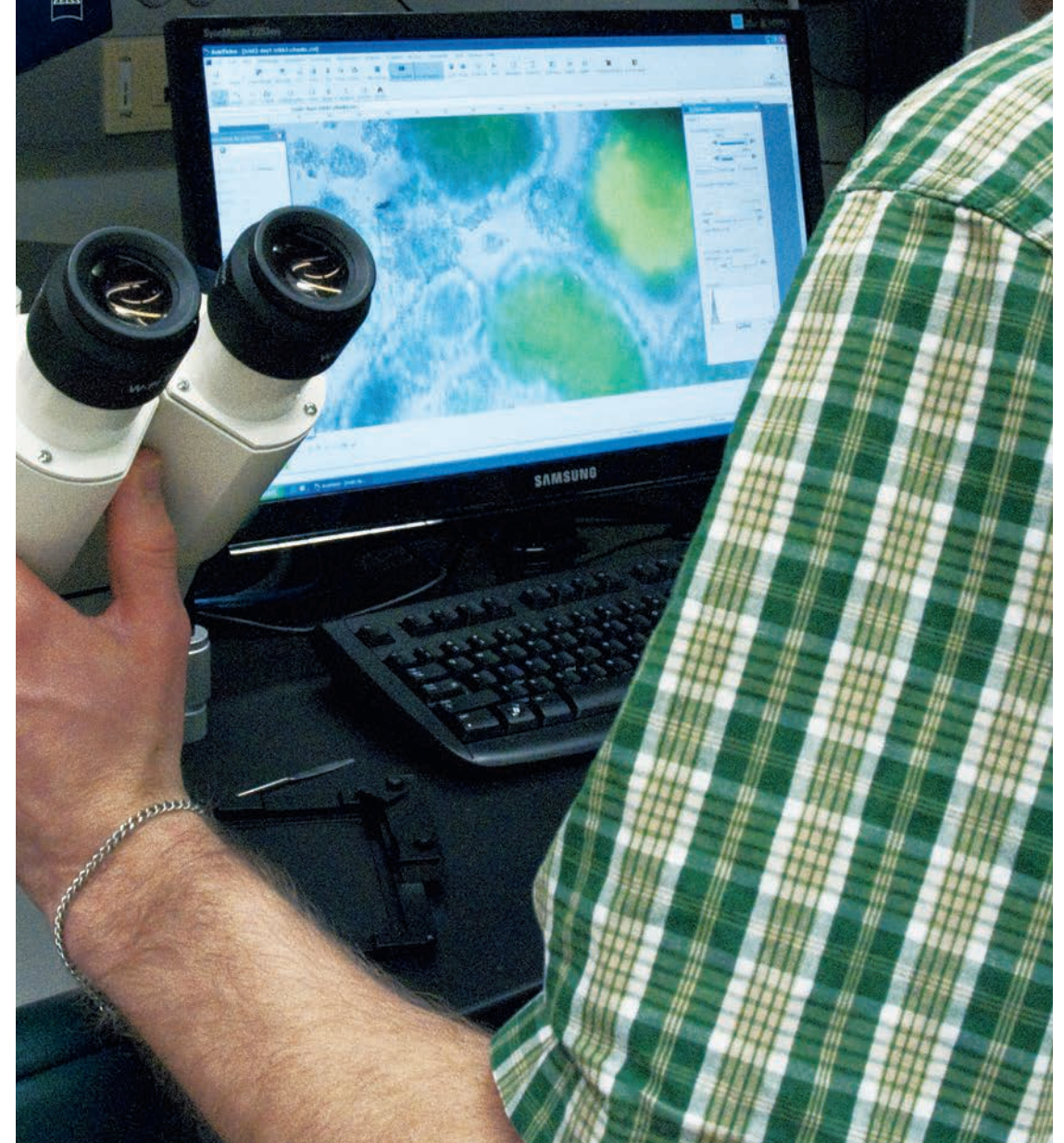


# Science and Engineering at Yale.\*

\* A Guide to Undergraduate Research, Teaching, and Resources

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







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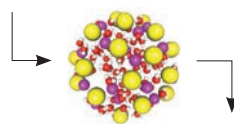
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## *Science and Engineering Leadership in an Age of Opportunity*

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 endophytes 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



## 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, a Yale doctoral student 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*

## 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.”

*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)

## Antifreeze Secrets of the Siberian Beetle

A group of Yale undergraduates has discovered how a Siberian beetle survives some of the cruelest winters on earth. Their work, featured on the cover of *The Journal of Biological Chemistry* in April, began as an undergraduate research project for the International Genetically Engineered Machine (iGEM) competition in 2011. The potent antifreeze protein culled from the beetle, *Rhagium inquisitor*, has the potential to make ice cream smooth and creamy or help preserve transplant organs long enough to save lives. "We were fortunate to find just the right protein to work with and to have mentors here at Yale willing to donate time and resources to discover its structure," said senior Aaron Hakim, co-lead author of the study. The protein possesses an extremely flat surface, an unusual structure that assists it in binding to ice and inhibiting its formation.

## Undergraduate Entrepreneurs

Yale undergraduates headed six of the ten companies that were formed during the 2012 Yale Entrepreneurial Institute Summer Fellowship Program. Presentations to investors and business mentors at the end of this annual summer boot camp included a plan to sell discounted movie tickets, an online autism therapy program, a kit that allows individuals to plan their own funerals, and

a new technology to convert wastewater generated in oil and gas production into valuable chemicals. A panel of four business advisers ultimately chose the undergraduate start-up Panorama Education — a platform for schools to collect feedback from students, parents, and teachers — as one of two winners of the inaugural Yale University investment award.

## Innovation x2

3Derm Systems, cofounded by Yale College engineering majors Elizabeth Asai and Elliot Swart, won a \$150,000 Small Business Innovation Research grant in 2013 from the National Science Foundation for its inexpensive imaging device that aids in the early detection of skin cancers. The company also won the Innovators award at Healthbox Boston, a health technology incubator program.

## First in Racing

Bulldogs Racing, an undergraduate student group sponsored by the School of Engineering & Applied Science that designs, builds, and competes in a hybrid gas-electric racecar, won the 2013 intercollegiate Formula Hybrid International competition at New Hampshire Motor Speedway in May. The Yale team's car was voted best hybrid vehicle overall, with first-place finishes in the categories of efficiency and innovation, fastest hybrid acceleration time, fastest endurance lap, fastest average endurance lap time, and fastest autocross lap — a blistering 49.2 seconds over a 750-meter track.

## Hacking for Social Good

Juniors Seth Thompson and Geoffrey Litt — majoring in Mathematics/Computer Science and Electrical Engineering/Computer Science, respectively — were members of a four-student team whose online platform for cross-language video mentoring, "Take Flight," won the 2013 NYUAD International Hackathon for Social Good in the Arab World.

## Post-Yale Fellowships

Yale undergraduates have been awarded some of the country's most prestigious fellowships for postgraduate study next year. For the first time, two Yale students — Biomedical Engineering major Kavitha Anandalingam and Molecular Biophysics & Biochemistry major Jonathan Liang — have been selected as Churchill Scholars and will study at Cambridge. Anandalingam will work on an interdisciplinary research project on motor control, with a long-term goal of creating neural prosthetic devices that can perform the function of damaged limbs; Liang, who is interested in the role of non-coding RNA in human disease, will work on a project to understand the global genomic profile of breast cancer. Varsity track-and-field athlete Dakota McCoy, an Ecology & Evolutionary Biology major — one of the record eight Yalies to win a Rhodes Scholarship this year — will study zoology at Oxford. Sejal Hathi, a Molecular, Cellular, &

Developmental Biology major and Global Health Fellow, was one of six Yalies to win a Soros Fellowship; cofounder of S2 Capital, a nonprofit micro venture capital fund that invests in young social entrepreneurs in the developing world who are working to improve health care, advance gender equity, and spur economic growth, she will begin medical school at Stanford. And Computer Science major Sam Spaulding — one of six Yale College seniors awarded a National Science Foundation Graduate Fellowship — is off to MIT for a Ph.D. in computer science; for his senior project he developed a robotic system that uses the semantic content of a conversation to learn about objects in the world.

## Top Honors in Rocket Competition

The Yale Undergraduate Aerospace Association became the first team in competition history to safely recover an egg in the Astro-Egg Lander contest at this year's "Battle of the Rockets," sponsored by the American Institute of Aeronautics and Astronautics and Praxis, Inc. The team's YSS *Eli Whitney* rocket reached altitudes of 1,571 and 1,599 feet, and the lander returned the egg safely to the ground both times.

## New Cameroon Water Project

Having won the Premier Project Award from Engineers Without Borders—USA in 2011 for its five-year project to bring clean

water to the Kikoo community in Cameroon, Africa, the undergraduate EWB team has returned to Cameroon to begin a water distribution project in the nearby village of Rohvitangitaa. The students conducted health and topological surveys and developed a memorandum of understanding with the village to lay the foundation for a second successful partnership.

## Course Kudos

The Yale College course Rain Forest Expedition and Laboratory was one of fifteen winners of the Prize for Inquiry-Based Instruction from *Science* magazine. Students, who spend spring break in the Amazon rain forest gathering a class of microbes called endophytes for analysis at Yale over the rest of the term and the summer, have classified new endophytes and been published in scientific journals. Professor and course cofounder Scott Strobel says students in the course pursue Ph.D.s at three times the rate of other Yale science majors, and more than 80 percent continue their research after the course concludes. "They immediately become the world expert in the particular organism they have identified," Strobel says. "They know how it grows, they know how it behaves, they know what its activity is. I think that's a very empowering experience for students."

### 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.

## 70

Undergraduates each year for the past five years have coauthored published research.

# \$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.

## 93%

Admission rate for Yale College graduates to medical schools (national average 45%).

## 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**  
**Astronomy & Physics**  
**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**  
**Energy Studies**  
**Engineering Sciences**  
English  
**Environmental Engineering**  
**Environmental Studies**  
Ethics, Politics, & Economics  
Ethnicity, Race, & Migration  
Film Studies  
French  
**Geology & Geophysics**  
German

German Studies  
Global Affairs  
Greek, Ancient & Modern  
History  
History of Art  
**History of Science, History of Medicine**  
**History of Science, Medicine, & Public Health**  
Humanities  
Italian  
Judaic Studies  
Latin American Studies  
Linguistics  
Literature  
**Mathematics**  
**Mathematics & Philosophy**  
**Mathematics & Physics**  
**Mechanical Engineering & Materials Science**  
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

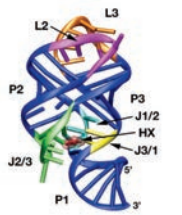
Robert Schoelkopf and Michel Devoret are creating basic building blocks for a future quantum computer. These computers of tomorrow, researchers say, will store, process, and transfer huge amounts of information unimaginably quickly and in spaces that are almost inconceivably small—visible only with an 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."

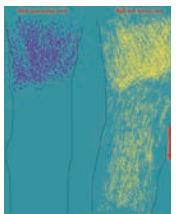


Professors Michel Devoret (left) and Robert Schoelkopf



## New Class of Antibiotics

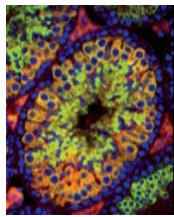
After imaging and "inventing" riboswitches, RNA sequences that can bind and act as sensors of various molecules, Ronald Breaker, Henry Ford II Professor of Molecular, Cellular, and Developmental Biology and professor of Molecular Biophysics and Biochemistry, discovered natural riboswitches in the genomes 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.

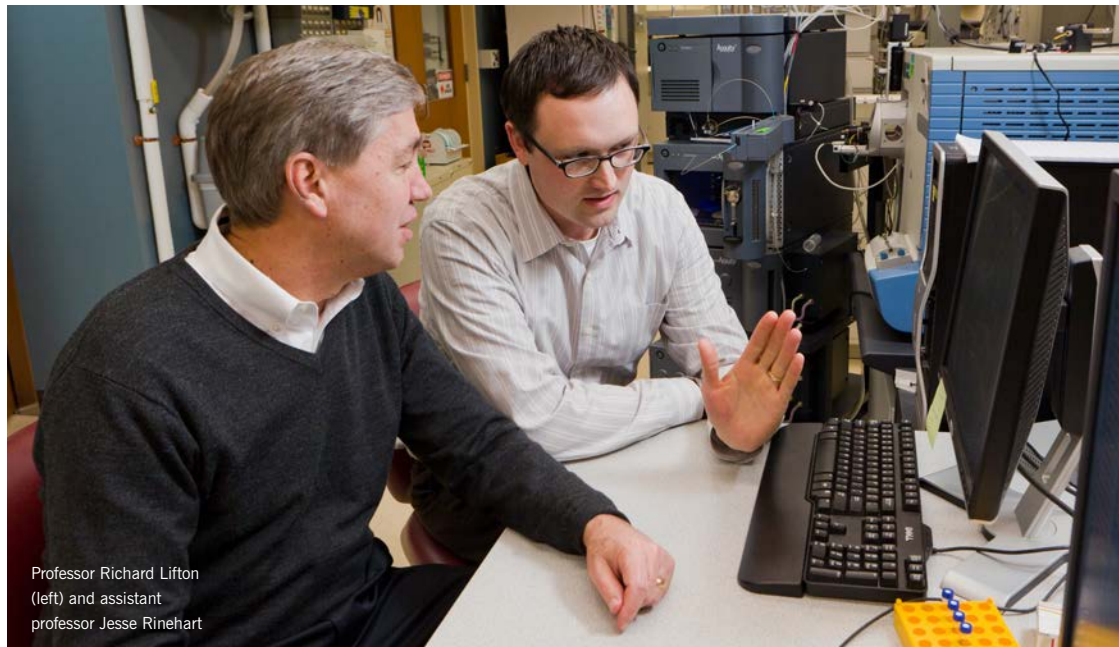
#### Saving Lives through Genetics

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.



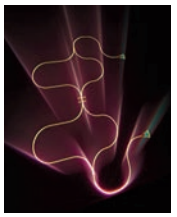
Professor Richard Lifton (left) and assistant professor Jesse Rinehart



#### "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

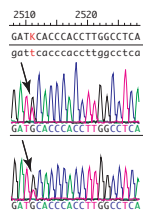
While the force of light is too weak to be used to power devices in everyday use, Hong Tang, associate professor of Electrical Engineering, and his engineering team have found that it can be harnessed to drive machines—when scaled to nano-proportions. This research is opening the door to a future new 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

Frank Slack, professor of Molecular, Cellular, and Developmental Biology, and Dr. Joanne Weidhaas, associate professor of Therapeutic Radiology, are cancer researchers at Yale. They 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.

## Green Chemistry in Policy and Practice

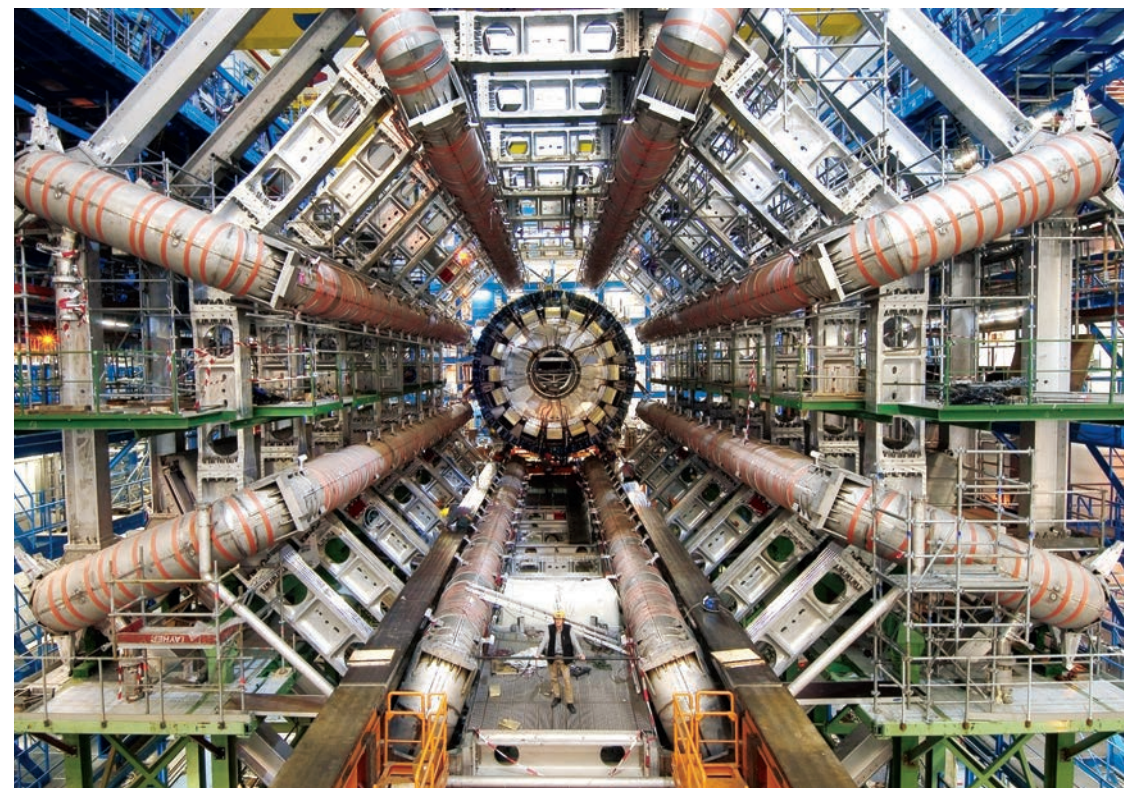
Yale is easily one of the foremost centers in the world for green chemistry and green engineering. Indeed, “the father of green chemistry” is Yale chemist Paul Anastas. In 1991, when Anastas served as chief of the Environmental Protection Agency’s chemistry branch, he coined the term “green chemistry” to describe the design of safer chemicals and chemical processes to replace the use of hazardous substances. Later he led Yale’s Center for Green Chemistry & Green Engineering before being tapped by President Obama to return to the EPA.

One of Yale’s next generation of innovators in green chemistry and engineering is Julie Zimmerman, associate professor jointly appointed to the Department of Chemical and Environmental Engineering and Yale’s School of Forestry & Environmental Studies. 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.

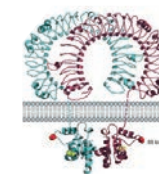


Associate professor Julie Zimmerman and associate professor Jordan Peccia, director of undergraduate studies in Environmental Engineering



## Hunting for New Phenomena with the World’s Largest Atom Smasher

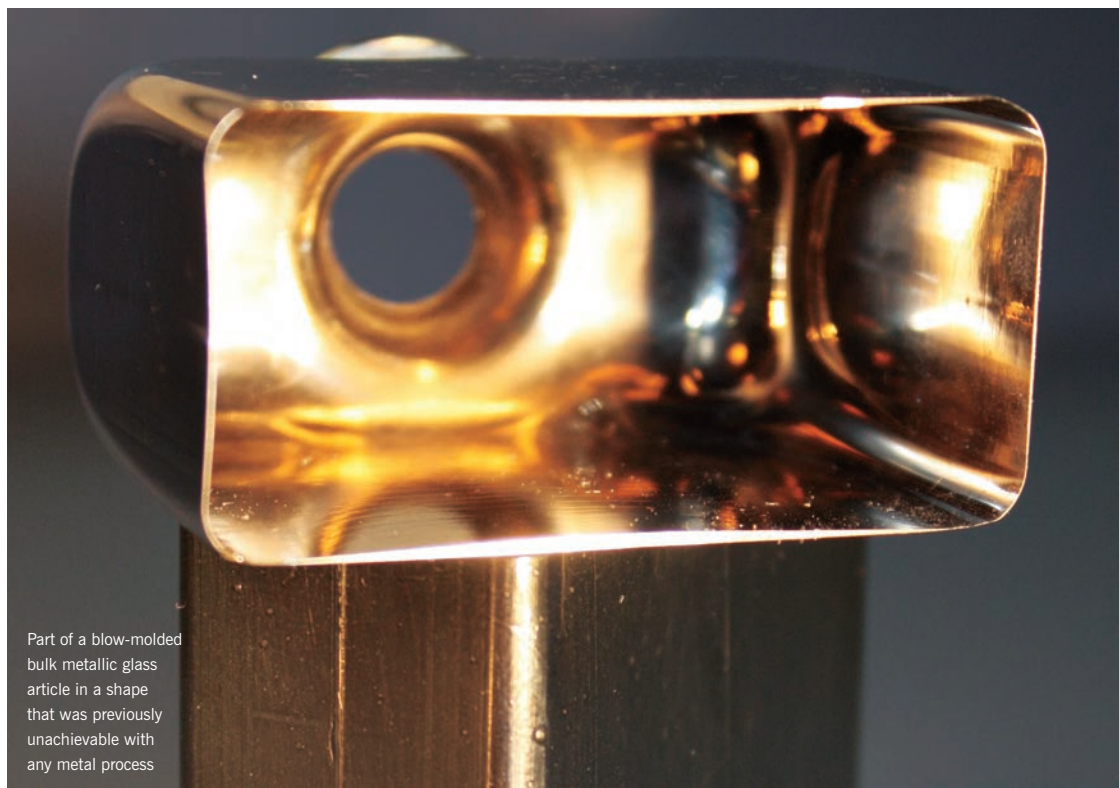
The Large Hadron Collider—the world’s largest atom smasher—was built in collaboration with thousands of scientists from hundreds of universities across the globe, including Yale. Keith Baker, Sarah Demers, Tobias Golling, and Paul Tipton, professors of Physics at Yale, use the Large Hadron Collider to 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 thermo-plastic 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  $\beta$ -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,  $\beta$ -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](http://www.accessscientific.com)

**Achillion Pharmaceuticals**  
Infectious disease therapeutics  
[www.achillion.com](http://www.achillion.com)

**Affomix (acquired by Illumina)**  
Antibody screening technology  
[www.illumina.com](http://www.illumina.com)

**Axerion Therapeutics**  
Therapeutics for neurological diseases and injuries  
[www.axeriontherapeutics.com](http://www.axeriontherapeutics.com)

**BioRelix**  
Antibiotic discovery  
[www.biorelix.com](http://www.biorelix.com)

**C8 Sciences**  
Cognition training software  
[www.c8sciences.com](http://www.c8sciences.com)

**CoolSpine LLC**  
Cooling catheter for cardiothoracic surgery  
[www.coolspine.com](http://www.coolspine.com)

**Great Basin Corp.**  
Point-of-care diagnostics for infectious diseases  
[www.gbscience.com](http://www.gbscience.com)

**Hadapt, Inc.**  
High-speed data analytics  
[www.hadapt.com](http://www.hadapt.com)

**JS Genetics**  
Genetic tests  
[www.jsgenetics.com](http://www.jsgenetics.com)

**Kolltan Pharmaceuticals**  
Cancer therapeutics  
[www.kolltan.com](http://www.kolltan.com)

**MiraDx**  
Cancer diagnostics  
[www.miradx.com](http://www.miradx.com)

**M/Z Diagnostics**  
Diagnostics on mass spectrometry platforms  
[mzdiagnostics.com](http://mzdiagnostics.com)

**New Haven Pharmaceuticals**  
Therapeutics for gastrointestinal disorders  
[newhavenpharma.com](http://newhavenpharma.com)

**NovaTract Surgical**  
Minimally invasive surgical products  
[www.novatract.com](http://www.novatract.com)

**Oasys Water**  
Cleantech for seawater desalination  
[www.oasyswater.com](http://www.oasyswater.com)

**P2 Science, Inc.**  
Green surfactants  
[www.p2science.com](http://www.p2science.com)

**Prevention Pharmaceuticals**  
Over-the-counter medicines  
[www.preventionpharmaceuticals.com](http://www.preventionpharmaceuticals.com)

**Rachiotek LLC**  
Spine stabilization device  
[www.rachiotek.com](http://www.rachiotek.com)

**Rib-X Pharmaceuticals**  
Antibiotics for drug-resistant infections  
[www.rib-x.com](http://www.rib-x.com)

**SilviaTerra**  
Remote-sensing forest management software  
[www.silviaterra.com](http://www.silviaterra.com)

**Sonic Golf**  
Training device for golf  
[www.sonicgolf.com](http://www.sonicgolf.com)

**VaxInnate**  
Novel vaccines for infectious diseases  
[www.vaxinnate.com](http://www.vaxinnate.com)

**Vidus Ocular (acquired by OPKO)**  
Device to treat glaucoma  
[www.opko.com](http://www.opko.com)

**Vutara**  
High-performance microscopy devices  
[vutara.com](http://vutara.com)



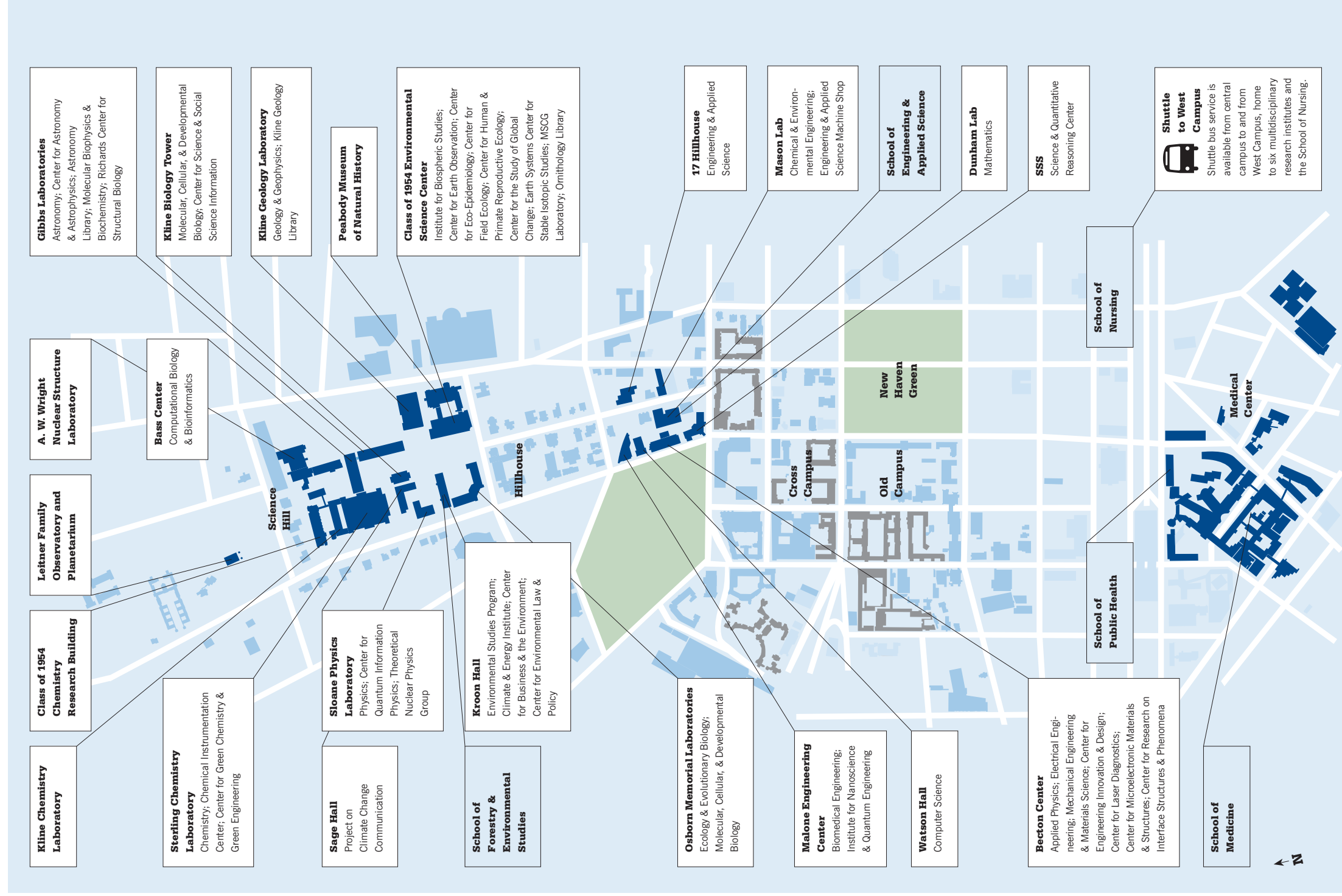
# Connected Campus.

*(Designed for easy access)*

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.

## 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.**





# 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.

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 promises a unique design and engineering experience.

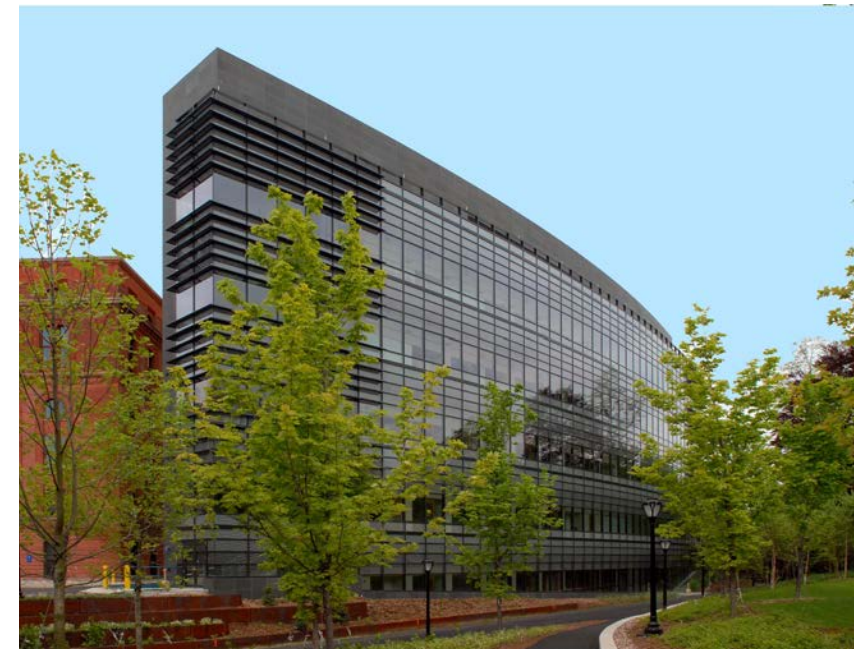
"The center empowers Yale students to realize their creative vision," says director Eric Dufresne, John J. Lee Associate Professor of Mechanical Engineering and Materials Science. "The center will help students bridge the gap between formal course work and the real challenges that face society."

## 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

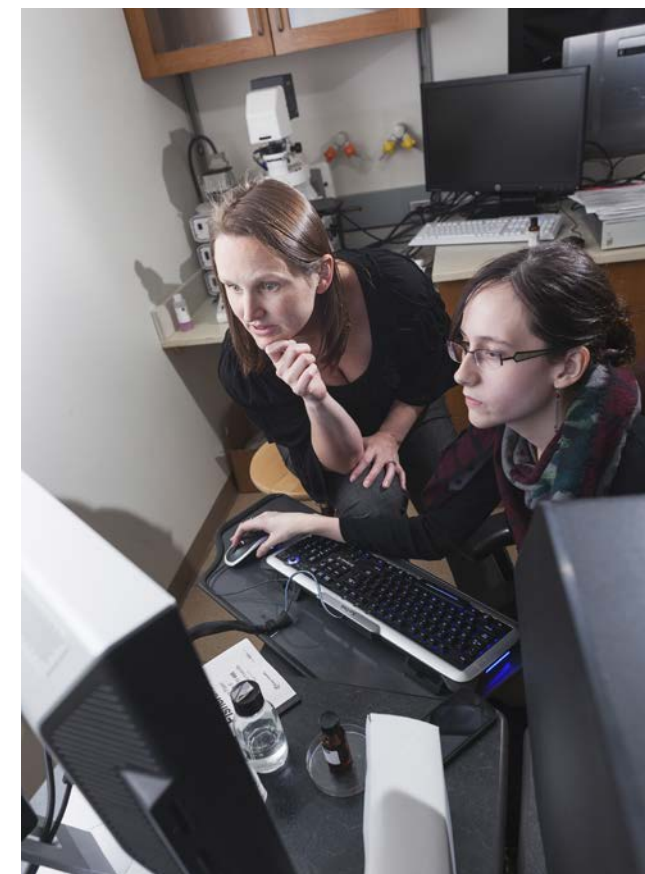
BME-Economics major Michelle Tseng is working on the implantation of engineered lung tissue into rats, with the long-range goal of creating a tissue-engineered lung.

### 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

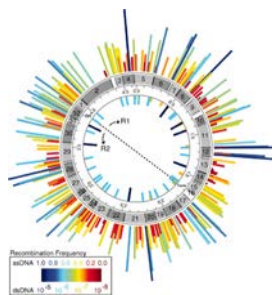
BME major Nimit Jain is developing mathematical models to analyze MRS data to track metabolism in the human liver.



"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 multidisciplinary 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.

### BioDesign Institute

Connecting cell biology and engineering, focusing specifically on the design principles that unite living and synthetic materials at the nanoscale.

### 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.

### 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

**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.”



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.”

**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 Schmittenmaer** “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

**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.”

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.”

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

**Charles Schmittenmaer** “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. Schmittenmaer**  
Professor of Chemistry

Professor Schmittenmaer’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; Physical Chemistry with Applications in the Physical Sciences I



**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)*

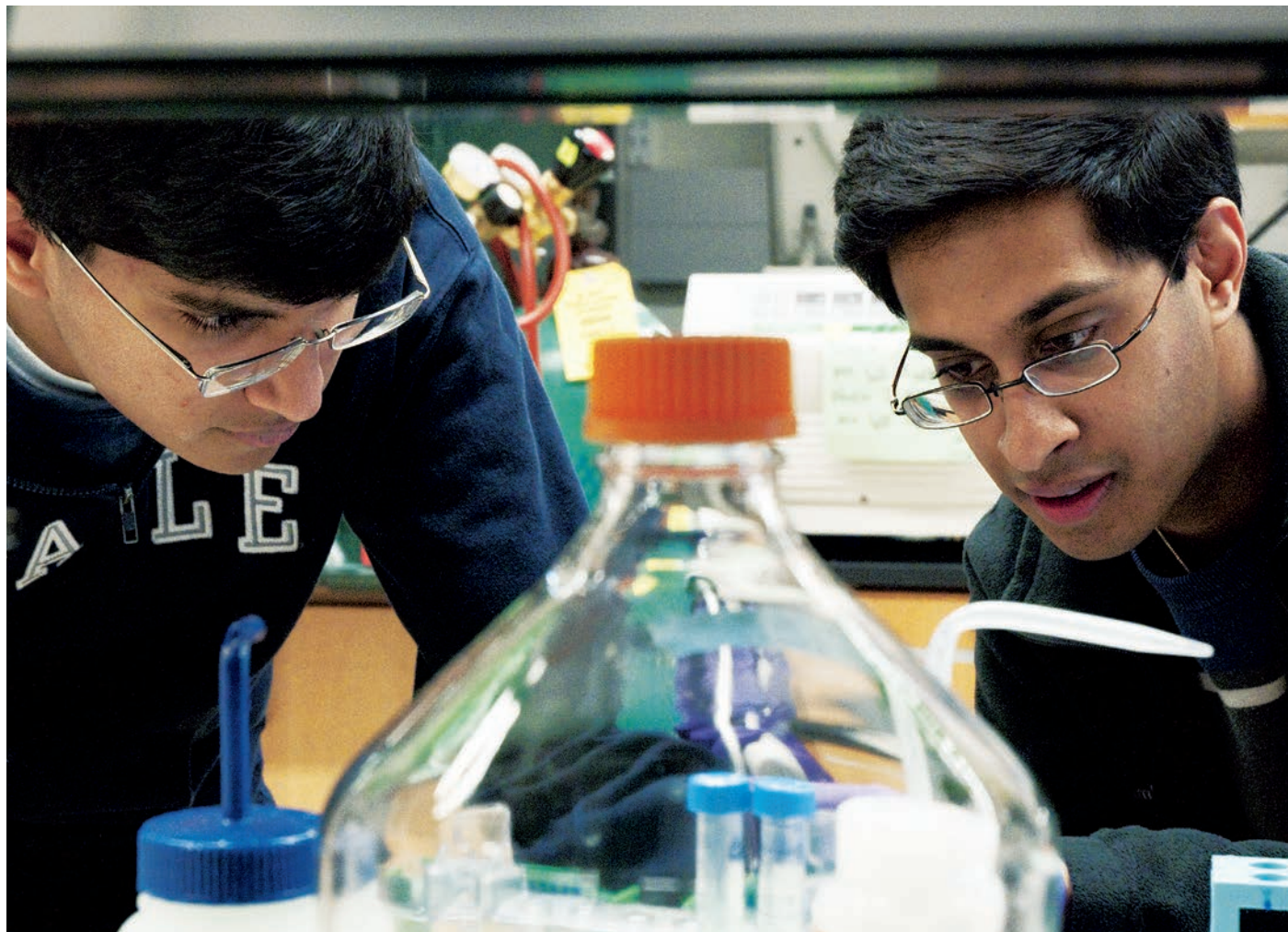
many snags they may encounter; and they need to be able to communicate their results to others, preferably in an articulate and exciting way.”

**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

**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.”

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** “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



**John W. Harris**

Professor of Physics; Chair of the Yale Science Council;  
former Director of the A. W. Wright Nuclear Structure 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

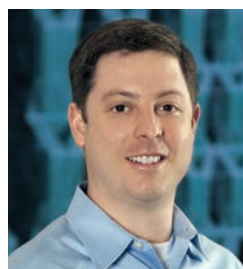
General Physics Laboratory;  
Quantum Physics and Beyond (for nonscientists); Modern Physical Measurement



# 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.



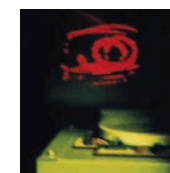
### Persistence and Patent

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.

"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."

### 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

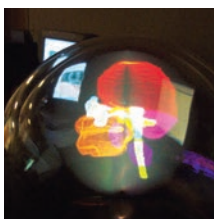
Things finally started to turn around. I met a journalist known for chronicling the happenings of Silicon Valley. After watching an image of the HIV virus rotating in space projected from my 3-D prototype, he wrote an article for the *Wall Street Journal* on the invention and my difficulty finding funding.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



### 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.

### 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

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

**John Fenn**, Chemistry, 2002 (Ph.D. from Yale 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)





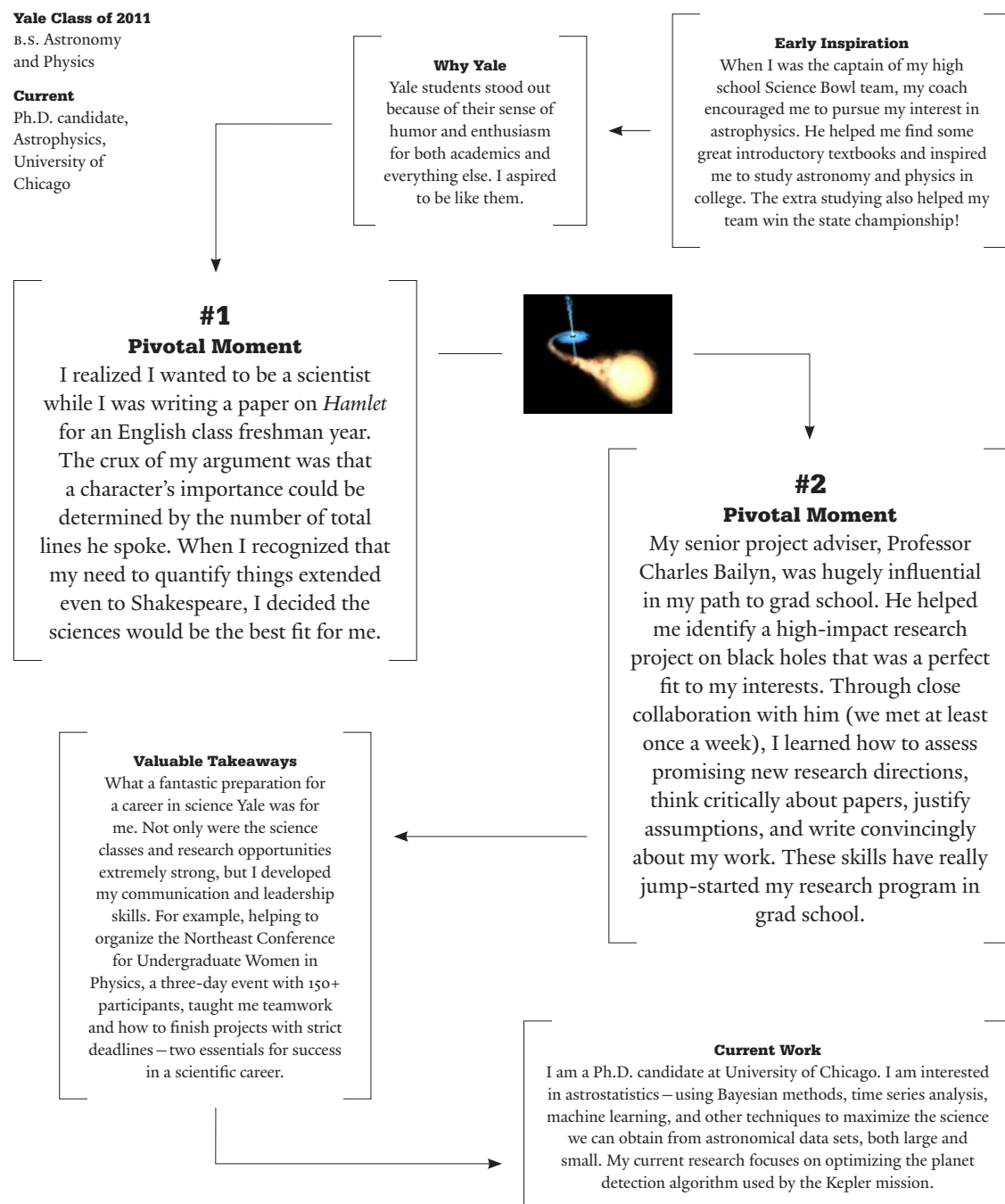
**Laura Kreidberg**

**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.”



**Daniel Rosenfeld**

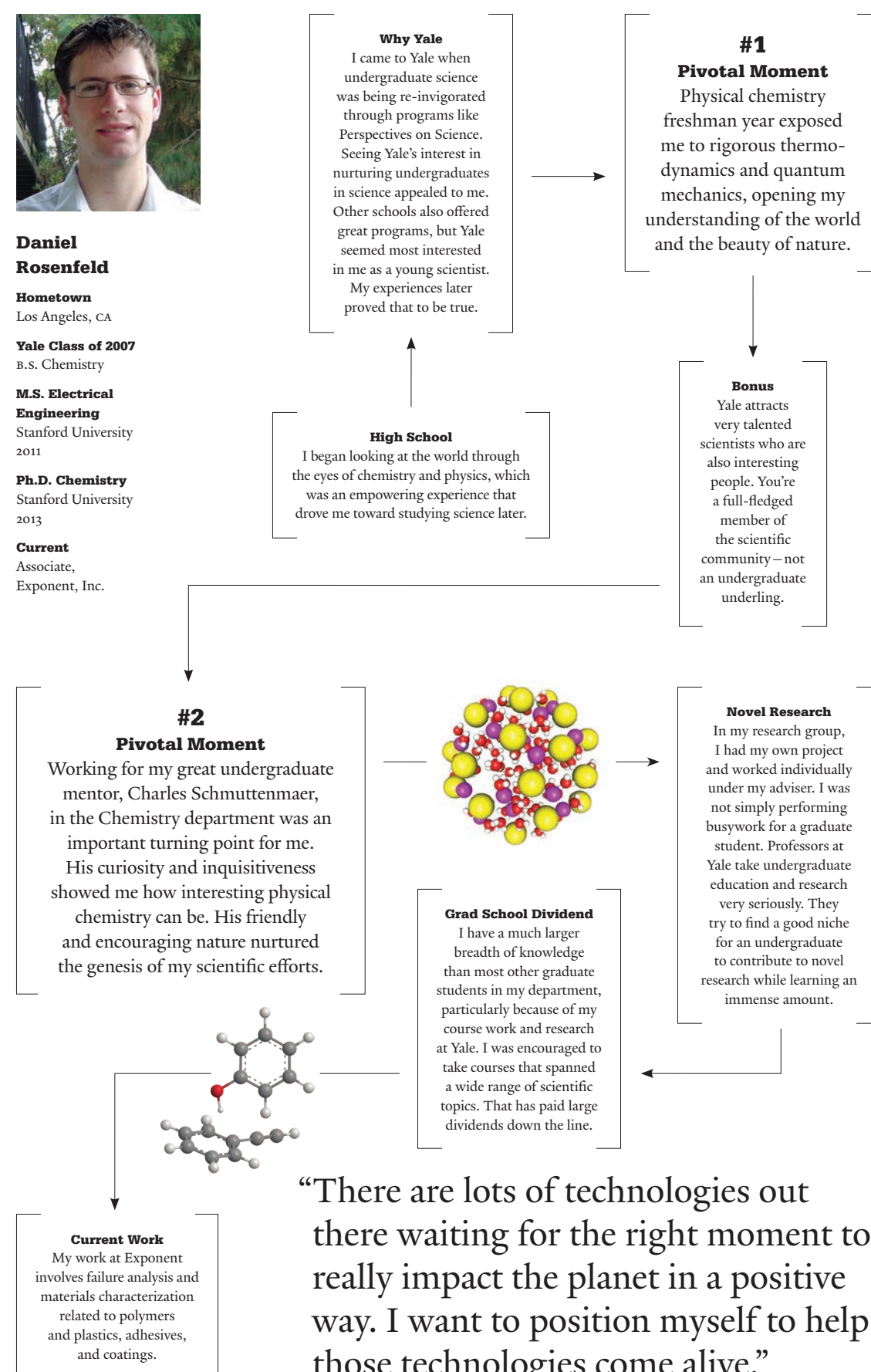
**Hometown**  
Los Angeles, CA

**Yale Class of 2007**  
B.S. Chemistry

**M.S. Electrical Engineering**  
Stanford University  
2011

**Ph.D. Chemistry**  
Stanford University  
2013

**Current**  
Associate,  
Exponent, Inc.







\*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 request or download our insider's guide to all that is Yale at: [admissions.yale.edu](http://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.** Study groups and 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.

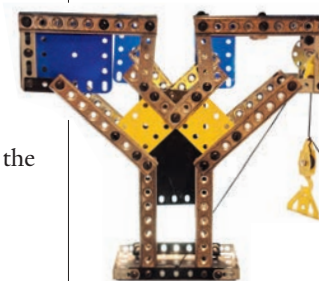
## Pursuits.

**Bulldog! Bulldog! Bow, Wow, Wow!** Playing



for Yale — The Game, the mission, the teams, the fans, and, of course, Handsome Dan.

**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.



### 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.





# 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 is approximately \$39,750, 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%.*
- > *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 2013–2014**

Tuition	\$44,000
Room	\$7,430
Board	\$6,070
Books & personal expenses	\$3,400
Total	\$60,900

**Yale Net Price Calculator**

[admissions.yale.edu/yale-net-price-calculator](http://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**

- Jeff Brenzel**, B.A. 1975, Dean of Undergraduate Admissions, 2005–2013
- Ayaska Fernando**, B.S. 2008, Senior Assistant Director
- 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
- 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
- Yve Ludwig**, B.A. 2000, M.F.A. 2005
- Additional design: Chika E. Ota**, B.A. 2011, Rollins Fellow, Office of the University Printer
- Text: Andrea Jarrell; Liz Kinsley**, B.A. 2005
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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, 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 covered veterans.

Inquiries concerning these policies may be referred to the Director of the Office for Equal Opportunity Programs, 221 Whitney Avenue, 203.432.0849. For additional information, see [www.yale.edu/equalopportunity](http://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 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](http://www.yale.edu/bulletin).

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

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Science and Engineering at Yale College 2013–2014

