection criteria for biomaterials include more than favorable mechanical and chemical properties and the ability to be precisely shaped—biocompatibility is an absolute necessity. "We knew we had a superior material over currently used implant materials, and we now have found out that we can indeed put it in the human body," says Schroers.

Natural Proteins by Design

Scientists dream of the day when they can create designer proteins capable of inhibiting harmful interactions, modifying substrates, or guiding cellular machines to where they are needed within the body. Though that dream may be far down the road, Alanna Schepartz, Milton Harris Professor of Chemistry and professor of Molecular, Cellular, and Developmental Biology, took an important first step forward when she and her team created the first synthetic protein in the lab. "Creating artificial proteins is somewhat of a holy grail," says Schepartz. "A fair number of people thought it would be impossible to synthesize a molecule that could come close to behaving like a natural protein that has benefited from billions of years of evolution."

Schepartz's team created a short ß-peptide that assembles into an "octameric bundle" shape that exhibits all the traits of natural bundle proteins, but with some additional potential benefits. "Unlike natural peptides and proteins, ß-peptides are not broken down by enzymes, not altered significantly by metabolism, and seem not to jump-start the immune system the way a foreign natural protein can," Schepartz says. That means scientists may one day be able to design drugs with all the functions of natural proteins, but which won't be broken down by the body.

From Lab to Start-Up.

Yale's Office of Cooperative Research plays a huge role in guiding faculty and student innovations from the laboratory to the marketplace. More than 40 ventures commercializing technologies discovered in Yale laboratories have been launched in recent years.

Access Scientific
Vascular access device
www.accessscientific.com

Achillion Pharmaceuticals
Infectious disease therapeutics
www.achillion.com

Affomix (acquired by Illumina)
Antibody screening technology
www.illumina.com

Axerion Therapeutics
Therapeutics for neurological diseases and injuries
www.axerion therapeutics.com

CaroGen Corp.
Vaccine development
www.carogencorp.com

C8 Sciences
Cognition training software
www.c8sciences.com

CoolSpine LLC
Cooling catheter for cardiothoracic surgery
www.coolspine.com

Great Basin Corp.
Point-of-care diagnostics for infectious diseases
www.gbscience.com

Hadapt, Inc.
High-speed data analytics
www.hadapt.com

JS Genetics
Genetic tests
www.jsgenetics.com

Kolltan Pharmaceuticals
Cancer therapeutics
www.kolltan.com

Melinta Therapeutics
Antibiotics for drug-resistant infections
www.melinta.com

MiraDx
Cancer diagnostics
www.miradx.com

M/Z Diagnostics
Diagnostics on mass spectrometry platforms
mzdiagnostics.com

New Haven Pharmaceuticals
Therapeutics for gastrointestinal disorders
newhavenpharma.com

NovaTract Surgical
Minimally invasive surgical products
www.novatract.com

Oasys Water
Cleantech for seawater desalination
www.oasyswater.com

P2 Science, Inc.
Green surfactants
www.p2science.com

Prevention Pharmaceuticals
Over-the-counter medicines
www.prevention pharmaceuticals.com

Rachiotek LLC
Spine stabilization device
www.rachiotek.com

SilviaTerra
Remote-sensing forest management software
www.silviaterra.com

Sonic Golf
Training device for golf
www.sonicgolf.com

VaxInnate
Novel vaccines for infectious diseases
www.vaxinnate.com

Vidus Ocular (acquired by OPKO)
Device to treat glaucoma
www.opko.com

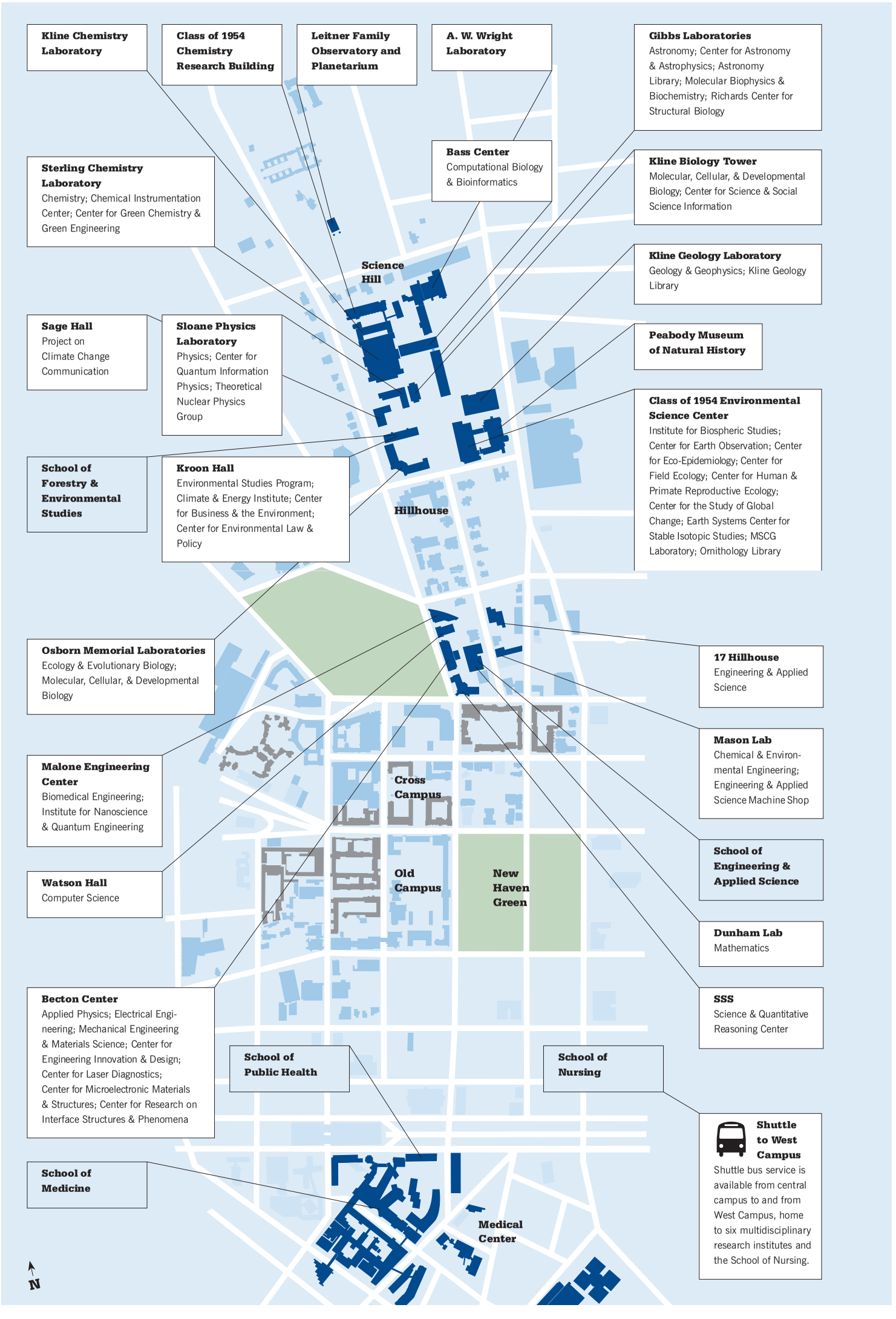
Vutara
High-performance microscopy devices
vutara.com

Connected Campus.

(Designed for easy access)

Walking Times
Bass Center to Sloane Physics Lab **3 min.**
Gibbs Labs to Osborn Memorial Labs **4 min.**
Old Campus to Becton Center **8 min.**
Kline Biology Tower to Cross Campus **10 min.**
Malone Center to School of Medicine **15 min.**

As a student at Yale you are situated on central campus, midway between Science Hill to the north, with its laboratory and classroom buildings, and the School of Medicine to the south. Both are just a ten-minute walk from central campus. Altogether that means hundreds of labs, each pursuing different kinds of research and easily accessible to where students live and work. Here you will find literally any kind of research that may interest you.



Building the Future.

(Investing in new facilities, fueling new discoveries)

A new era of discovery is changing lives for the better in every part of the globe—and Yale is prepared as few institutions are to advance knowledge and apply it to today's greatest challenges. Having recently concluded a decade-long, $1 billion program of expansion and renovation of STEM facilities, we continue to devote significant resources to strengthening Yale's capacity for interdisciplinary research in science, engineering, and medicine. Some of our newest buildings, initiatives, and student projects are featured here.

Kroon Hall *(left)* Kroon Hall, home to Yale's School of Forestry & Environmental Studies, completed in 2009. Certified LEED Platinum by the U.S. Green Building Council, it is a showcase of the latest developments in green building technology, a healthy and supportive environment for work and study, and a beautiful building that actively connects students, faculty, staff, and visitors with the natural world. Kroon is an anchor for long-term sustainable development of our Science Hill.

Center for Science and Social Science Information *(above)* CSSSI opened in 2012 in Kline Biology Tower on Science Hill. A collaboration between the University Library and ITS, it offers state-of-the-art information services in a technology-rich environment. Among its resources are computer workstations with comprehensive software suites, group study and presentation preparation rooms with video recording capabilities, a StatLab computer classroom with dual-display workstations and new collaborative technologies, and an on-site 180,000-volume print collection as well as an extensive and growing electronic collection. Librarian subject specialists and tech support staff offer high-level research support, including assistance with discipline-specific software.

Science Hill

From nuclear physics to new molecule synthesis, from ecosystem and conservation biology to genetic and optical investigations, Science Hill facilities foster cutting-edge, cross-disciplinary research.

Center for Engineering Innovation and Design
The new Yale Center for Engineering Innovation and Design is an 8,500-square-foot facility, with adjoining café and high-tech study space. It offers Yale students an unparalleled environment for collaborative design and innovation, with group work areas, meeting rooms, and fabrication facilities for metal, plastics, wood, biomedical materials, and electronic devices. It is an intellectual hub where people with common interests exchange ideas, learn from one another, and hone the skills that are needed to create engineering solutions to challenging, real-world problems.

"The center empowers Yale students to realize their creative vision," says director Eric Dufresne, John J. Lee Associate Professor of Mechanical Engineering and Materials Science. "The center will help students bridge the gap between formal course work and the real challenges that face society."

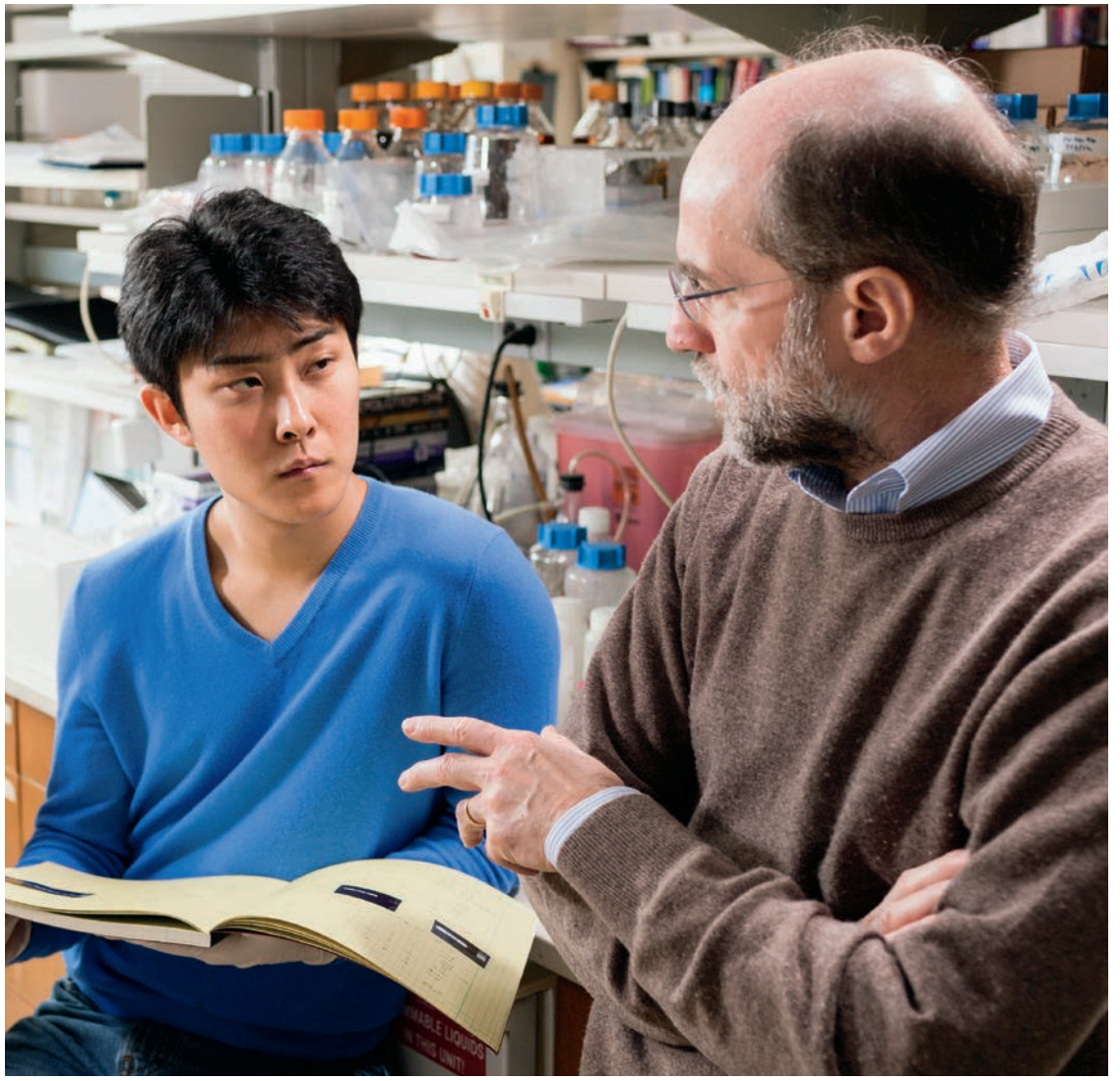
Courses, workshops, and projects at the center require the application of a broad array of engineering principles and bring together students and faculty in all of Yale's engineering majors – biomedical, chemical, electrical, environmental, and mechanical. But the center is open to students in all majors, for both academic and extracurricular projects. "Innovation is catalyzed by people with diverse backgrounds working together to attack the same problem," says Dufresne.

Anchored in the outstanding liberal arts tradition of Yale College, the center delivers a unique design and engineering experience.

Yale Engineering

It is an exciting time to be in Yale Engineering, with $50 million in funding for new faculty; increased support for undergraduate research opportunities, student associations, and entrepreneurship initiatives; and continued infrastructure growth. Whether it's nanoscience, targeted drug delivery, or sustainability issues, our faculty and students are engaged in the most innovative research of our time.

Malone Engineering Center *(right)* This five-story, 64,700-square-foot laboratory building was completed in 2005 and achieved a LEED Gold rating for sustainable design. The research and teaching that take place at Malone focus on the forefront areas of biomedical engineering, materials science, and nanotechnology and bring together in full partnership faculty from the Schools of Engineering & Applied Science and Medicine. Designed to be comfortable, practical, elegant, and high-tech, it offers students and faculty ready access to the latest equipment, computers, and communications technology.



Yale Medicine

On Yale's medical campus, just three blocks from the College, leading thinkers in fields from genetics to biomedical engineering and nanoscience, as well as researchers and physicians working on cancer, neurological disorders, and cardiovascular disease, break new ground every day. You can take classes taught by medical school faculty, work in their labs, shadow doctors on their rounds, and volunteer at Yale-New Haven Hospital. And the research opportunities available to undergraduates at the School of Medicine are extraordinary.

Cellular Neuroscience, Neurodegeneration, and Repair Program
MB&B major Ryan Park *(left)* is working toward a joint B.S./M.S. degree. His project uses biochemical and high-resolution imaging methods to study the role of a protein called dynamin in membrane trafficking.

Department of Cell Biology
MCDB major Henrietta Bennett *(below)* is working on a project focused on the association between telomeres and the nuclear envelope – a hot topic in the aging field.

MCDB major Sunny Jones studies the mechanisms of SNAREs, proteins that fuel the trafficking of vesicles through the Golgi apparatus of the cell.

Departments of Dermatology and Genetics
MB&B major Jonathan Fisher is studying genetic mutations that lead to skin cancer.

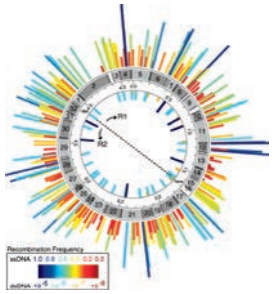
Department of Immunobiology
MCDB major Christopher Chow is working on the cells that control the immune system's reaction to viruses.

Department of Anesthesiology
BME-Economics major Michelle Tseng is working on the implantation of engineered lung tissue into rats, with the long-range goal of creating a tissue-engineered lung.

Departments of Biomedical Engineering, Therapeutic Radiology, and Pediatrics
BME major Kavitha Anandalingam is working on the use of polymer nano-particles to deliver DNA constructs for gene therapy of cystic fibrosis.

Departments of Internal Medicine, Diagnostic Radiology, and Biomedical Engineering
BME major Nimit Jain is developing mathematical models to analyze MRS data to track metabolism in the human liver.

"You don't have to be pre-med to take advantage of the great opportunities and great mentors in laboratories at the medical school. I work in a cell biology lab studying interactions between chromosomes and the nuclear envelope in fission yeast. Our work is medically relevant, but it's also interesting from the perspectives of general biology and biophysics. After all, good science is collaborative and interdisciplinary. My research at the medical school and my relationships with my lab members have been the most rewarding and productive of my experiences at Yale."
MCDB *major Henrietta Bennett*



"I've been doing my senior research project in assistant professor Farren Isaacs's lab in the Systems Biology Institute. The Isaacs Lab is focusing on extending the results of a technology called multiplex automated genome engineering (MAGE). MAGE can be used as a powerful genome editing tool. My project is designed to increase the efficiency of MAGE, making possible an *in vivo* gene synthesis platform. Each time I come to the lab I'm amazed by the sheer acreage of West Campus. The opportunities for growth here are extraordinary. I can't wait to see what it looks like in a few years."
Mathematics and MCDB *major*
Josh Pan

West Campus

At its West Campus, Yale is building something entirely new: a distinctive scientific community that facilitates interactions between Science Hill and medical school scientists and engineers. Just a seven-minute shuttle ride from central campus, West Campus provides the physical and conceptual space for innovative collaboration. Six broadly multi-disciplinary research institutes here tackle problems and develop solutions that extend beyond traditional departmental boundaries, transforming the way biomedical, chemical, and engineering research is conducted at Yale.

Cancer Biology Institute Focusing on fundamental and translational cancer biology, driving research through the pursuit of novel therapeutics.

Chemical Biology Institute Emphasizing research in synthetic biology and products biosynthesis; the pursuit of novel, biologically active small molecules is the backbone of the institute.

Energy Sciences Institute Focusing on the challenges facing the environment and energy sectors, from alternative and sustainable fuels to carbon mitigation technologies and energy storage.

Microbial Diversity Institute The first of its kind, focused on discovering, characterizing, and harnessing the microbial world by investigating microbe-based processes in the environment and in health.

Nanobiology Institute Focusing on the discovery of principles that unite living and synthetic materials at the nanoscale.

Systems Biology Institute Focusing on the biology of regulatory networks, particularly the biology of gene regulatory networks that underlie the identity and life of cells, providing a springboard for the integration of mathematical theory and bioinformatics.

Mentoring Future Leaders.

(Scientists and engineers talk about teaching)

A remarkable commitment to and capacity for teaching undergraduates sets Yale apart from other great research universities. To get a good sense of just how integrated undergraduate teaching and world-class research are here, one only needs to compare the overlap in faculty names between those making research breakthroughs and those listed in the Yale course catalog. Faculty say some of their best research ideas are often sparked in the classroom. Students say they are amazed by the incredible access they have to people who really are changing the world through science and engineering. We asked some of these great teachers and researchers why Yale is an extraordinary place to study and practice science and engineering.

Q What sets the Yale science and engineering experience apart from those at other research universities?

Kyle Vanderlick "The very things that make Yale a great place to conduct research also make the University a great place to learn. Students have access to world-class scholars, state-of-the-art facilities, and a collaborative culture supporting exploration and personal development. In short, engineering is about pushing the boundaries of what mankind can do through technological innovation. This simply cannot be done without a broad understanding of humanity, nor without the rich set of communication skills necessary to convey new and complex ideas. This is what engineering at Yale is all about."

Mark Saltzman "There's something different about rigorous training in engineering embedded in a liberal arts tradition. One of the features of a liberal arts education is that you're required to take courses in all sorts of different things. For instance, we think it's important that our students study a foreign language as well as the social sciences. Taking different kinds of classes creates a different sort of curiosity. Our students bring that curiosity to the kinds of questions they're asking and trying to answer in science classes and engineering research labs. It's certainly a different experience than at other places I've been where, if you're an engineering or science major, you're studying the same kinds of things in the same kind of way that other students around you are studying. You're also living with other science and engineering majors. Here, students are living among future historians, future economists, English majors, and political science majors, all bringing their own brands of thought to questions and ideas."

Mark Saltzman "There are 16 faculty members in Biomedical Engineering and we have 20 to 25 majors each year, so nobody is anonymous. Every student does research. They all do a significant senior project. They all take classes with most of the faculty during their time here. At graduation when I meet their parents, I know something significant about each student. That's pretty rare."

Q How are classroom science and engineering different from research in the lab?

Meg Urry "What we teach in science classes are tools and a way of thinking. The tools are basic concepts like gravity, forces, acceleration, motion, thermodynamics, and fluids that are manifested everywhere in nature. In the lab, we apply those concepts to different aspects of nature. In my own

Joan A. Steitz
Sterling Professor of Molecular Biophysics and Biochemistry; Howard Hughes Medical Institute Investigator

Professor Steitz is recognized for her research, which could help improve diagnosis and treatment of autoimmune diseases such as lupus. She discovered snRNPs (pronounced "snurps"), small particles in cells that are necessary for converting raw genetic information into active proteins. These particles produce messenger molecules that can be read directly into proteins. They are therefore critical for carrying out all of the body's most basic biological processes, such as developing the immune system or the brain.

Recent Courses
Principles of Biochemistry II; Medical Impact of Basic Science

Meg Urry "It's like the difference between learning to speak French well (understanding basic physics concepts) and reading French literature (working in a physics lab). You have to do the first in order to do the second."

lab, we think about radiation from hot plasmas and relativistic particles. Elsewhere in physics we might think about the behavior of fundamental particles or atoms or molecules."

Charles Schmuttenmaer "Classroom learning is absolutely essential for success in research. Like Meg, I think of it as filling a toolbox with all sorts of tools. Some are rather generic, like hammers and saws, and some are quite specialized, like a pulley puller or a plumber's basin wrench. Not every project will need every tool, but the more you have in your toolbox, the better equipped you'll be to tackle something new. The daily practice of science is characterized by creatively and innovatively solving research problems with all the tools at one's disposal. By definition, you're doing things in a research setting that have never been done before. That's what makes it research, after all. I think the creative aspects of scientific research are often overlooked or underestimated."

Mark Saltzman "That is the obvious difference—that in the classroom you're talking about accumulated knowledge and ideas that have been tested and known in lots of different ways, so it's not so controversial or open-ended. Almost everything you do in a research laboratory is open-ended, and there is not any one way to get from point A to point B. Sometimes you don't even know what point B is. You're probing to find it in different ways and you don't know what the outcome will be."

Joan Steitz "The old idea of a scientist being an iconoclast who has a brilliant idea and then goes into the lab and does an experiment all by him- or herself, looks at the data, and then comes to a lofty conclusion is so faulty. Students here learn how communal the scientific enterprise is."

Q What qualities and skills do you look for in students who want to join your lab team?

Charles Schmuttenmaer "Beyond a strong background and ability in math and science, I look for people who can solve problems independently while working with others on a team. It is not a situation where I have all the answers and dole out my knowledge to them. I look for people who are resourceful. People who leave no stone unturned when confronted with data that doesn't seem to make sense. The sooner young researchers learn that the information they need will not be neatly packaged in some particular textbook, the sooner they will be successful."

John Harris "We are looking for students who are excited about science and are motivated to learn new concepts and make new discoveries. They need to think independently and for the benefit and success of the research project and team. In terms of skills, they need to have the ability to understand new concepts, to clearly articulate questions and ideas, and to communicate their questions, ideas, and concepts to others."

Joan Steitz "Communication skills are essential. In experimental science you're starting from a tradition of knowledge. From there you put together a hypothesis and test that hypothesis. But this is always done by people talking to each other, people evaluating each other's data. Yale is particularly good at teaching students how to communicate at a high level with faculty, postdocs, and research subjects."

Meg Urry "They need to be smart, motivated, persistent, and good communicators. No one of those qualities is sufficient in and of itself—they need all four. They have to want to discover new knowledge; they have to master the tools of discovery; they need to be able to finish a project, however

Charles A. Schmuttenmaer
Professor of Chemistry

Professor Schmuttenmaer's research uses THz technology to determine characteristics of photo-excited reactions. "My group has recently formed a solar energy collaboration with three other Chemistry professors. My students and I use THz spectroscopy to help unravel the inner workings of dye-sensitized solar cells—a potential alternative to silicon solar cells, and a potential way to make hydrogen or other fuels directly from sunlight."

Recent Courses
Comprehensive General Chemistry II; Molecules and Radiation II; Perspectives on Science and Engineering

Meg Urry
Israel Munson Professor of Physics and Astronomy; Director of the Yale Center for Astronomy and Astrophysics

Professor Urry chairs the Physics department. She studies actively accreting supermassive black holes, also known as Active Galactic Nuclei (AGN), and the co-evolution of these black holes with normal galaxies.

Recent Courses
Advanced General Physics; Gravity, Astrophysics, and Cosmology; Perspectives on Science and Engineering

Kyle Vanderlick
Dean of the School of Engineering & Applied Science; Thomas E. Golden, Jr. Professor of Chemical & Environmental Engineering

Dean Vanderlick is a leading expert on interfacial forces—interactions that occur near or between surfaces. She conducts research that aims to measure, control, and understand the properties of interfaces and thin films, especially those with relevance to materials science and biology. Her research group specializes in the application and development of experimental methods designed to probe the properties of surfaces, confined fluids, and membranes. Her work has led to new and fundamental insights across a range of areas spanning from metallic adhesion in micro/nano-scale devices to the action of antimicrobial peptides on cell membranes.

W. Mark Saltzman
Goizueta Foundation Professor of Biomedical Engineering and Chemical & Environmental Engineering; Professor of Cellular and Molecular Physiology

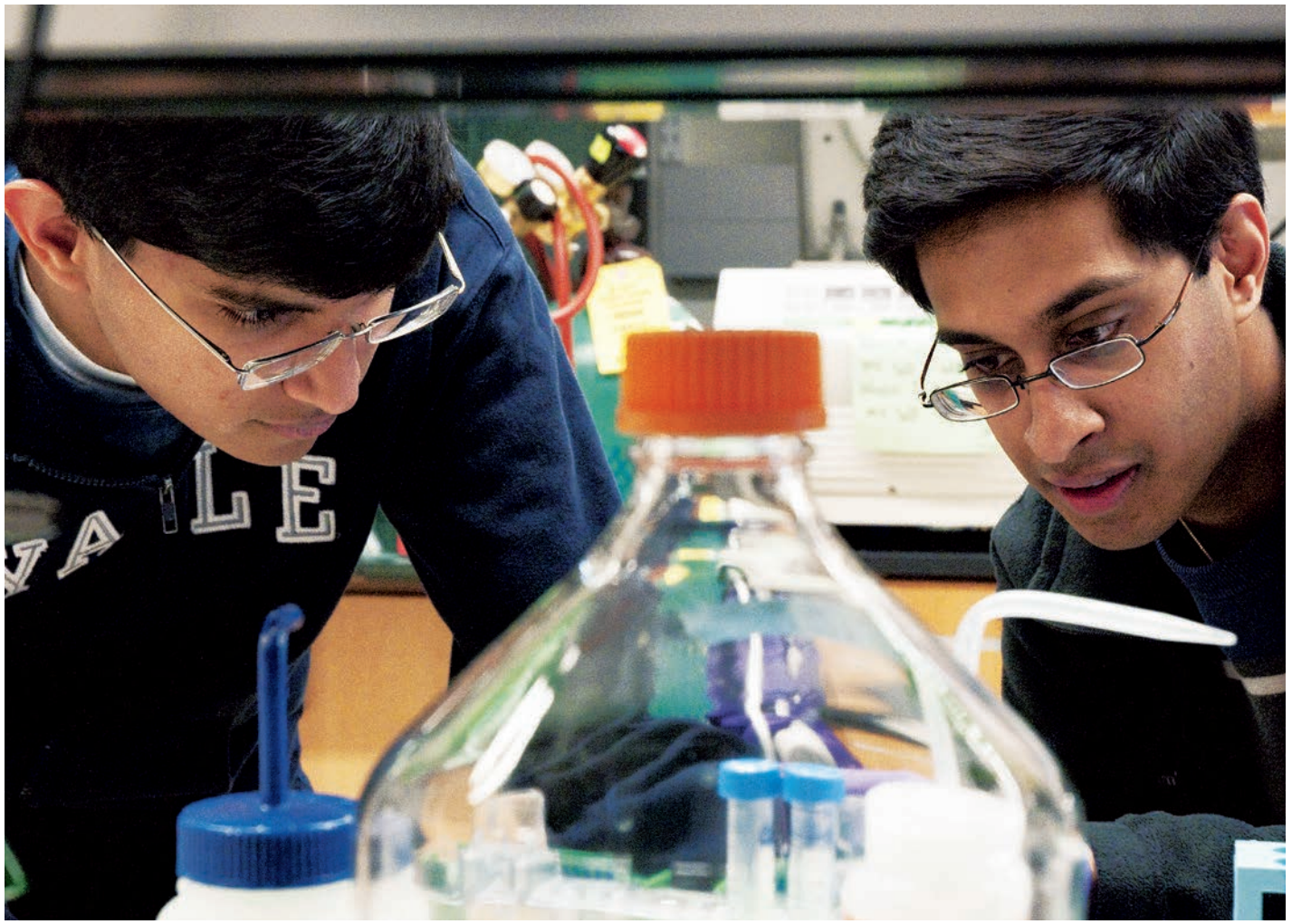
Professor Saltzman is the founding chair of Yale's Biomedical Engineering department. His research interests include drug delivery to the brain, materials for vaccine

(continued in right column)

many snags they may encounter; and they need to be able to communicate their results to others, preferably in an articulate and exciting way."

Q Based on your personal experience of being an active research scientist, what do you think students need in order to be successful?

Joan Steitz "What every scientist who succeeds comes to appreciate is that there is really something very special about discovering something—no matter how small it is—that nobody else has ever known. When you first develop that film or look under the microscope and discover something new, you're the only person in the universe with that knowledge. You have to be turned on by the curiosity to ask new questions and by the joy of finding the answers. As an undergraduate, because my role in labs had always been helping someone else on that person's project, I didn't understand how exciting it was to have my own project. I became completely hooked after that. In my lab, I make sure every undergraduate has his or her own project from the start. Even though they are working closely with somebody who knows more and who obviously cares whether their project succeeds or not, it is completely up to the undergrad as to whether that project succeeds. It's theirs."



Kyle Vanderlick "Engineering today at Yale is very different from its inception in the mid-1800s. We're not building bridges, we're curing diseases, cleaning and protecting our environment, computing at the quantum scale, and solving the energy crisis. More than an education in technological innovation, Yale engineering is a curriculum for leadership in the twenty-first century."

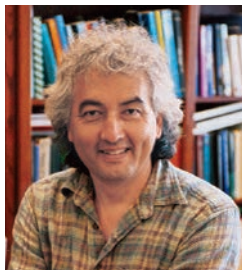
Kyle Vanderlick "Quantitative reasoning, teamwork, and the habit of breaking complex problems into manageable pieces—these are the skills needed to be a successful engineer. Engineering is a purposeful and powerful way of thinking. It prepares students for fulfilling careers in engineering right after college, but it is also a broad and foundational education that well serves students interested in business, medicine, law, and for an endless list of life pursuits in today's technologically driven world."

Mark Saltzman "I have a lot of faith in the power of human connection—that somehow people use the examples that they see in order to envision their own path. That is why it's so important for working scientists and students to be in the classroom together. Students can get the facts from any number of places, but in the classroom they have human examples of interesting ways to approach problems, human examples of paths they might want to replicate in some way."

Meg Urry "I agree. The process of doing science is a bit like an apprenticeship. We show them how to ask a question, how to find the answer, and then we help them learn to present their results to others. And along the way, I hope we also show them that professors are mortals, that our profession is one we love and enjoy, and that we can combine work with a full and satisfying life."

delivery, and tissue engineering; he has published three books and more than 200 research papers, and he has ten patents in his fields. He has also received two Teaching Materials Awards from the Whitaker Foundation for his work on textbooks in tissue engineering and biomedical engineering principles for freshmen.

Recent Courses
Physiological Systems; Frontiers of Biomedical Engineering; Engineering of Drug Delivery



John W. Harris
Professor of Physics; Chair of the Yale Science Council; former Director of the A. W. Wright Laboratory

Professor Harris is the group leader of Yale's Relativistic Heavy Ion Group. Relativistic heavy ion physics is of international and interdisciplinary interest to nuclear physics, particle physics, astrophysics, condensed matter physics, and cosmology. The primary goal of this field of research is to recreate in the laboratory a new state of matter, the quark-gluon plasma, which is predicted by the Standard Model of particle physics to have existed ten millionths of a second after the Big Bang (origin of the universe) and may exist in the cores of very dense stars. The experiments are carried out at the Large Hadron Collider in Geneva, Switzerland.

Recent Courses
General Physics Laboratory; Quantum Physics and Beyond (for nonscientists); Modern Physical Measurement

Paths to Success.

(From high school to Ph.D., mapping the routes)

Yale undergraduates studying science and engineering are ideally positioned for top Ph.D. programs and career success. Here, three graduates trace the major steps they took to get where they are today.

Gregg Favalora

Hometown
Teaneck, NJ

Yale Class of 1996
B.S. Electrical Engineering

M.S. Engineering Sciences
Harvard University 1998

Current
Principal, Optics for Hire (OFH)

#1 Pivotal Moment
By the time May of my senior year arrived, I could project a checkerboard of dots in the air. No one seemed particularly impressed except my adviser, Professor Peter Kindlmann, who gave me exceptional guidance, and the department chair, Professor Mark Reed, who pledged departmental financial support.

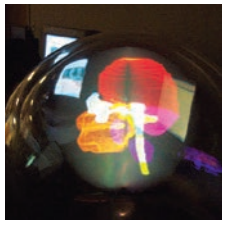
Persistence and Patent
I knew I was onto something. By the end of the summer after graduation, my projector was displaying 3-D images of Homer Simpson's head, an air traffic scene, and the letter "Y." This made believers out of a bigger circle of people and I earned a patent for the invention.

Investor Search
A three-year investor search followed. It was the height of the dot-com boom. Investors were pumping huge amounts of money into the craziest of dot-com ventures, but no one was interested in work with three-dimensional images that could potentially help surgeons operate on cancer patients. Meanwhile, my parents were buying me groceries, and my team of engineers was living off McDonald's Bag of Burgers special—six for $3. Things looked bleak.

#2 Pivotal Moment
Things finally started to turn around. I met a journalist known for chronicling the happenings of Silicon Valley. After watching an image of the HIV virus rotating in space projected from my 3-D prototype, he wrote an article for the *Wall Street Journal* on the invention and my difficulty finding funding. Soon I had so many offers I had to turn investors away.

Why Yale
Everything you hear and read about Yale's commitment to undergraduates is completely true. You get a front-row ticket to theory and practice. Best of all, your future opportunities, whether you become a professional engineer or not, really are right at your fingertips.

Today
I work at Optics for Hire, which acquired the 3-D patents from my company, Actuality Systems, in 2009. OFH invents or improves optics-based products. For example, for GE we made a handheld light-gun that uses diffraction to inspect giant turbine blades. For medical device companies, we've created optical blood inspectors and complex lenses. People call us for everything from "greentech" (LED lighting) to video game technologies to laser-based measurement systems.



It All Started at Yale
For my senior project as an electrical engineering major, I created a three-dimensional projection system. The system exploited the persistence of human vision by projecting one-dimensional images very quickly onto a rotating screen so that a viewer's eyes perceived an aggregate 3-D image.

High School
What began as a dream in high school became real at Yale, and today continues to lead me along a path of corporate leadership, technology, and invention.

"While it's true that not every senior project can turn into a successful start-up company, I implore engineering majors to embrace the opportunity to do a design project and to apply a ridiculous amount of persistence to it, because there's nothing like the feeling of having made this thing that no one else in the world has ever made before."

Yale Legends

Benjamin Silliman, one of the first American professors of science and founder of the *American Journal of Science,* America's longest-running scientific journal

Eli Whitney, inventor of the cotton gin

O.C. Marsh, America's first vertebrate paleontologist

F. Herbert Bormann, founder of modern ecosystems ecology

Benjamin Spock, revolutionized child psychology

Paul B. MacCready, pioneer of solar-powered flight

Francis S. Collins, director of the Human Genome Project and now director of the National Institutes of Health

William E. Boeing, cofounder, Boeing Aircraft

Lee De Forest, inventor of the triode, which made commercial radio broadcasting feasible

J. Willard Gibbs, father of chemical thermodynamics and physical chemistry

George Bird Grinnell, founder of the Audubon Society

Grace Murray Hopper, developed the basis for the programming language COBOL

Elias Loomis, creator of the first weather maps

Harvey Cushing, father of neurosurgery

G. Evelyn Hutchinson, created the field of limnology

Benoit Mandelbrot, creator of fractal geometry

Recent Nobel Laureates

James Rothman, Physiology or Medicine, 2013 (B.A. from Yale 1971; Fergus F. Wallace Professor of Biomedical Sciences and Professor of Cell Biology and Chemistry)

Thomas Steitz, Chemistry, 2009 (Sterling Professor of Molecular Biophysics and Biochemistry and Professor of Chemistry)

John Fenn, Chemistry, 2002 (Ph.D. 1940; Yale faculty, 1967 to 1987)

Raymond Davis, Jr., Physics, 2002 (Ph.D. 1942)

David Lee, Physics, 1996 (Ph.D. 1959)

Eric Wieschaus, Physiology or Medicine, 1995 (Ph.D. 1974)

Alfred G. Gilman, Physiology or Medicine, 1994 (B.S. 1962)

Erwin Neher, Physiology or Medicine, 1991 (biophysicist at the Max Planck Institute for Biophysical Chemistry who was previously a post-doctoral fellow at Yale)

Sidney Altman, Chemistry, 1989 (Sterling Professor of Molecular, Cellular, and Developmental Biology and Professor of Chemistry)

Laura Kreidberg

Hometown
Reno, NV

Yale Class of 2011
B.S. Astronomy and Physics

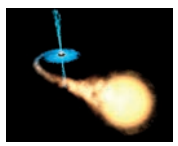
Current
Ph.D. candidate, Astrophysics, University of Chicago

"The best thing about Yale is the students. It was great to learn about the ultimate fate of the universe in a cosmology class, but it was even better to sit down at dinner with some philosophy majors to sort out what it all meant."

Early Inspiration
When I was the captain of my high school Science Bowl team, my coach encouraged me to pursue my interest in astrophysics. He helped me find some great introductory textbooks and inspired me to study astronomy and physics in college. The extra studying also helped my team win the state championship!

Why Yale
Yale students stood out because of their sense of humor and enthusiasm for both academics and everything else. I aspired to be like them.

#1
Pivotal Moment
I realized I wanted to be a scientist while I was writing a paper on *Hamlet* for an English class freshman year. The crux of my argument was that a character's importance could be determined by the number of total lines he spoke. When I recognized that my need to quantify things extended even to Shakespeare, I decided the sciences would be the best fit for me.



#2
Pivotal Moment
My senior project adviser, Professor Charles Bailyn, was hugely influential in my path to grad school. He helped me identify a high-impact research project on black holes that was a perfect fit to my interests. Through close collaboration with him (we met at least once a week), I learned how to assess promising new research directions, think critically about papers, justify assumptions, and write convincingly about my work. These skills have really jump-started my research program in grad school.

Valuable Takeaways
What a fantastic preparation for a career in science Yale was for me. Not only were the science classes and research opportunities extremely strong, but I developed my communication and leadership skills. For example, helping to organize the Northeast Conference for Undergraduate Women in Physics, a three-day event with 150+ participants, taught me teamwork and how to finish projects with strict deadlines—two essentials for success in a scientific career.

Current Work
I am a Ph.D. candidate at University of Chicago. I am interested in astrostatistics—using Bayesian methods, time series analysis, machine learning, and other techniques to maximize the science we can obtain from astronomical data sets, both large and small. My current research focuses on optimizing the planet detection algorithm used by the Kepler mission.

Daniel Rosenfeld

Hometown
Los Angeles, CA

Yale Class of 2007
B.S. Chemistry

M.S. Electrical Engineering
Stanford University 2011

Ph.D. Chemistry
Stanford University 2013

Current
Associate, Exponent, Inc.

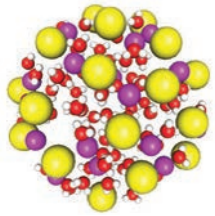
Why Yale
I came to Yale when undergraduate science was being re-invigorated through programs like Perspectives on Science. Seeing Yale's interest in nurturing undergraduates in science appealed to me. Other schools also offered great programs, but Yale seemed most interested in me as a young scientist. My experiences later proved that to be true.

#1
Pivotal Moment
Physical chemistry freshman year exposed me to rigorous thermodynamics and quantum mechanics, opening my understanding of the world and the beauty of nature.

High School
I began looking at the world through the eyes of chemistry and physics, which was an empowering experience that drove me toward studying science later.

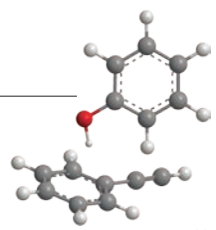
Bonus
Yale attracts very talented scientists who are also interesting people. You're a full-fledged member of the scientific community—not an undergraduate underling.

#2
Pivotal Moment
Working for my great undergraduate mentor, Charles Schmuttenmaer, in the Chemistry department was an important turning point for me. His curiosity and inquisitiveness showed me how interesting physical chemistry can be. His friendly and encouraging nature nurtured the genesis of my scientific efforts.



Novel Research
In my research group, I had my own project and worked individually under my adviser. I was not simply performing busywork for a graduate student. Professors at Yale take undergraduate education and research very seriously. They try to find a good niche for an undergraduate to contribute to novel research while learning an immense amount.

Grad School Dividend
I have a much larger breadth of knowledge than most other graduate students in my department, particularly because of my course work and research at Yale. I was encouraged to take courses that spanned a wide range of scientific topics. That has paid large dividends down the line.



Current Work
My work at Exponent involves failure analysis and materials characterization related to polymers and plastics, adhesives, and coatings.

"There are lots of technologies out there waiting for the right moment to really impact the planet in a positive way. I want to position myself to help those technologies come alive."

Yale.*

(A world unlike any other)

*In this book we have introduced you to what makes Yale an extraordinary place to be a scientist and engineer. Yet a whole world of lives, studies, places, and pursuits beyond science and engineering awaits you at Yale that we haven't begun to address. As Physics Intensive major Michelle Trickey says, "You can't get this confluence of people or the culture of inquisitiveness while having fun very many other places. It's just special here." A Yale historian once defined what makes it so special this way: "Yale is at once a tradition, a company of scholars, a society of friends." We would like you to have your own guide to that tradition, that company, and such friendships. (You can download our insider's guide to all that is Yale at: admissions.yale.edu.)

Here is a taste of what you will find.

Lives.

Freshman Diaries. Yale's newest students chronicle a week in the first year and give some advice.

Anatomy of a Residential College. Yale's residential college system is unparalleled and enhances the pleasure of attending Yale like nothing else. Far more than dormitories, our 12 residential colleges have been called "little paradises"—endowed with libraries, dining halls, movie theaters, darkrooms, climbing walls, ceramics studios, and many other kinds of facilities—and each has its own traditions. Each college is home to a microcosm of the undergraduate student body as a whole. (For science and engineering majors this means that your friends will be actors and economists, musicians and linguists, artists and historians as well as biologists and physicists.) With their resident deans and masters, affiliated faculty, legendary intramural sports teams, and Master's Teas with world leaders, the residential colleges are an incomparable experience.

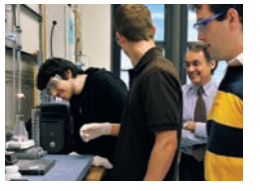
Bright College Years. In many ways friendship defines the Yale experience. One student sums it up: "It's about the people, not the prestige."

Studies.

A Liberal Education. Freedom to think. Yale's educational philosophy, more than 80 majors, the meaning of breadth, and some startling numbers.

College Meets University. An undergraduate road map to the intersection of Yale College and the University's graduate and professional schools.

Blue Booking. Yale is one of the only universities in the country that lets you test-drive your classes before you register during what's known as "shopping period." Preparing to shop is a ritual in and of itself, signaled by the arrival online of the Blue Book, Yale College's catalog of more than 2,000 courses.



Eavesdropping on Professors. Why being an amazing place to teach makes Yale an amazing place to learn.

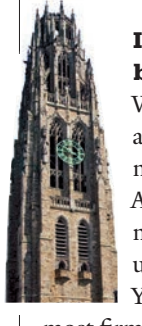
Two, Three, Four, Five Heads Are Better Than One. Why Yalies like to learn together.

Next-Gen Knowledge. For Yalies, one-of-a-kind resources make all the difference.

Think Yale. Think World. Over and above ordinary financial aid, Yale awards more than $6 million for fellowships, internships, and relief from summer earnings obligations in order to guarantee that every student who wishes will be able to work or study abroad. Eight Elis define "global citizen" and share their pivotal moments abroad.

Connect the Dots. From start-up capital and internships to top fellowships and a worldwide network of alumni, Yale positions graduates for success in the real world.

Places.



Inspired by Icons. Why architecture matters. Among the nation's oldest universities, Yale is the one most firmly defined by its architecture.

Noah Webster Lived Here. Bumping into history at Yale.

Nine Squares. The modern university, the cosmopolitan college town.

Elm City Run. On a run from East Rock to Old Campus, one student explains why New Haven is the perfect size.

Here, There, Everywhere. Fourteen Yalies, where they're from, and where they've been.

Pursuits.

Bulldog! Bulldog! Bow, Wow, Wow! Playing for Yale—The Game, the mission, the teams, the fans, and, of course, Handsome Dan.

State of the Arts. From the digital to the classical, Yale's spectacular arts options.

The Daily Show. A slice of Yale's creative life during one spring weekend.

Shared Communities. Yale's tradition of Cultural Houses and affinity organizations and centers.

ELIterati. Why Elis are just so darned determined to publish.

Sustainable U. Where Blue is Green.

Political Animals. Today's and tomorrow's leaders converge at the Yale Political Union, the nation's oldest debating society.

Keeping the Faiths. Nurturing the spiritual journeys of all faiths.

Difference Makers. Through Dwight Hall, Yale's Center for Public Service and Social Justice, students find their own paths to service and leadership in New Haven.

The Good News about the Cost of Yale.

If you are considering Yale, please do not hesitate to apply because you fear the cost will exceed your family's means. Yale College admits students on the basis of academic and personal promise and without regard to their ability to pay. All aid is need-based. Once a student is admitted, Yale will meet 100% of that student's demonstrated financial need. This policy, which applies to U.S. citizens and to international students alike, helps to ensure that Yale will always be accessible to talented students from the widest possible range of backgrounds.

The Financial Aid Office is committed to working with families in determining a fair and reasonable family contribution and will meet the full demonstrated need of every student for all four years with an award that does not require loans. Today, 53% of undergraduates qualify for need-based scholarships from Yale. The average annual grant from Yale to its students receiving financial aid for the 2013–2014 academic year was approximately $40,800, or about two-thirds of the cost of attendance.

Yale also provides undergraduates on financial aid with grant support for summer study and unpaid internships abroad based on their level of need.

"If you get into Yale, we feel sure that cost will not be a barrier in your decision to attend."

Jeremiah Quinlan, Dean of Undergraduate Admissions

> *Yale Financial Aid Awards do not include loans. 100% of a family's financial need is met with a Yale grant and opportunities for student employment.*

> *Families with annual income below $65,000 (with typical assets) are not expected to make a financial contribution toward a student's Yale education. 100% of the student's total cost of attendance will be financed with a Financial Aid Award from Yale.*

> *Families earning between $65,000 and $200,000 annually (with typical assets) contribute a percentage of their yearly income toward a student's Yale education, on a sliding scale that begins at 1% and moves toward 20% and higher.*

> *Yale awards all aid on the basis of financial need using a holistic review process that considers all aspects of a family's financial situation.*

Costs for 2014–2015

Tuition	$45,800
Room	$7,800
Board	$6,200
Books & personal expenses	$3,450
Total	$63,250

Yale Net Price Calculator
admissions.yale.edu/yale-net-price-calculator

To help estimate your Yale financial aid award before you apply, we encourage you to use the Yale Net Price Calculator. The calculator generates a sample financial aid award based on the information you supply and on Yale's current aid policies. The process should take less than ten minutes. The calculator cannot capture all the information an aid officer would use to evaluate financial need, but it should provide a good and useful starting point.

Visit **http://admissions.yale.edu/financial-aid**

Creative Team

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Ayaska Fernando, B.S. 2008, Associate Director of Undergraduate Admissions

Steven M. Girvin, Deputy Provost for Science & Technology; Eugene Higgins Professor of Physics & Applied Physics

Jeremiah Quinlan, B.A. 2003, Dean of Undergraduate Admissions

William A. Segraves, Associate Dean for Science Education, Yale College; Research Scientist and Lecturer, MCDB

Rebecca Tynan, Associate Director of Undergraduate Admissions

Kyle Vanderlick, Dean of the School of Engineering & Applied Science; Thomas E. Golden, Jr. Professor of Chemical & Environmental Engineering

Design: Pentagram

Michael Bierut, Pentagram. Senior Critic in Graphic Design at the School of Art, and Senior Faculty Fellow at the School of Management

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Additional photography and images: Robert Batey; Wei Deng and Haifan Lin; Sarah Forrest Photography; Farren J. Isaacs et al., *Science* 15 (July 2011), fig. 2; Robert Lisak; Manuscripts & Archives/Yale University Library; Michael Marsland; NASA/ESA; Rush University Medical Center; Jan Schroers; Harold Shapiro; Lisa Wilder; Gale Zucker

Some of the Breaking News stories were adapted from *YaleNews,* published by the Office of Public Affairs & Communications; some of the Innovation Incubator stories were adapted from the *Yale Bulletin & Calendar* "Innovators" supplement written by **Daniel Jones** and **Bill Hathaway** and also published by the OPAC.

Printed on Mohawk Options, a 100% postconsumer recycled paper manufactured with wind-generated electricity.

The University is committed to basing judgments concerning the admission, education, and employment of individuals upon their qualifications and abilities and affirmatively seeks to attract to its faculty, staff, and student body qualified persons of diverse backgrounds. In accordance with this policy and as delineated by federal and Connecticut law, Yale does not discriminate in admissions, educational programs, or employment against any individual on account of that individual's sex, race, color, religion, age, disability, status as a protected veteran, or national or ethnic origin; nor does Yale discriminate on the basis of sexual orientation or gender identity or expression.

University policy is committed to affirmative action under law in employment of women, minority group members, individuals with disabilities, and protected veterans.

Inquiries concerning these policies may be referred to Valarie Stanley, Director of the Office for Equal Opportunity Programs, 221 Whitney Avenue, 3rd Floor, 203.432.0849. For additional information, see www.yale.edu/equalopportunity.

In accordance with federal and state law, the University maintains information on security policies and procedures and prepares an annual campus security and fire safety report containing three years' worth of campus crime statistics and security policy statements, fire safety information, and a description of where students, faculty, and staff should go to report crimes. The fire safety section of the annual report contains information on current fire safety practices and any fires that occurred within on-campus student housing facilities. Upon request to the Office of the Associate Vice President for Administration, PO Box 208322, 2 Whitney Avenue, Suite 810, New Haven CT 06520-8322, 203.432.8049, the University will provide this information to any applicant for admission, or prospective students and employees may visit http://publicsafety.yale.edu.

In accordance with federal law, the University prepares an annual report on participation rates, financial support, and other information regarding men's and women's intercollegiate athletic programs. Upon request to the Director of Athletics, PO Box 208216, New Haven CT 06520-8216, 203.432.1414, the University will provide its annual report to any student or prospective student. The Equity in Athletics Disclosure Act (EADA) report is also available online at http://ope.ed.gov/athletics.

In accordance with federal law, the University prepares the graduation rate of degree-seeking, full-time students in Yale College. Upon request to the Office of Undergraduate Admissions, PO Box 208234, New Haven CT 06520-8234, 203.432.9300, the University will provide such information to any applicant for admission.

For all other matters related to admission to Yale College, please call the Admissions Office, 203.432.9300.

The Work of Yale University* is carried on in the following schools:

Yale College Established 1701
Graduate School of Arts and Sciences 1847
School of Medicine 1810
Divinity School 1822
Law School 1824
School of Engineering & Applied Science 1852
School of Art 1869
School of Music 1894
School of Forestry & Environmental Studies 1900
School of Public Health 1915
School of Architecture 1916
School of Nursing 1923
School of Drama 1925
School of Management 1976

*For more information, please see www.yale.edu/bulletin.

BULLETIN OF YALE UNIVERSITY Series 110 Number 17 October 1, 2014 (USPS 078-500) is published seventeen times a year (one time in May and October; three times in June and September; four times in July; five times in August) by Yale University, 2 Whitney Avenue, New Haven, CT 06510. Periodicals postage paid at New Haven, Connecticut.

Postmaster: Send address changes to Bulletin of Yale University, PO Box 208227, New Haven CT 06520-8227

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The closing date for material in this bulletin was August 1, 2014.

The University reserves the right to withdraw or modify the courses of instruction or to change the instructors at any time.

Statement of ownership, management, and circulation
Owned and published by Yale University, a nonprofit corporation existing under and by virtue of a charter granted by the General Assembly of the Colony and State of Connecticut, and located in the town of New Haven in said State. Editor: Lesley K. Baier. Editorial and Publishing Office: 2 Whitney Avenue, New Haven, Connecticut.

Extent and Nature of Circulation	*Average No. Copies Each Issue During Preceding 12 Months*	*No. Copies Single Issue Published Nearest to Filing Date*
a. Total Number of Copies (*Net press run*)	5,742	16,000
b. Paid and/or Requested Distribution		
(1) Outside-County Paid/Requested Mail Subscriptions Stated on PS Form 3541	3,881	11,497
(2) In-County Paid/Requested Mail Subscriptions Stated on PS Form 3541	0	0
(3) Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid/Requested Distribution Outside USPS	1,819	4,468
(4) Requested Copies Distributed by Other Mail Classes Through the USPS	0	0
c. Total Paid and/or Requested Circulation [*Sum of b (1), (2), (3), and (4)*]	5,700	15,965
d. Nonrequested Distribution (*By Mail and Outside the Mail*)		
(1) Outside-County as Stated on PS Form 3541	0	0
(2) In-County as Stated on PS Form 3541	0	0
(3) By Other Mail Classes Through the USPS	0	0
(4) Nonrequested Copies Distributed Outside the Mail	0	0
e. Total Nonrequested Distribution [*Sum of d (1), (2), (3), and (4)*]	0	0
f. Total Distribution (*Sum of c and e*)	5,700	15,965
g. Copies not Distributed	42	35
h. Total (*Sum of f and g*)	5,742	16,000
i. Percent Paid and/or Requested Circulation (*c divided by f times 100*)	100%	100%

Bulletin of Yale University
New Haven, Connecticut 06520-8227

Periodicals Postage Paid
New Haven, Connecticut

admissions.yale.edu