Not Just Another Class:
Berkeley's Undergraduates Perform Research in Graduate Labs

By Greg Butera

One was the first author of a paper published in a scientific journal. Another is ultimately responsible for redesigning the equipment for her experiment. A third presented a paper at a conference. Not unusual for a graduate student, but these are stories told by Berkeley sophomores, juniors, and seniors.

Students in the College of Chemistry experience the curriculum and award-winning faculty that have made the College of Chemistry a top-rated institution in the United States. Some of the more enterprising students take an extra step, finding positions in the research groups that consistently make Chemistry and Chemical Engineering among the highest ranked graduate programs in the nation.

Herb Strauss, Associate Dean for Undergraduate Students, says that his office is available to assist students looking for research projects. "The College strongly encourages undergraduate research, especially if the student plans to go on to graduate or medical school," says Strauss. Recommendations from a close working relationship with a professor are very useful in the graduate admissions process, he adds.

Around 20-25 percent of our undergraduates (about 50-70 in each department) take advantage of this opportunity each semester. Students from majors outside of the College of Chemistry also do research with our professors, and some College majors do research in physics, engineering, molecular and cell biology, or other units on campus. "We also have a large number of international students who come to work in our labs doing research projects for the last semester of their undergraduate degrees," said Chemical Engineering Department Chair Harvey Blanch, "from Germany, Sweden, Norway, and other countries, which adds an international flavor to the labs."

However, several professors agreed that research is not for everyone. They suggest that some students are better served through a co-op with industry, or summer internships. The students who succeed in research are disciplined, unafraid to ask questions, and willing to put in the time every week to do the experiments while dealing with a rigorous Berkeley schedule, even when exam time comes around.

Most students put in 10-20 hours a week, sometimes more. It is more than having just another class in your schedule. "If you really like the subject, research is motivating," says George Borg, a student in Jon Ellman's organic chemistry group. "But the balance of research and classes can be stressful." He admitted making many sacrifices to focus on his research, taking fewer electives than he'd have liked. Some weeks, he said, he would log 30 hours in lab. "I would race around the lab, set up my experiment, go to class, and then return for the results," said Borg.

Failures are certain to occur, and successes require blood, sweat and tears. The potential for learning is huge. However, says Chemical Engineering Professor Jay Keasling, "all science and engineering projects have the potential for failure, a concept that is difficult, if not impossible, to teach in a classroom."

Wilson Mok, a chemical engineering sophomore working in Chemistry Professor Ron Cohen's lab, says that what he has learned most is to be independent. "In classes we

> *"At Berkeley, the focus is on your future. Summer internships and research have helped me understand and decide my future."*
>
> **Samantha Ozuna**

are given work, but here you have to provide your own solutions," he said. "My topic is very broad and open, so you have to break it down, set small goals. You don't realize this when taking classes. It can be very time consuming, since there are unlimited amounts of background information" that can be used in the research.

Cohen says undergraduates can do just about everything graduate students can do, though it takes them longer. "The key is whom to ask, how to learn what the project is," said Cohen, "and to create new knowledge and learn from other people."

It may be surprising, but students with an outstanding GPA don't always make the best researchers. Since the ability to do research involves working with your hands and a disciplined approach to solving problems, the classroom is not always the best measure of a student's potential. This is one "class" where test-taking and memorization skills won't help. It can be repetitious, like a job, but it is mainly what the student puts into the experience that counts. Opportunities abound for students who are willing to tough out the challenge. They can jump start their careers while working on their bachelor's degree.

Many professors admit that their own research experience as an undergraduate persuaded them to follow the academic path. "Most academics started out in undergraduate research, and discover that playing in a lab is a lot of fun, and that someone may even pay you to do it," said Chemistry Professor Ken Raymond. "I was going to medical school until my experience," added Keasling.

Students often are not quite sure what to do when they graduate. Undergraduate research helps them explore what graduate school might be like and provides closer contact with faculty. Since many undergraduates are paired with graduate students or postdocs, it also provides an important mentoring opportunity for future academics being trained in the graduate program.

Undergraduate research teaches critical thinking and organizational skills, giving students the opportunity to find their motivation, to develop and speak about a technical project, and to write a student paper. Unlike in classroom research, in a research program a student is performing science that has never been done before. Students learn how to fix equipment and experiment with theory. Many Berkeley undergraduates have published papers in scientific journals as a result.

The projects given to undergraduates tend to be smaller, more defined projects than those done by grad students. They aren't open ended, usually having an endpoint so the student isn't completely lost. "Since they don't have the experience with the literature or the field that grad students or professors would have, we have to define it a little better," said Keasling, who typically oversees 10-12 undergraduates each semester. But to their credit, "undergrads are not afraid to do experiments," he said. "They have no bias, and they aren't predisposed to some theory like some of the rest of us are."

Berkeley students are smart and work hard. They put in long hours on top of a rigorous course schedule. "I've published papers with undergrads, without any grad students involved," said Keasling. Chemistry Professor Jon Ellman adds, "Having undergraduates reinstills our enthusiasm because they are so enthusiastic, making it lots of fun for me and my grad students." It can be a fun, clublike atmosphere in the lab. Working with graduate students having a few more years of experience is like having an older sibling help you along, says Borg.

Ozuna (center), with her grad student mentor, Cliff Wang, and advisor Jay Keasling.

In Keasling's lab, most undergraduates choose experimental projects. But in his and in other labs, some students choose to do computer modeling or simulations. There are opportunities for students interested in any aspect of chemistry or chemical engineering, if they look hard enough.

Ken Raymond is also one of two vice-chairs of the chemistry department, who are in charge of all graduate admissions. "We looked at the 15-20 percent of grad students who don't finish their Ph.D., and we found that people with undergraduate research experiences are the least likely to drop out," said Raymond. "Voluntary drops in first year are often because people just don't like doing research."

The freshman seminar (Chem 98), says Strauss, introduces new students to a diverse group of faculty members and research areas in the college that may be of interest to students. "This is to both help define the fields of chemistry and chemical engineering," he said, "and help students determine a direction for their studies."

To find a research project, students are encouraged to start with professors teaching their classes, their advisor, or Dean Strauss. Information on faculty research is also available in graduate publications and on faculty web pages. Each professor has a different capacity to take students, since lab space can be a problem. However, there was universal agreement that any student wanting an experience will be able to find one somewhere. Ellman takes only four students per semester, which is not sufficient to accommodate all who are interested. However, he notes that there are great research opportunities at the plethora of biotech companies in the Bay Area for co-ops and summer research opportunities.

Does it take away from coursework? It depends on the student. "If they have time, by all means those interested should do it," says Strauss. Most students take it for credit during the semesters, and often win fellowships or get paid by their research advisor to work during the summer. ♦

Training for the future...

Samantha Ozuna's advisor suggested she try a research project, so she found a project in Professor Keasling's biochemical engineering lab that involves genetic engineering and the metabolism of cadmium, a heavy metal that is toxic in biological systems. She has studied the expression of the enzyme cysteine desulfhydrase in *E. coli*, which breaks down cysteine in the cell and produces hydrogen sulfide (H_2S) and other products. Cadmium reacts with H_2S to produce cadmium sulfide (CdS), which then precipitates on the outside of the cell, removing the toxin.

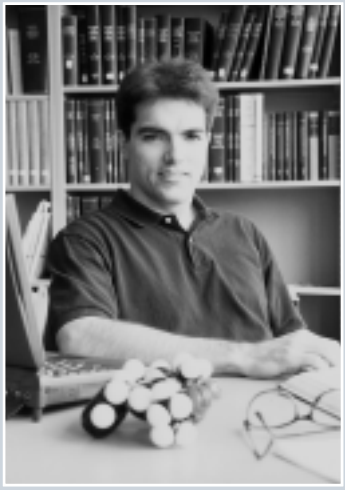
"We did growth experiments to figure out if the gene expression actually results in the removal of cadmium," she said. They analyzed cadmium ion concentration, growth of cells, and the solid CdS, determining that cadmium indeed decreases as CdS levels increase, and that the cells can be genetically engineered to increase the removal of Cd ions.

"It's fun in Jay's group—it's comfortable, not like work," said Ozuna. "I just treated the research as I would another class." She became good friends with her mentor, graduate student Cliff Wang. "Cliff gave me lots of responsibility," she said., even though she felt it took a long time for her to figure out what they were doing.

"At Berkeley, the focus is on your future," she says. "Summer internships and research have helped me understand and decide my future." Ozuna has taken advantage of many opportunities at Berkeley: she spent her third year abroad in Costa Rica, "studying Spanish and traveling in Central America," she said. "It was a great break from the science." She also presented a paper on her research at the California Alliance for Minority Participation, a statewide symposium for undergraduate researchers in Santa Barbara. She won the award for Exceptional Achievement in Research—Oral Presentation, Engineering.

This semester, Ozuna started an internship at Bayer, and she finds that her training has been in areas where she already has experience. "Learning how to operate in a laboratory setting, how to analyze data and other basic lab skills are important tools that you would otherwise have to learn from scratch," says Ozuna. She will be working to insert genes into hamster kidney cells to express human protein factor 8, a drug which hemophiliacs need to help clot their blood. She has an offer to work for Merck & Co., Inc. in Pennsylvania after graduating this spring, working in the cell culture development department that focuses on the production of vaccines. ♦

Lasting Effects of an Undergraduate Research Experience



˝At Berkeley, students need ambition to find a research position in a lab,˝ says Justin Dubois, (B.S. Chem, ´91). ˝and once they get it, they have to prove they will stay and work hard. Other undergrads covet their positions.˝

Justin DuBois, now an assistant professor of chemistry at Stanford, remembers bugging every TA who would listen for a job in the summer. "I loved the lab and would have been happy just to wash dishes," said DuBois. When he started, he felt it was hard to find research positions in labs. But by the time he graduated, there were many students talking their way into lab positions.

"The experience really prepared me for grad school," said DuBois. As an undergraduate researcher, he noted that he had different goals, but his routine in the lab was similar.

He obtained a position in Ken Raymond's lab working on metal ion recognition, and said that the experience convinced him he wanted to be a professor like Raymond. "I wasn't even a science major until I started my research," he said. "It was hugely influential. I had phenomenal teachers in chemistry."

His research involved building ligands that would recognize metal ions because of their shape. "The vanadyl ion is more like an ellipsoid than a sphere," explained DuBois, "and we tried to design, synthesize, test, and redesign systems to recognize selectively, and bind with it."

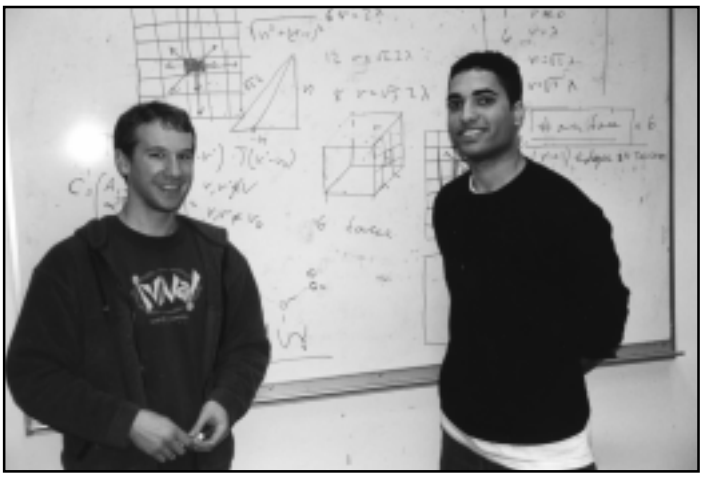
Wanting to continue work in the same field, he realized that a degree focusing on synthetic organic chemistry would assist this research. "I felt at the time that learning how to synthesize complex molecules would provide me the tools to address problmes in other areas of chemistry," he said, "including the kind of work that Ken does." He earned his Ph.D. in organic chemistry at Caltech, but he moved back to bioorganic and inorganic chemistry in his postdoc at MIT.

"I think my undergraduate experience made me a better professor," said DuBois "I can remember what it's like to balance classes and research, and better appreciate what my students are going through." At Caltech, MIT and Stanford, DuBois has mentored undergraduates in the lab, and he has two in his group this semester. "I am hoping to convince pre-med majors to go to graduate school in chemistry," he said. "As a grad student at Caltech, I worked with one undergrad who has gone on to grad school at Harvard. To me, that was one of the greatest rewards of my graduate experience."

He thinks students should be encouraged to work in a graduate lab, but he agrees this experience isn't for everyone. Not every graduate student is meant to be a mentor—mentoring an undergrad is not easy, he said, and can take time away from a graduate student's research. "In the end, however, it can be extremely rewarding to see them develop into productive members of the research group," he said.

DuBois only recently took his job at that other well-known Bay Area university. "The best thing that ever happened to me was that Stanford rejected me as an undergraduate and that I got a Berkeley education instead," said DuBois. "I have such great memories of Berkeley, roaming the halls of Latimer."

Berkeley's faculty certainly would have benefited from having DuBois' dynamic personality, exciting research, and enthusiasm for teaching. While he decided to go to Stanford (which he said was one of the hardest decisions he's ever made), perhaps one can take solace in the fact that Stanford's chemistry department is quietly turning into Berkeley's South Campus: he joins former Raymond lab members Dan Stack and Keith Hodgson, who also teach there.♦



Graduate student Phillip Geisler (l) works as a mentor for C. Brian Roland (r) in Chandler's theoretical research group.

It's Possible (in theory...)

C. Brian Roland is a senior looking to graduate this May. He decided to pursue research because he planned to go to medical or graduate school, and he convinced one of his chemistry professors, David Chandler, to take him on. "He taught my favorite classes covering quantum mechanics and statistical mechanics," said Roland. "I liked his style of teaching, and his particular understanding of physical phenomena." He wants to study the physics of biomolecules and was very interested in the applications of theory to technology. "I like that I can contribute both intellectually and practically to society (through theoretical research)," said Roland.

Chandler thinks that undergraduate research is valuable. "You can't get from books or courses what you need, to learn what scientific discovery is like," he said. "You need to watch how most of your effort doesn't work, and need to stretch your intellectual power to succeed."

At the same time, he doesn't often take undergraduates in his own lab because their math and computer programming skills are not developed enough after the junior year to have a significant role in his theoretical research. "Brian is one of the few students I thought would be productive in my lab," said Chandler. "He's in the same league as the best first-year grad students."

This past summer, Roland learned to program basic code for molecular dynamics. Now he is using that computer knowledge on a project that simulates the positions of particles in a system at certain points in time.

Chandler's lab does a great deal of work studying hydrophobic effects of molecules in liquid systems. Roland's project, which studies hydrophobic effects—manifestations of the effective attraction between apolar species in water—sprang from a bet between Roland's graduate student mentor Gavin Crooks and Chandler. They are trying to prove the existence of a controversial phenomenon: a drying layer created in liquid systems.

"Experimentalists think that a drying layer doesn't exist near a liquid-solid or liquid-liquid interface," explains Roland, but Chandler (via the Lum-Chandler-Weeks theory) says it does. Chandler, Roland and Crooks developed a simple model that would suggest an answer, though they were unsure what that answer would be. Roland will present his findings at the end of this semester.

> ***"I really want to learn from these guys. I can read a book anytime, but I want to learn as much as I can from the group members while I'm still here."***
>
> **C. Brian Roland**

Experiments have shown that macroscopically sized plates made of an apolar material, placed close to each other in water, are indirectly attracted to each other by the movement of water between the plates. "This is caused by the fact that water density near the plates depletes, creating a vapor layer or drying layer," explained Roland, "which enables the correlated motions of water." He is now working with a computer algorithm that tries to understand the behavior of a simple system, such as a droplet of oil in water.

Roland uses Monte Carlo simulations of lattice models. His algorithm attempts to predict the standard behavior of the system by estimating the probability of occurrance of every combination of how particles in the system can be organized according to system energy states. This is useful, he says, because "proteins have hydrophobic and hydrophilic regions, and may act like the plates in the other experiment. This phenomenon may describe a previously unknown force important to the folding of proteins," which, if understood, could permit the development of better biotechnology.

"This research experience is a tremendous help for my career," says Roland, who is now certain he is going to graduate school for theoretical chemistry, perhaps at MIT, Cornell, Stanford or Harvard next fall. "It has helped me develop connections in the field and determine my direction." ♦

Getting Published

"Research is more creative than taking courses," says George Borg. "Not like classes with deadlines, but personally motivating, allowing you to be creative." He, like several of the other students interviewed, had a class with his research advisor. His enthusiasm for organic chemistry won him a research position in Ellman's lab.

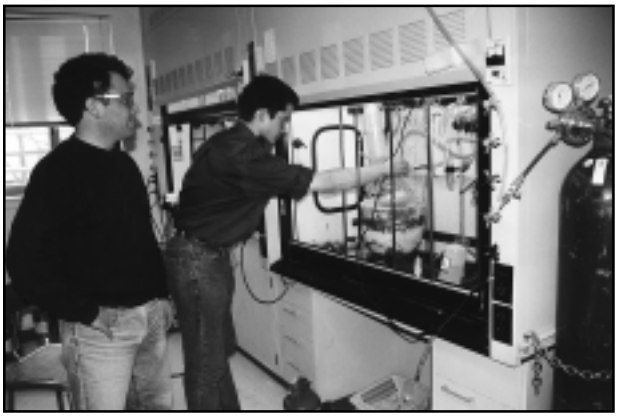
Borg probably isn't your typical student. He decided early that he wanted to be a synthetic organic chemist, and he decided to graduate in only seven semesters to free up a semester enabling him to concentrate on research before going to graduate school at Harvard, MIT, UC Irvine, or Stanford next fall. Last year he won a scholarship from Pfizer Pharmaceuticals to support his research. He presented his findings at Pfizer in October with 15 other scholarship winners. He's also been the first author on one paper published in the journal *Tetrahedron Letters*, and he is finishing a follow up project that is sure to get him another published paper, this time without a graduate student sharing the credit.

His first project was closely supervised by graduate student Derek Cogan. "We would discuss what experiments to do, how to do them, and then discuss my results," explained Borg. He studied a process to make highly enantioselective production of amine compounds. Ellman explained that amines are an important functional group in 74 percent of all pharmaceuticals. The reaction that they developed produces single enantiomers, compounds having a specific molecular orientation that is the most biologically useful.

> ***"At Berkeley, you can work in a group performing cutting-edge research. It takes you outside of textbooks and puts you in the center of real life."***
>
> **George Borg**

"We designed reactions to give the amines biologically active compounds," said Borg. They manipulated many different reagents, solvents, temperatures and concentrations to optimize the reaction, and examined whether the reaction would work with many different compounds. Since Cogan's graduation, Borg is working on a related project, making unnatural amino acids in an enantioselective fashion using a similar reaction pathway.

He's always been attracted to academia (his parents are both professors) but his research experience was his first real contact with both professors in his field and industry. "Now I know a lot more about what the world of chemistry entails, and what my options are," said Borg. "Research teaches you chemistry on a day to day basis, and teaches you what questions to ask, and what kind of experiments to do on chemical systems." ♦



Borg (r) working in a fume hood, as advisor Jon Ellman looks on.

Not Just for Upperclassmen

Wilson Mok is new to research. As a chemical engineering major, he found he was attracted to atmospheric research, and secured a position in Professor Ron Cohen's chemistry lab. "I'm not sure about my future, so I want to learn about the different aspects of chemistry and engineering," said Mok, thinking that research would give him a different perspective from classwork. He has yet to choose his concentration in chemical engineering, but he thinks it will be biotechnology or materials. But when he began the project as a freshman, he said, it was easier to connect with ozone and pollution than other topic areas in chemical engineering.

His project studies ozone pollution in the troposphere. Mok, along with grad student mentor Michael Dillon, is working on developing models to interpret data of concentration measurement of trace gases to understand ozone pollution and production. "NO_2 is a precursor of ozone. There are no really accurate measurements of NO_2 accumulation," he said. They built a computer model which includes light in the atmosphere, concentrations, rate constants, air layers, and the chemistry going on in each layer. The goal is to use their knowledge of the chemistry in the atmosphere and measurements of other gases in the atmosphere to model NO_2 concentrations, that they have not been able to measure until last year. "Basically, this info will help us gain a more complete picture of the chemistry in the atmosphere," said Mok.

> *"I'm not sure about my future, so I want to learn about the different aspects of chemistry and engineering."*
>
> **Wilson Mok**

"We are now using a more complex algorithm and are in the process of comparing our model results with actual measurements." If scientists can understand how NO_2 acts in the atmosphere, ozone production will be better understood.

Mok and Dillon are also designing a calibration system for lab instruments that use lasers to measure trace gases in the atmosphere. They are building a system in which gas diffuses through a membrane in precisely controlled concentrations. Mok worked on the computer algorithm that controls heating of the unit to keep it at a constant temperature.

Mok says the chemistry itself is challenging, but he is using many skills in this research that will apply to a career in chemical engineering. "I am actually using more engineering skills than I anticipated: computer programming and modeling, problem solving, using physics and math to analyze data." ♦

Sophomore Wilson Mok (right), discussing his computer model with graduate student mentor Michael Dillon.

Doing it Yourself

"I've always wanted to do research," says Riham Morcos, a junior working in Chemical Engineering Professor Clayton Radke's lab. "I want to apply what I've learned from my classes." She did internships at Chevron after her freshman and sophomore years and received the Chevron Undergraduate Research Award to fund her research this year.

Morcos says she shopped around for an interesting project. She first e-mailed all the chemical engineering faculty but found success only after reading articles on faculty research and targeting a few professors with a renewed effort. Her Chevron internship and her classes gave her the experience to begin a fairly independent project with Radke last year.

"It is unusual that I have my own project," she says. "Most of the other undergrads doing research are working under a graduate student." Morcos works directly with Radke, as do all the members in his group. "I like students to be on their own and do a real individual project," says Radke. "I feel it is a better experience when they work directly with me, but there are few students who can do this. Students who have the best lab experience are the ones with the discipline to be independent and keep trying when the going isn't easy...to solve problems, and to reach out to others in our lab for help."

Morcos' project takes up where a former graduate student's master's thesis left off, but in a slightly different direction. She analyzes protein adsorption at fluid-fluid interfaces, examining how the surface tension of protein in solution changes over time to determine if protein adsorption is reversible, and to learn how surfactants and proteins interact. Her current experiment studies protein adsorption onto bubbles or oil drops attached to a substrate, with a computer model that analyzes the shape of the bubble and determines the rate of adsorption. She spent several months just developing the approach to the problem and building the equipment, and she said she is now beginning to see results.

"It's fun to do research," says Morcos. "It provides the experience to solve problems, which makes experiments work better." And the time commitment in the lab is necessary, she says. During the semester she has a full course load, but still spends 10-15 hours per week in the lab. When she is running an experiment, she spends weekends in the lab. Research often changes direction midstream, and design changes in equipment or approach are often necessary. "A postdoc in the lab does a similar experiment and has been helpful in improving the design of the equipment," says Morcos, though she is ultimately responsible for the direction of the project.

"The research is for the student, not for my benefit," says Radke. "They learn about who they are and figure out if they want to go on in this area. It is a proving ground for graduate school, and by all means all students planning on graduate school should do it."

This past summer she juggled research in both Radke's lab and on another Chevron internship, working on process modeling for petrochemical research and studying microencapsulation of oil droplets. "Riham is having great fun, doing interesting things, and I enjoy working with her," says Radke. "Her project could eventually be a master's thesis if done by a graduate student." She plans on staying in Radke's group until graduation, with a Ph.D. as her next career move, though she's still not sure whether she'll end up in industry or academia. When she isn't in the lab, she's often organizing events as an officer in the student chapters of AIChE and in the Engineering Joint Council. ♦

"Students who have the best lab experience are the ones with the discipline to be independent and keep trying when the going isn't easy...to solve problems, and to reach out to others in our lab for help."

Chemical Engineering Professor Clayton Radke