

Researching Applications of Microbial Symbiosis

In the 19th century, lichen microbiologist Heinrich Anton de Bary coined the word “symbiosis” to describe any two unlike organisms living together in some long-term association. Today, faculty in the Department of Microbiology are building on de Bary’s phrase and growing their expertise in the area of microbial symbiosis and its potential applications in medicine and agriculture. Heidi Goodrich-Blair, Erik Zinser, Steve Wilhelm, and Sarah Lebeis each investigate microbial symbioses from far-ranging environments.

Symbioses vary as each agent in an association acts in self-interest. Darwin acknowledged nature’s lack of altruism in *The Origin of Species* when he wrote: “I do not believe that any animal in the world performs an action for the exclusive good of another . . . yet each species tries to take advantage . . . of the other.”

Many interactions are mutually beneficial, and many others are one-sided. An egret perched safely on an ox or a spider with its web affixed among a tree’s branches are benign guests to their hosts (a commensalism), but mosquitoes, lice, and tape worms sustain themselves with detriment to their hosts (a pathology). Organisms that bond over many generations may coevolve to fit each other’s needs (a mutualism).

“When such associations occur, the genes of each organism are selected by virtue of their association,” says Heidi Goodrich-Blair, David and Sandra White Professor and head of microbiology.

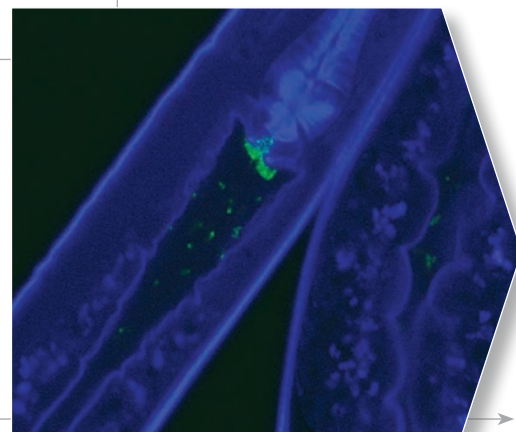
How symbioses originate, persist, and change across generations is Goodrich-Blair’s current research focus. Some organisms are born in unison with their symbiont, like plants and their chloroplasts, but others are born separately and find each other in the environment.

“It’s this selection process that fascinates me. How is it that a new hatchling picks its symbiont out from the crowd?” says Goodrich-Blair, who studies the relationship between a bacterium and a nematode, a small soil-swelling roundworm that reproduces and thrives inside insect carcasses.

Once most of the insect carcass is consumed, a new generation of nematodes develops into an infective variety, gathers its bacterial symbiont, and journeys into the soil to hunt for its next victim. When an insect plods along, the nematode hops on, crawls into its natural openings, and gnaws into the insect’s blood cavity, or hemocoel, where it unleashes its bacterial accomplice. The bacterium produces anti-immune proteins that hinder the insect’s defenses. Within a day, the insect is overwhelmed by a growing colony of unwelcome dinner guests and dies.

While the outcome is bleak for the insect, the nematode and bacteria share a vital mutualism. The bacterium is virulent to insects and helps the nematode feed from the cadaver, but cannot invade the insect’s hemocoel on its own. The nematode helps the bacteria gain entry; the insect is soon vanquished and consumed.

When leaving the insect cadaver, how does the nematode select which bacteria to take with it? Goodrich-Blair thinks the nematode can recognize molecules on the bacteria that are “honest signals” of their symbiotic abilities.



Symbiosis 1: A *Steinernema carpocapsae* entomopathogenic nematode (blue) actively ingests and associates with *Xenorhabdus nematophila* symbiotic bacteria (green).

To test this, she and her team study the bacterial genes and proteins necessary to colonize the nematode and investigate their function in symbiosis.

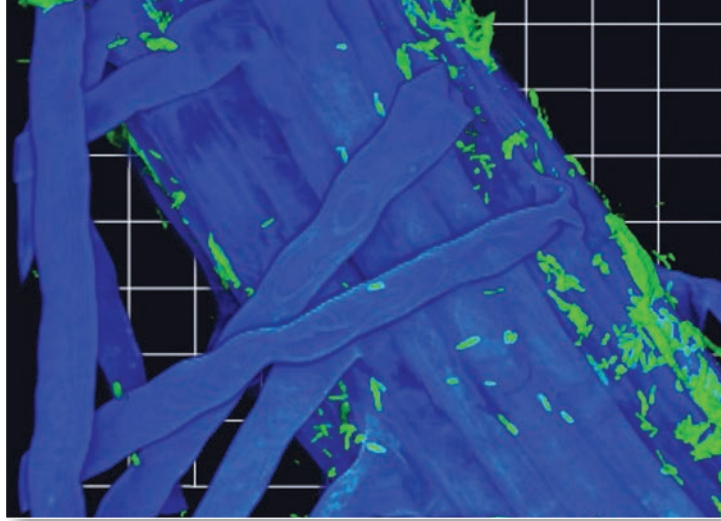
Erik Zinser, associate professor of microbiology, studies *Prochlorococcus* (“Pro” for short), a genus of cyanobacteria known as the most abundant photosynthetic organism on Earth. Due to its importance in global nutrient cycling, it has received considerable attention from the oceanographic community. Researchers, however, have had difficulty growing *Pro* in the laboratory. Recently, Zinser and his lab team coaxed *Pro* into forming colonies on agar media, an important tool in the microbiologist’s experimental repertoire. The key to this success was recognizing *Pro*’s symbiotic tendencies. *Pro* is an autotroph. It derives its energy from the sun and expels oxygen and carbon-rich organics, which are used by heterotrophic organisms cohabiting with *Pro*.

“As soon as we plated *Pro* with its familiar heterotrophs, we had 100 percent plating efficiency,” Zinser says. “Every time we put a cell down, it grew.”

The foundation of this relationship is that in both culture media and the shallow ocean, the heterotrophs protect *Pro* from oxidative stress caused by hydrogen peroxide (H₂O₂), a chemical highly destructive to *Pro*, but quickly neutralized by its heterotrophic partners. Zinser considers this relationship a loosely-defined symbiosis.

“While many different heterotrophs can do the job, if the heterotrophs weren’t there, *Pro* would be in a world of hurt,” Zinser says.

As biology progresses, revelations occur less from studying complexities within individual organisms and more from their interactions with others and their environment.



Symbiosis 2:
Arabidopsis roots (blue) colonized with a novel *Herbaspirillum* sp (green).

“Ninety-nine percent of what we know in microbiology comes from studying isolated organisms,” says Steve Wilhelm, Kenneth and Blaire Mossman Professor of Microbiology. “But, when you mix organisms, they can change their behavior, entirely.”

Wilhelm studies how toxic freshwater cyanobacteria called *Microcystis* bloom, which is a growing problem in lakes, reservoirs, and rivers worldwide. Some blooms are caused by anthropogenic deposition of nutrients into water, especially when coupled with increasing global temperatures. Wilhelm and his team have learned that blooms also depend on the activity of the rest of the microbial community, which suggests this harmful alga may have (unknown) microbial benefactors in their freshwater habitat.

“When we see *Microcystis* bloom, it hordes nutrients and chokes out the competition, but, without the entire microbiome, *Microcystis* doesn’t bloom nearly as well,” Wilhelm says.

Beyond identifying and characterizing such interactions, microbiologists at UT hope to apply symbiosis research to medicine and agriculture.

The human gut microbiome facilitates a varied diet and regulates susceptibility to ailments such as obesity and diabetes. Wilhelm and his group discovered

that after exposing genetically identical mice with different microbiota to malaria, some are less symptomatic than others. He hopes to identify resistant microbial communities that could be deployed in human patients.

Sarah Lebeis, assistant professor of microbiology, investigates mutualisms between microbes and plants for their potential application in agriculture. One application is to take microbes that improve drought resistance in arid-climate plants and incorporate them into agricultural crops for a not-so-rainy day. Lebeis sizes up different bacteria for their ability to colonize plants and compares their genes.

“You can’t be symbiotic if you can’t colonize in the first place,” says Lebeis, who wants to narrow down genes that enable colonization to learn what to look for in potential symbiotic candidates to reach beneficial goals like improving drought resistance and increasing productivity.

Among the staggering diversity of life on Earth, organisms have developed ingenious ways of interacting with each other to achieve their individual goals of survival. As we uncover and investigate these symbioses we not only learn ways to enhance our own endeavors, but also gain a deeper appreciation for the astounding wonders in nature.



Goodrich-Blair Wraps Up First Year as Department Head

This has been an exciting academic year for the Department of Microbiology. The year started with the faculty, staff, and students welcoming Jeremiah Johnson and me in August of 2016. Johnson joined the faculty as an assistant professor and is interested in microbial pathogenesis. I arrived just in time to take the reins as head of microbiology and the David and Sandra White Professor after Jeff Becker's retirement from an illustrious career in administrative leadership and academic science. Becker has been a tremendous source of information, support, and advice as I learn my new role as department head.

Throughout the year, I had the privilege and pleasure of learning about the fascinating research being conducted by our faculty, post-doctoral fellows, and graduate and undergraduate students. One of the distinctive features of our department is the emphasis on field research.

Colleen Jonsson, professor and the director of the National Institutes of Mathematical and Biological Synthesis (NIMBioS) conducted a virus-sampling trip in Paraguay. Karen Lloyd, assistant professor and recipient of a College of Arts and Sciences and Chancellor's Awards for research, went to Norway and Costa Rica.

I had opportunities to see the students who went on these sampling trips present their initial results and was impressed by their enthusiasm, knowledge, and ideas. Thanks to the David and Sandra White travel awards, our students are traveling to international conferences to share their data and show the world the excellence of research here at UT. I look forward to learning more about these exciting research avenues and the impact our microbiology faculty and students have on the world.

I also am impressed with the department's excellence in instruction and outreach. Some highlights include our NSF research experience for undergraduates (REU) program, which Steve Wilhelm, Kenneth and Blaire Mossman Professor, and Gary LeCleur, research associate professor, successfully renewed. This program brings 10 to 12 undergraduates, many from underprivileged backgrounds, to campus for the summer to conduct research in faculty labs. LeCleur also worked with high school students on a project selected for inclusion in the "Mission 9" space flight. Jill Mikucki, assistant professor, helps undergraduate students reach for the stars through her new astrobiology course. Erik Zinser, associate professor, received the College of Arts and Sciences Excellence in Teaching Award in part for the

development of a unique physiology course in which students "build" their own microbe. I deeply appreciate the value our faculty and staff place on instruction and am proud to be part of a group of such outstanding teachers.

Finally, the new Mossman Building construction is progressing rapidly! Approximately half our faculty will move into the building summer of 2018. Over the next year, please keep an eye out for announcements about events marking the completion and occupation of this new state-of-the-art research and instructional space.

In his last newsletter, Professor Becker conveyed the enduring excitement and importance of microbiology as a field that reveals the "secrets of life" and impacts our understanding and stewardship of the world around us. In my first newsletter, I am proud to share the accomplishments of our excellent scientific community at UT. We are pushing the boundaries of knowledge and training the next generation of scientists to continue in this endeavor.

-HEIDI GOODRICH-BLAIR

David and Sandra White Professor
Head of Microbiology



To read more news
& updates visit:
micro.utk.edu/newsletter

UNDERGRADUATE RESEARCH LEADS TO PASSION FOR SCIENTIFIC DISCOVERY

Students of microbiology often gravitate toward this field for its diversity of subject matter and applications. Lorenz Barcelona is one such student.

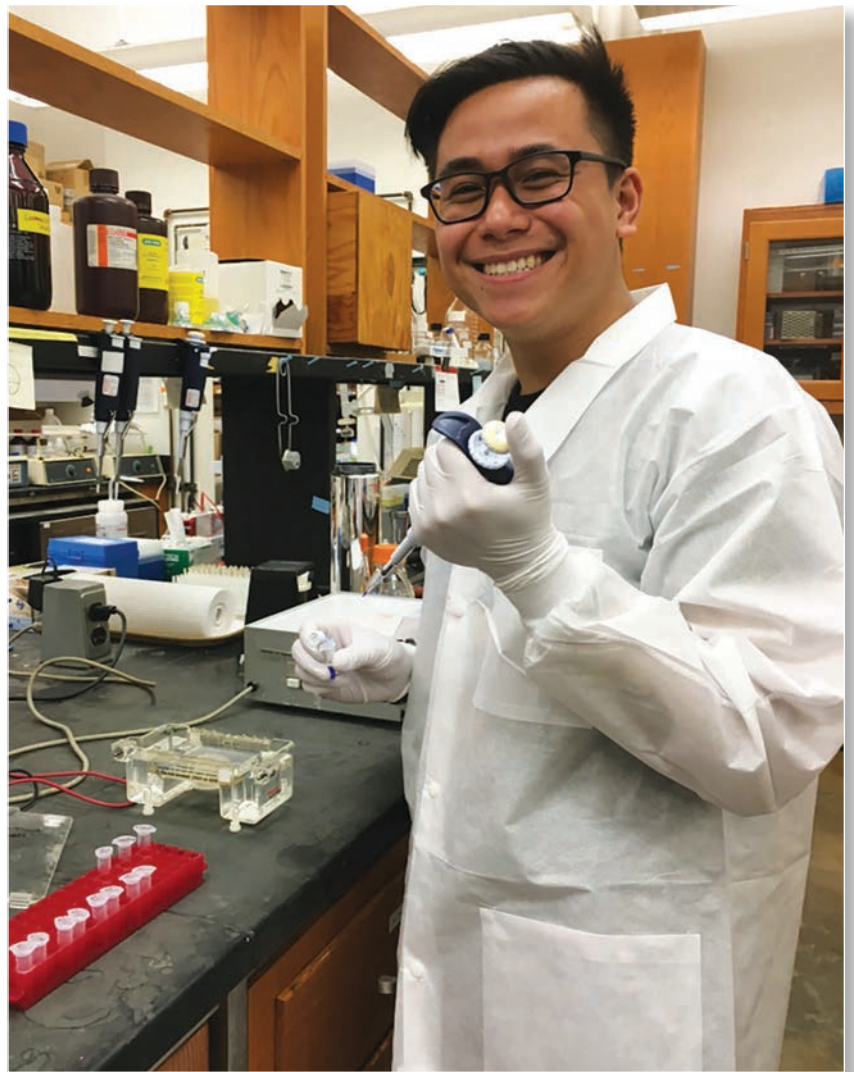
“When I took my first micro class with Professor Fozo, I fell in love with microbiology and declared it as my major,” says Barcelona, who graduated this May with a bachelor’s in science. “From the start, I have enjoyed my micro classes way more than any others.”

Since January 2016, Barcelona, who has a special interest in using microbiology to develop more effective medicines to treat disease, worked in Becker’s lab learning how G-protein-coupled receptors (GPCRs) on the membrane of eukaryotic cells that transduce external stimuli produce intracellular responses. Many diseases involve malfunctioning GPCRs, including diabetes and cancer. For Barcelona, with aspirations in medicine, this project is right up his alley.

“Over 40 percent of the drugs on the market target GPCRs,” Barcelona says. “In our yeast model, we’re modifying the genes that code for GPCRs to test how we can develop more effective drugs for such chronic and deadly diseases.”

Yeast, a microorganism, provides an excellent model system to study GPCR and apply the knowledge to other eukaryotes. In his experiments, Barcelona manipulates segments of the yeast genome that encode a specific GPCR that orchestrates a fungal mating ritual. When a mating pheromone, called “alpha-factor,” from the yeast cell of mating type “alpha” binds with the GPCR on a cell of mating type “a,” it activates the mating pathway. Both “a” and “alpha” cells grow projections (called a “shmoo”) toward each other in preparation for mating, when the shmoo fuse the two cells into one.

Using methods of mutagenesis, Barcelona alters each amino acid in the GPCR genes independently and observes the downstream effects of his manipulation in subsequent generations of yeast. One goal is to find which amino acids he can replace with another molecule, benzoyl phenylalanine (Bpa), that can be activated by UV light to capture proteins without disturbing the normal function of the GPCR or the mating process.



“Working in Professor Becker’s lab has deepened my understanding of microbiology and affirmed my interest in applying it to improve human health,” Barcelona says. “Doing research has definitely influenced my learning. No other class has helped me understand biology more.”

Participating in undergraduate research also introduced Barcelona to the passionate culture that surrounds scientific discovery.

“Doing research in the lab has made me feel like I was part of something; like I was part of the micro family,” Barcelona says.

Now his eyes are set on medical school, but Barcelona would be just as happy continuing his studies in microbiology in grad school here at UT.

“If this med school thing doesn’t work out, I’d love to go here, because I already love everyone here.”

PHD STUDENT LOOKS TO MICROBES FOR STORY OF GLACIAL EVOLUTION

About 3.5 billion years ago, soon after the Earth had cooled, microbial life was actively changing its environment and leaving traces in the fossil record. Remnants of microbes in sediment, called stromatolites, provide snapshots of the Earth across many geologic ages. Today, microbes appear almost everywhere on Earth, from the base of the Marianas Trench to the top of the stratosphere, from high-Andean super-saline lakes to the underbellies of glaciers. Anywhere temperatures support complex organic materials, we find microbes interacting with their environments.

Can understanding contemporary microbial activity and how they form fossils teach us about the future of the planet? This is a central question guiding the research of Joy Buongiorno, a doctoral student in Karen Lloyd's lab. Buongiorno is interested in the intersection of biotic and abiotic processes, their characteristic traces in the geologic record, and the stories they may tell about the evolution of the environment in which microbes thrive.

Buongiorno has a BS in zoology from Tennessee Tech University and received her MS in geology from UT. For her doctoral work, she studies the geological role of microbes and recently visited the northernmost human settlement on Earth to understand how microbes interact with arctic glaciers.

Just north of the 78th parallel, on the coast of Kongsfjorden, a bay tucked into the icy archipelago of Svalbard, Norway, lies Ny Ålesund, a research town dedicated to glaciology, geology, biology, and physics. Nearby and next to two massive glaciers, Kongsbreen and Kronebreen, are the silty glacial sediments that Buongiorno studies.

During her recent field trip, funded in part by a grant from the Explorer's Club, Buongiorno realized something peculiar about the sediments beneath the glaciers. As the glaciers melted, calving into the fjords, she noticed they had carried iron from the terrain during the long journey to the fjord.

"The iron was settling to the bottom and disrupting the natural diagenetic profile that you would normally see in sediments elsewhere," Buongiorno says.

In normal sediments, one would expect to see sulfate promptly processed into methane, but this time the sulfate, which readily interacts with iron, was trapped in an oxidation cycle.

"The chemistry beneath the glaciers in Kongsfjorden is super strange, so we're expecting to see some



Can understanding contemporary microbial activity and how they form fossils teach us about the future of the planet?

really unique microorganisms and metabolisms in the sediments," Buongiorno says.

Beyond discovering and cataloguing new microbes, glacial sediments allow scientists to trace the lifetimes of the Kongsfjorden glaciers, prime specimens in ongoing climate change studies.

"As the glaciers retreat, we'll no longer have that conduit transferring oxidized iron-heavy minerals into the water, which will most likely alter the geochemistry and microbial behavior," Buongiorno says.

To test this hypothesis, she is analyzing multiple sediment samples, tracing a linear profile of the region along the tongue of the glacier and into the fjord. Buongiorno hopes her Arctic study will yield a unique perspective on the way microbial communities beneath these glaciers change over long periods of time.

Along with her endeavors playing in Arctic mud, Buongiorno also strongly promotes science literacy and served as co-president and organizer of Darwin Day, an annual campus-wide celebration and initiative to educate the public about evolution. In May 2016, the UT Police commended Buongiorno for assisting in the apprehension of a thief who stole more than \$100,000 in property from campus buildings. Buongiorno also runs the microbiology department's Twitter feed, which you can follow @UTKMicrobiology.

Biology Meets Subduction

This February, **Karen Lloyd** and her graduate student, **Kate Fullerton**, visited Costa Rica for a sampling expedition with the **Deep Carbon Observatory (DCO)**. The multidisciplinary field campaign, called “Biology Meets Subduction,” brought 25 DCO microbiologists, geochemists, and volcanologists from five nations: Costa Rica, the United States, Japan, Italy, and the United Kingdom.

The team studied the interface of life and volcanic systems and how carbon cycles between Earth’s surface and interior in the active subduction zone between the North American and Cocos tectonic plates.

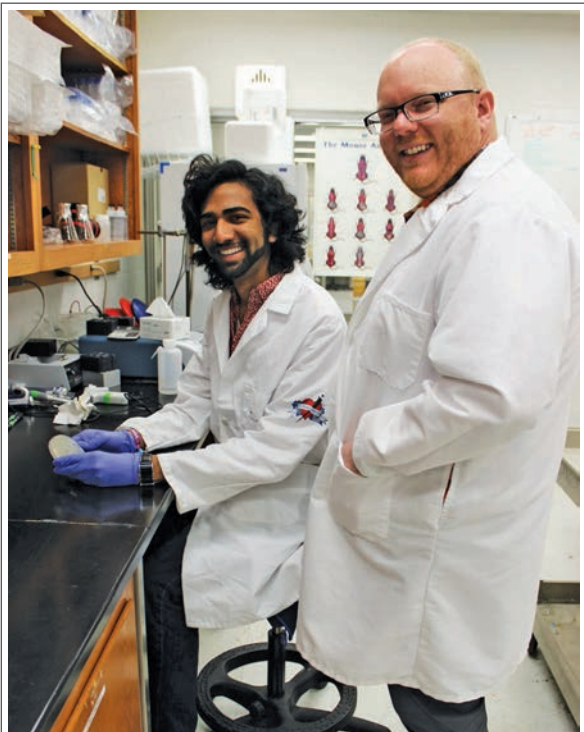
Over the course of 12 days, the team visited six field sites, including Poás and Arenal volcanoes and several springs along the Nicoya and Osa peninsulas. Lloyd and Fullerton, in collaboration with Donato Giovanelli (Earth-Life Science Institute, Japan and Rutgers University, United States) and Heather Miller (Michigan State University) will analyze their measurements of biogeochemical activity from the field to characterize microbial communities living within sediments and fluids from the volcanic region.

A group of photographers and videographers documented the excursion. To read their blogs, view photos and video from the field, and learn more about the “Biology Meets Subduction” project and the Deep Carbon Observatory, please visit <http://bit.ly/2mMPeNi>.

Graduate student, **Kate Fullerton** (left) and **Karen Lloyd**



PHOTOS BY TOM OWEN



Johnson Investigates Chickens Carrying *Campylobacter*

The chicken has been familiar to the human palate for millennia. As a source of two high-energy foods - its meat and its eggs - it is no wonder that almost every cuisine pays homage to the bird. As our population grows, so has that of the chicken to accommodate our commensurately ballooning appetites.

The United States alone consumes about a million chickens every hour. Aided by a highly industrialized system that raises, processes, packages, and delivers them to restaurants and dinner tables, an average factory farm processes 200,000 birds in a day. Such productivity increases the risk for food-borne contaminants. To reduce risk, carcasses are treated with a series of washes and baths.

Undergraduate student, **Kishen Patel** (left) and **Jeremiah Johnson**

“If you have one bad bird in the bunch, it can spoil them all,” says **Jeremiah Johnson**, assistant professor who studies *Campylobacter*, a notorious food-borne bacterium responsible for an estimated two million cases of gastroenteritis each year.

While chickens host several pathogens, none compares to *Campylobacter's* ability to cause human illness. *Campylobacter* resides in the gut of many bird species, apparently without harm. However, human consumption can lead to 10 days of tummy trouble, or, in severe cases, to illness linked to Guillain-Barré Syndrome, an autoimmune disease that deteriorates the myelin sheathe covering axons, resulting in potential paralysis.

“I want to know why chickens don’t get sick, but people do,” Johnson says.

With grant funding from the NIH and USDA, Johnson studies the colonization mechanisms of the bacteria and how they behave in the GI tracts of various species and seeks to identify bacteriophages (viruses) that could attack *Campylobacter* while leaving the chicken and its other microbiota alone. Such viral solutions may prove superior to using antibiotics because antibiotics must be developed periodically as target bacteria evolve, whereas bacteriophages can coevolve with the bacteria, thereby suppressing a population over many generations.

“Today, with bioinformatics, transcriptomics, and the ability to analyze *Campylobacter's* response in different scenarios, we’re able now to focus on the bigger picture,” Johnson says.

Microbiology Pioneer Positive About Future of the Field

Professor Emeritus Jeff Becker remembers his calling to science for its power to satiate his innate curiosity and affect positive change.

“When I was 10, DNA had just been modeled, along with thrilling new experiments in molecular biology,” Becker says. “I wanted to be a part of that.”

Since then, Becker has had a prolific research and teaching career, serving as Chancellor’s Professor and head of the microbiology department. He published over 240 peer-reviewed articles and mentored hundreds of undergraduate and graduate students, many working in academia and industry.

Becker continues in his 35th consecutive year of research funded through NIH on G-protein coupled receptors (GPCRs), a prominent class of cell membrane receptors that eukaryotic cells, like those belonging to animals and fungi, depend on to interact with their environments. When a GPCR detects a stimulus such as a molecule or photon of light, it may trigger a cascade of events that induce a predictable behavior such as cell division or influence the organism’s sensation of sight, smell, or taste.

GPCRs aid in many essential functions, but when they misbehave, existential catastrophe may follow. Becker wants to know how GPCRs signal to cells to change their physiology and behavior. To investigate the receptors, he and his students use yeast to model human cells, as both share over a third of their genomes, with strikingly similar GPCRs.

“We can do a lot with yeast systems quickly,” Becker says. “We can change the sequence of receptors using molecular biology, which is much easier to do in yeast cells than human cells.”

Although Becker pioneered new fields in microbiology, teaching has been the most rewarding aspect of his career. He also considers it a privilege to have participated in cultivating a multidisciplinary, cohesive department and greatly values the diversity of research of the faculty, which spans pathology, human health, ecology, energy, and environment.

“I’m proud to see many former students who are now professors or work in private industry and government. To me, that’s been my contribution to the world,” Becker says. “Part of our goal in hiring faculty was to bring in the smartest people who do good work, but are also great colleagues.”

As he steps down as department head, Becker is positive about the future. He notes the opening of the new Mossman building and predicts that its “open lab” design will generate exciting opportunities for intradepartmental collaboration. He is also proud to announce the Jeff and Nancy Becker Endowment in Microbiology to support undergraduate research.

“I look forward to seeing even more cooperation among our faculty involved in pathology and ecological processes,” Becker says. “Heidi has great vision, and I’m confident that we’re going to do great.”



Left to right:
**Karen Bunn,
Frank Bowden,
Jeff Becker,
Sandra White,
and Rod Bunn**

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MOSSMAN BUILDING SET TO OPEN FALL OF 2018

Work is almost complete on the construction of the Ken and Blaire Mossman Building, a new state-of-the-art classroom and laboratory facility set to open in fall 2018. Named for Ken and Blaire Mossman, UT alumni and generous supporters of the sciences at UT throughout their lives, the six-floor building will be the new home for portions of the Departments of Microbiology, Psychology, Nutrition, and Biochemistry, Cellular and Molecular Biology.

Faculty, students, and staff will benefit from the new building's layout, which facilitates structured and unstructured interactions and opportunities for collaboration. Labs feature an innovative "open lab" design, where three or four labs share one large space. Students with similar disciplinary interests can share equipment, resources, and ideas. Students will also benefit from window-lit study rooms just outside of their labs and large lecture halls with the latest audio-visual equipment. Mossman also features a vivarium and large office-labs specialized for computational biologists.

The integration of departments and disciplines within one building will facilitate cross-disciplinary collaboration. For example, it is becoming increasingly clear that microbes have deep impacts on animal nutrition and behavior, an area of research benefited by computational sciences. The interactive layout of the Mossman building will foster communication and training of a new generation of interdisciplinary research scientists.

This project is part of UT's ongoing effort to expand general class and laboratory space, as well as update science facilities on campus.

"I think it shows UT's strong commitment toward the future of STEM at the university," says Todd Reynolds, associate professor of microbiology who served on the advisory committee for the building's construction. "We as a faculty are very grateful to the Mossmans for their support and making this building possible."

