Welcome to the 2014/2015 Department of Chemistry. I am pleased to report that the Department continues its upward trajectory with renewed growth, recognition, and research success. We have new faculty hires, additional resources, renovated lab space, and recruited an exciting class of graduate students.

The Chemistry Department welcomes our newest hires. We successfully recruited Nathan Schley, as an assistant professor in inorganic chemistry. His particular area of interest is catalysis. We are also pleased to have recruited lecturers Alissa Hare for organic chemistry and David Kort for general chemistry. We would like to recognize the 30 years of service by Professor Tim Hanusa and the 35 years of service by Professor Prasad Polavarapu to the department, college and university. Professor Piotr Kasynski left the department to pursue opportunities in his home country of Poland. Finally, it is with great sadness that I note the loss of Professor Richard Armstrong, who died in June after a brief illness. Richard’s approaches to mentoring, teaching, research and service remain an inspiration to his students and colleagues.

A hallmark of our faculty is their dedication to research, teaching, and service. Once again, our faculty garnered awards both nationally and on campus. Examples include Professor Richard Caprioli, who won the VUMC Enterprise Faculty Award for his pioneering innovation in mass spectrometry; and Professor Jens Meiler, who was named to the inaugural class of Chancellor’s Faculty Fellows. The Chancellor’s Faculty Fellows represent the future of Vanderbilt. They offer energy and innovation for new basic discoveries, path-breaking scholarship, and creative expression. A team led by research assistant professor Joseph Conrad and graduate student Alexis Wong were recognized as Phase I finalists in the NIH Follow the Cell Challenge. Finally, I was named a fellow of the American Association for the Advancement of Science.

We are proud of all of our students both undergraduate and graduate. This past year, we graduated 25 students with ACS-certified bachelor degrees in Chemistry, most of whom will pursue graduate or professional studies. We also graduated 11 students with the Master’s degree and 13 students with the Ph.D. in chemistry. Our trainees are the recipients of a number of awards ranging from NIH training grant positions to the NSF Graduate Research Fellowship to GAANN (Graduate Assistantship in Area of National Need) fellowships.

The stories in the following pages will provide you with some perspective about what Vanderbilt Chemistry researchers are doing, the changing faces of the Department, the recognition that we continue to earn, and some insights into our students, past and present. As always, we would love to hear from you.

David Wright
Stevenson Professor and Chair
Department of Chemistry
Vanderbilt University
Infectious Disease Elimination Is Possible

By Danielle Kimmel, Ph.D. and Joseph Conrad, Ph.D. Wright Lab

By incorporating global education initiatives, research and development of new therapies and diagnostic technologies, and careful surveillance of existing cases, the burden of many infectious diseases has been reduced and is nearing elimination. Currently, scientists, governments, and public/private partnerships are devoting considerable research efforts toward new ways to eradicate devastating diseases, such as malaria. An interdisciplinary team of scientists at Vanderbilt University is contributing its research findings to global malaria eradication efforts with the help of a secret weapon, 3D printing.

Developing countries suffer from a high burden of infectious diseases as a result of limited resources supporting medical, water, and public health systems. Even with affordable and accessible treatments, high sensitivity diagnostic technologies used to detect infections in places like the United States are seldom available in the developing world. Unfortunately, it is precisely the effective identification of infections that is needed to reduce their spread, as well as speed delivery of care and treatment.

Malaria is a parasitic infection that completes life cycle steps in humans and mosquito hosts. Mosquitoes that take a blood meal from an infected individual can later transmit parasites to another person. Infected individuals do not necessarily become symptomatic until the parasite has reproduced in their blood and the number of parasites pass a tipping point. A higher parasite concentration makes the transmission of malaria more likely with subsequent mosquito bites.

In the case of malaria, the diagnostics that are used to detect malaria infection most often require a skilled microscopist, who examines blood specimens for the presence of infecting parasites. In low resource settings, the infrastructure and personnel to support microscopy is not readily available. One alternative diagnostic approach includes the use of rapid diagnostic tests (RDT), similar to a home pregnancy test. These lateral flow immunoassays are self-contained, do not require skilled technicians, electricity, or clean water. However, the sensitivity of these tests is insufficient to identify low level infections in individuals who may not have symptoms, but who may still transmit the disease to others.

Rapid diagnostic tests are generally sensitive enough to return a positive result when the parasite loads are high. In areas where malaria control efforts have progressed toward elimination, parasite loads can be much lower. Individuals with low-level infections may not be symptomatic; thus, diagnosis through clinical assessment is impossible. Further, these individuals may not receive treatment, allowing for the spread of malaria through a community even in the absence of widespread, symptomatic malaria.

At Vanderbilt, a cross-continental collaboration is working...
diligently to develop technologies to improve existing RDT sensitivity. Part of their work incorporates the use of 3D printing technology to manufacture materials on site in Zambia.

Working with the Vanderbilt-Zambia Network for Innovation in Global Health Technology, (VZ-NIGHT), an NIH Fogarty International Center funded research training program in the Department of Chemistry, scientists from the United States and Zambia have designed 3D printable devices that can “enhance the best tests to make them perform even better, and enhance the lower performing tests and make them perform adequately.”

In a model of distributed design and manufacture, 3D printers can be utilized in the iterative design process to develop device templates at Vanderbilt and send them for printing in the lab in Macha, Zambia. This enables collaborators in Zambia to print unique devices and immediately go into the field to test them.

Keersten Davis, Ph. D., a recent graduate who worked with device design for her dissertation, highlights the importance of the 3D printer for improving more than RDT sensitivity:

“Use of the 3D printer not only enables diagnostic capabilities in these endemic regions, but also fosters a further depth of collaboration between our academic world and the point of care settings for which we design.”

Using a 3D printer to rapidly manufacture devices specific to a researcher’s needs provides a great step forward for low-resource settings. Devices can easily be printed that require no running water or electricity to operate, making them ideal for rural locations without sophisticated laboratory support. Additionally, the devices themselves require very little training to operate, as noted by Lauren Gibson, a fourth-year graduate student. “One thing that really excites me about this device is its ease of use. I have watched a technician successfully enhance the signal of a malaria RDT after only minutes of training.”

Lwiindi Mudenda, a Zambian and a post-doctorial fellow for VZ-NIGHT, is dedicated to improving health in Zambia, “I care about malaria and efforts towards its eradication because it is a debilitating and sometimes fatal disease.” With the future of Zambian health in mind, Hellen Matakala, is undergoing training in the United States so that she can continue this research in Zambia, year-round. Hellen is particularly excited about the elimination of malaria. “Malaria is one of the leading causes of mortality and morbidity in Zambia, especially in rural areas where treatment of malaria is limited, therefore making the members of the rural community more susceptible to malaria infection. With the help and introduction of 3D printing and in the development of enhanced RDTs, we hope to detect malaria infection and administer treatment as early as possible saving more lives and making Zambia a healthy nation free of malaria.”

Supported in part by the National Institutes of Health, Fogarty International Center Grant #D43 TW009348

To watch a video of how the 3D printer works, please go to: news.vanderbilt.edu/2015/01/3d-printer-helps-fight-malaria-in-africa/
Creating bacterial “fight clubs” is an effective way to find new drugs from natural sources. That is the conclusion of a team of Vanderbilt chemists who have been exploring ways to get bacteria to produce biologically active chemicals which they normally hold in reserve. These compounds are called secondary metabolites. They are designed to protect their bacterial host and attack its enemies, so they often have the right kind of activity to serve as the basis for effective new drugs. In fact, many antibiotics and anti-cancer compounds in clinical use are either secondary metabolites or their derivatives.

In a proof-of-concept test of the fight-club procedure, the research team headed by Associate Professor of Chemistry, Brian Bachmann, and Stevenson Professor of Chemistry, John McLean, discovered a promising new class of natural compounds that exhibit anti-cancer activity. The discovery is reported in the article “Mapping microbial response metabolomes for induced natural product discovery,” published online by the journal ACS Chemical Biology on June 17.

Bacteria represent a vast untapped reservoir of biologically active compounds. There are an estimated five million trillion trillion bacterial cells on earth. They come in an astounding variety with the best estimate of the number of distinct species ranging from 120,000 to 150,000. Analysis of microbial genomes has shown that individual bacteria carry the blueprints for hundreds of secondary metabolites. However, biologists have had a hard time either getting bacteria to produce them or synthesizing them directly so they can assess their therapeutic value.

That’s where the “fight club” approach comes in. Research Associate, Dagmara Derewacz, came up with the idea of applying the analytical tools the Bachmann and McLean groups had developed to analyze what happens when microbes compete.

“It’s a ‘shoot first and ask questions later approach,’” said Bachmann, “which is opposite of the traditional approach to natural products drug discovery.”

The first microorganism the scientists put in the ring was Nocardiopsis, a bacteria that is found in the soil. They picked this particular strain because when its genome

---

**Fight Clubs Come to Vanderbilt**

By David Salisbury
was sequenced it revealed the presence of 20 gene clusters that carry blueprints for making secondary metabolites.

In order to stimulate the bacteria to produce some of these novel compounds, the researchers matched it with four challengers: the common gut organism Escherichia coli; Bacillus subtilis, a well-studied model organism; Tsukamurella pulmonis, which infects people with compromised immune systems; and, Rhodococcus wratislaviensis, which degrades hydrocarbons.

The researchers “co-cultured” Nocoardiopsis separately with each of the challenger microorganisms.

“What Brett Covington in my lab found and quantified was that in every case the product—the co-culture—was more than the sum of the two monocultures,” said Bachmann. “The co-cultures contained significantly more kinds of biological molecules than the two monocultures combined.”

The researchers were able to make this determination because of an advanced analytical chemistry technique capable of simultaneously identifying thousands of different biological compounds, which McLean and colleagues have helped pioneer. This technology, called ion mobility-mass spectrometry, combines ion mobility spectroscopy, which separates and identifies electrically charged molecules by the speed with which they travel through a gas-filled column, with mass spectrometry, precisely “weighs” individual molecules by how quickly they travel a given distance in the absence of gas.

The chemists estimate that the cell co-cultures contain somewhere between 20,000 to 50,000 different kinds of molecules. Ion mobility-mass spectrometry separates these molecules based on their size-to-weight ratio, which naturally sorts them into different regions that correspond to proteins, lipids, sugars, metabolites etc., and allows them to identify about 2,500 metabolites in each co-culture.

One of the biggest technical challenges stems from the wide range in concentrations of different molecules: the bacteria produce some compounds by the dozen but make others by the billions.

The secondary metabolites that the researchers were looking for are generally present in relatively low concentrations, so they had to come up with a method that helped them identify these compounds based on their qualities not their quantities.

They call the method they developed “self-organizing metabolomics maps” or SOM. “SOM is similar to the process Amazon uses to make recommendations for the products they sell,” said McLean.

Amazon monitors your Internet page views, your purchasing history and other information they have about you and makes a pattern out of the data. It puts your pattern on a tile and does the same for its millions of other customers. Next, it shuffles these tiles around until neighboring tiles share the most similar patterns. Then they recommend your last purchase to your neighbors and their last purchases to you.

“The SOMs we are using here do much the same thing. They take the patterns in the data we have about all these molecules and match those that behave similarly,” said McLean.

This procedure allowed the chemists to discover a new member of a class of biomolecules with broad-ranging activity that is produced when Nocoardiopsis comes into contact with Rhodococcus wratislaviensis. The scientists named this new compound ciromicin, after a Latin word meaning war/cite/disturb/invite. Ciromicin’s structure is similar to that of several FDA-approved antibiotics. The new compound has demonstrated both anti-tumor activity in vitro and the capability to modulate genes involved in programmed cell death.

“In the past, we’ve experimented with a number of ways to get bacteria to produce their secondary metabolites, including poisoning them with antibiotics and exposing them to rare earths, but the fight club approach is the most effective method we’ve found, by far,” said McLean.

The research was supported by National Institutes of Health grants GM092218 and T32 GM 0650086.
A major challenge in the fight against AIDS (acquired immunodeficiency syndrome) is the ability of the causative agent HIV (the human immunodeficiency virus) to evade the immune system. One mechanism that the virus uses to accomplish this goal is the resistance of its Env protein to antibody attack. Env is a surface glycoprotein comprising a trimer of the transmembrane gp41 subunit capped by a trimer of gp120. Env plays a critical role in the fusion of HIV with a target cell membrane. Most antibodies that neutralize HIV bind to gp120, suggesting that immune defense against the virus is possible if a vaccine can be designed that leads to the efficient production of gp120-targeted antibodies. However, this goal has been frustrated by the presence of the gp120 V1/V2 domain that has a highly variable sequence, making it difficult to produce single antibodies that are effective against a broad range of viral strains.

Now, Jens Meiler of Vanderbilt's Department of Chemistry, in collaboration with James Crowe of Vanderbilt's Department of Pathology, Immunology, and Microbiology, have collaborated to bring a new approach to this vexing problem. [J. R. Willis, et al. (2015) J. Clin. Invest., published online May 18, DOI:10.1172/JCI80693].

Working with colleagues at The Scripps Research Institute in La Jolla, California, the Vanderbilt researchers began with a "parent" antibody isolated from the blood of an HIV-infected person that was a strong "neutralizer" of HIV in laboratory tests. The researchers then used the Rosetta computer program, which can predict the structure of a protein from its amino acid sequence, to "redesign" the antibody.

By changing a single amino acid, they were able to increase the stability of the antibody when it bound to HIV's envelope protein. The researchers didn't change the interface between the antibody and the virus. Rather, by increasing its thermodynamic stability, the antibody became more rigid and better able to fit the HIV protein like a lock and key.

"By changing a single amino acid, we made it four times more potent, four times stronger and it also started killing even more HIV strains than the parent antibody," said Crowe.

The original, isolated antibody is now being produced in great quantities from a single clone of immune cells, and thus is a "monoclonal" antibody. It currently is being tested in clinical trials. Crowe said the redesigned antibody could be added to the study as a second-generation version.

The field of redesigning antibodies has grown quickly out of the need to treat and prevent debilitating and often-fatal viral infections, and from technological advances.
that have made it possible to "see" and strengthen the interactions between virus and virus-killing antibodies.

HIV is a wily opponent. Every day it evolves, or alters the envelope protein on its surface, to evade immune detection. A single person infected with HIV carries more variations of the virus than all the influenza strains isolated worldwide, Crowe said. The immune system simply cannot keep up.

In 2013, Scripps scientists led by Ian Wilson, Ph.D., and Andrew Ward, Ph.D., reported in the journal Science the structure of the HIV envelope protein using crystallography and cryo-electron microscopy. "Now that we know what it looks like," Crowe said, we can better understand how to target it.

Last year, Crowe and another colleague at Scripps, William Schief, Ph.D., reported in the journal, Nature, that "computational protein design" can be used to induce potent neutralizing antibodies of respiratory syncytial virus (RSV), a leading cause of respiratory infections in young children. "That was the first paper in which people agreed that computer design of a vaccine worked," he said.

The Meiler and Crowe lab findings are exciting not only because they have led to the discovery of a more potent antibody against HIV, but also because they reveal the power of computational modeling in the design of antibodies with improved properties. Out of five mutants tested, two exhibited the desired properties of increased binding affinity, suggesting a high (40%) success rate for the modeling approach. This is clearly much higher than the success rate expected for random mutation and testing, so this approach leads to substantial and important savings in time and resources. The Meiler and Crowe groups will continue their efforts through a recent $9 million grant from the National Institutes of Health that will enable them to apply their methods to the development of better vaccines against influenza virus.

Structure and proof of principle in hand, scientists are now using the computer to generate neutralizing antibodies against parts of the envelope protein that don’t change. Down the road, Crowe said, "if computational design … can predict how viruses evolve in the future, we could potentially design antibodies and vaccines for viruses before they occur in nature."

Toward that end, Crowe and Meiler have organized the Interface Group, a diverse collaboration of scientists across campus, including an expert in game theory who is modeling the interplay between viruses and the immune system.

The study was supported in part by National Institutes of Health grants AI078407, AI082362, AI100663 and AI084817.

J. Meiler and J. Crowe; "Structure based design of antibodies and vaccines"; NIH (NIAID) (1U19 AI117905); 1 June 2015–31 May 2020.

Research was funded by National Science Foundation grants DMR-0938330, EPS-1004083 and CHE-1253105; U.S. Department of Energy grant DE-FG02-0946554; Office of Science contract DE-AC02-05CH11231; and by ORNL’s Basic Energy Sciences/Materials Science and Engineering Directorate and Center for Nanophase Materials Science.

Vanderbilt lands $9M grant to improve flu vaccines

Vanderbilt University researchers Jens Meiler, Ph.D., and Dr. James Crowe Jr. have received a $9 million grant from the National Institutes of Health to design flu vaccines more effective than those currently offered.

The five-year grant will also fund the study of new antibody therapies, according to a release. Current flu vaccines are weakened forms of the virus that trigger immune responses against viral proteins, but the proteins are constantly changing, meaning the vaccines are not 100% effective. About 30,000 Americans die every year from influenza complications, according to the release.

“Vaccines could be improved if they induced immunity against the unchanging part of the proteins,” said Meiler, co-principal investigator with Crowe, “or if universal antibodies could recognize every strain of the flu.” The project will be completed in collaboration with The Scripps Research Institute in La Jolla, California.

“We’re going to design synthetic flu proteins to be better than the natural infection,” Crowe said. “We couldn’t do it in the past, but now we can design these vaccine candidates on the computer, we can synthesize them in the lab, and we can make a molecule that never existed before, and that’s better than the virus that existed in nature for inducing immunity.”

Funding provided by National Institutes of Health grant number U19 AI117905.
Vanderbilt Team First to Blend High-End Imaging Techniques

Vanderbilt University researchers have achieved the first “image fusion” of mass spectrometry and microscopy—a technical tour-de-force that could, among other things, dramatically improve the diagnosis and treatment of cancer.

By Bill Snyder

Mass spectrometry provides a very precise accounting of the proteins, lipids, and other molecules in a given tissue, but in a spatially coarse or pixelated manner. Combining the best features of both imaging modalities allows scientists to see the molecular make-up of tissues in high resolution.

“That to me is just phenomenal,” said Caprioli, the Stanford Moore Professor of Biochemistry, professor of chemistry, and director of the Mass Spectrometry Research Center.

Caprioli said the technique could redefine the surgical “margin,” the line between cancer cells and normal cells where the scalpel goes to remove the tumor. Currently that line is determined by histology—the appearance of cells examined under the microscope. But, many cancers recur after surgery. That could be because what appear to be normal cells, when analyzed for their protein content using mass spectrometry, are actually cancer cells in the making.

Caprioli is internationally known for his pioneering innovations in the field of mass spectrometry. His contributions include development of a patented micro-electrospray technology that enables techniques such as multi-dimensional liquid chromatography/mass spectrometry (LC/MS), and which is now used worldwide for protein identification. He developed ultra-high sensitivity methods for analysis of neuropeptides, and pioneered molecular analysis in living animals. In the late 1990s, Caprioli’s lab developed a technique called imaging mass spectrometry (IMS) using matrix-assisted laser desorption/ionization (MALDI). Essentially a “molecular microscope,” the technique measures the distribution, spatial rearrangement, and alteration in expression levels of proteins, lipids, and other biological molecules in cells and tissues. It has particular relevance to cancer and has informed the study of human glioblastomas, as well as tumors of the breast, colon, prostate, and lung. More recently, the Caprioli team reported the first “image fusion” of mass spectrometry and microscopy, a technological tour-de-force that allows scientists to see the molecular make-up of tissues in high resolution.

“The application of image fusion approaches to the analysis of tissue sections by microscopy and mass spectrometry is a significant innovation that should change the way that these techniques are used together,” said Douglas Sheeley, Sc.D., senior scientific officer in the National Institute of General Medical Sciences (NIGMS). “It is an important step in the process of making mass spectrometry data accessible and truly useful for clinicians,” he said.

The image fusion project was led by Raf Van de Plas, Ph.D., a research assistant professor of biochemistry who also has a faculty position at Delft University of Technology in the Netherlands. Other co-authors were postdoctoral fellow Junhai Yang, Ph.D., and Jeffrey Spraggs, Ph.D., research assistant professor of biochemistry.

Using a mathematical approach called regression analysis, the researchers mapped each pixel of mass spectrometry data onto the corresponding spot on the microscopy image to produce a new, “predicted” image.

It’s similar in concept to the line drawn between experimentally determined points in a standard curve, Caprioli said. There are no “real” points between those that were actually measured, yet the line is predicted by the previous experiments.

In the same way, “we’re predicting what the data should look like,” he said.

*The research was supported in part by National Institutes of Health grants GM058008 and GM103391.*

“The application of image fusion approaches to the analysis of tissue sections by microscopy and mass spectrometry is a significant innovation that should change the way that these techniques are used together.”
Nashville, Tennessee, also known as Music City, is home to Vanderbilt University and musically connected ACS Chemical Neuroscience Editor-in-Chief, Craig Lindsley, Ph.D. ACS Axial caught up with Lindsley at his two labs, one on campus and one off, to find out what projects he is currently working on and which musicians he's recently spotted around town.

By day Lindsley is a co-Director at the Vanderbilt Center for Neuroscience Drug Discovery, where he serves as the Director of Medicinal Chemistry and Drug Metabolomics and Pharmokinetics. He is also a professor of pharmacology and chemistry at Vanderbilt University. His focus is on research that expands on possible treatments for diseases that most in big pharma have already written off—schizophrenia, autism, Parkinson’s, Alzheimer's, and rare diseases like fibrodysplasia ossificans progressiva (FOP).

At Lindsley’s on-campus lab, researchers focus on making tool compounds to publish and validate novel targets. It is home to six graduate students and two postdocs. Research from the lab has been published in ACS Chemical Biology, ACS Chemical Neuroscience, ACS Medicinal Chemistry Letters, Biochemistry, and the Journal of Medicinal Chemistry.

However Lindsley is most excited about his laboratory at the Cool Springs Life Sciences Center, a 20-minute drive from Vanderbilt’s main campus.

Built to plans that Lindsley personally oversaw only five years ago, the lab is located in an industrial park and houses a variety of lab equipment seen at biotech companies. This off-campus lab is the staff-scientist arm of the Vanderbilt Center for Neuroscience Drug Discovery, employing roughly 40 staff scientists. Here, Lindsley and team develop patented compounds for licensing. And they have been quite successful.

Results from recent research led to several patents being licensed to large...
companies like Johnson & Johnson, AstraZeneca, La Jolla Pharmaceutical Company, Seaside Therapeutics, Karuna Pharmaceuticals, and Ono. The patents in turn have paid for new research, and have helped to fund the general expenses that come from operating a 15,000-square-foot medicinal chemistry and drug metabolism and pharmacokinetics lab in this space.

On the drive to the Cool Springs lab, Lindsley spoke about his love for Nashville, his family of seven, and, per this writer’s request, some of the musicians he sees when hanging out downtown—he mentions having spotted Robert Plant and Alison Krauss, Jack White, Keith Urban, and many others who have made their homes in Tennessee.

An avid Kiss fan, Lindsley has photos of himself with Gene Simmons covering the walls of his office. Twenty years ago, Lindsley met Simmons, Kiss’ Israeli-born rock-bassist, at the first Kiss convention tour in Burbank, California. Now, he sees Simmons before shows when Kiss plays in Nashville.

Over the years, Lindsley has collaborated with other celebrities for causes including the Michael J. Fox Foundation for Parkinson’s Research, where he received initial funding for mapping out the mGlu4 PAM portfolio his group licensed to Bristol-Myers Squibb, and for which they received three years of collaborative sponsored research.

In the evenings, Lindsley is a devoted father of five, making time for family, dinner, and homework before he does a final email check.

Craig Lindsley
Selected as Thomson Reuters Highly Cited Researcher

The Department of Chemistry congratulates Craig Lindsley on being selected as a Thomson Reuters Highly Cited Researcher. Highly Cited Researchers are described by Thomson Reuters as “represent[ing] some of the world’s most influential scientific minds. About three thousand researchers earned this distinction by writing the greatest number of reports officially designated by Essential Science Indicators as Highly Cited Papers—ranking among the top 1% most cited for their subject field and year of publication, earning them the mark of exceptional impact.”
Researchers at Vanderbilt University have established the molecular basis for the function of Replication Protein A (RPA), a DNA binding protein that is a crucial “scaffold” for genome replication, response to damage and repair.

With colleagues at Yale University, they also determined that the small, highly charged protein DSS1 acts on RPA to function as an essential co-factor for the key tumor suppressor BRCA2 (breast cancer susceptibility protein 2). Individuals with BRCA2 mutations exhibit genomic instability and are predisposed to breast, ovarian, and other cancers.

In the journal *Molecular Cell*, the researchers report that DSS1 functions as a DNA “mimic” for RPA. DSS1 “remodels” RPA so it releases its strong grip on DNA to enable processing by BRCA2 and repair of devastating DNA double-strand breaks. However, DSS1 is elevated in tumor samples, and higher DSS1 expression is associated with therapy resistance and poor prognosis. Inhibition of DSS1 expression in these tumors, by alleviating resistance, could enhance standard chemotherapy, the researchers conclude.

The DSS1 studies were led by Walter Chazin, Ph.D., Chancellor’s Professor of Medicine, professor of biochemistry, and director of the Vanderbilt Center for Structural Biology; and Patrick Sung, D.Phil., Ph.D., professor of molecular biophysics and biochemistry and of therapeutic radiology at Yale. Claudia Wiese, Ph.D., assistant professor of radiation cancer biology at Colorado State University, was co-senior author of the *Molecular Cell* paper.

“This study resolves a long-standing conundrum about how DNA gets transferred from RPA to BRCA2,” said Chazin.

Sung added, “Our collaborative, multidisciplinary approach was essential for understanding the very high degree of biological and mechanistic complexity of DSS1 action at the critical initial stage of the repair of highly toxic DNA double strand breaks.”

The importance of RPA in maintaining and propagating the genome is due to its ability to bind very strongly to single stranded DNA (ssDNA). Since DNA is so important, it is stored with a complete back-up copy, and the two copies together make up the well-known DNA double helix.

This helical storage form of DNA is very stable, but in order to read the DNA code, it is necessary to unwind the double helix into its separate strands. Unwound single strands of DNA (ssDNA) are very susceptible to being damaged and readily form irregular tangles. Nature, therefore, evolved proteins such as the RPA protein in humans to protect ssDNA and keep it organized.

RPA is a very complicated protein and it has remained challenging to understand how it functions.

An important step forward was made when the Chazin group reported last month a description of the functional dynamics of RPA in the journal *Structure*. Chazin and his colleagues used NMR (nuclear magnetic resonance) techniques to define how RPA domains, portions of the protein with distinct biochemical functions, move in space.

Their work demonstrated how RPA is able to use some of its eight domains to bind to sections of DNA of interest, and simultaneously use other domains to recruit the proteins required to replicate or repair this DNA.

In a commentary written in the same journal, Patrick Loria, Ph.D., professor of chemistry and of molecular biophysics & biochemistry at Yale, noted, “In this elegant work, Chazin and co-workers show in part how the flexibility of RPA enables such a complex set of interactions to occur.”

The two studies add to the growing body of data detailing the intricacies of DNA replication and repair, and suggest it may be possible to modify the function (or compensate for the dysfunction) of various essential proteins, including BRCA2, RPA and DSS1, to stop tumor growth and improve therapeutic outcomes.

*The study in *Structure* was supported in part by National Institutes of Health grants GM065484 and CA092584. The study in *Molecular Cell* was supported in part by NIH grants ES0125252, ES007061, CA168635, CA092584 and ES021454.*
It is true that bacteria cause a number of serious illnesses. No doubt that explains the negative view that the public has about the multitude of invisible microorganisms that swarm all around us. Just look at all the anti-bacterial soaps, sprays and wipes on the market.

In recent years, however, scientists have become increasingly aware of the fact that our microbial fellow-travelers provide many benefits and have a much more profound effect on our lives than we had previously realized.

This growing realization culminated in the announcement of a high-level research initiative that would focus on the interactions between bacteria and animals and plants, including humans.

‘Microbial manifesto’

A “Unified Microbiome Initiative” was proposed by key members of the American Society for Microbiology with the backing of both the White House Office of Science and Technology Policy and The Kavli Foundation of Oxnard, CA. This call to scientific arms was made in two complimentary articles: “A unified initiative to harness Earth’s microbiomes” published in the journal Science and Microbiology and “Create a global microbiome effort” published in the journal Nature.

According to the chemist, the biologists want tools that don’t exist yet: instruments that operate non-destructively at the micron scale, can identify the small molecules that bacteria use to communicate with one another and can observe the methods the bacteria use to control their environments.

“‘Microbial manifesto’

A “Unified Microbiome Initiative” was proposed by key members of the American Society for Microbiology with the backing of both the White House Office of Science and Technology Policy and The Kavli Foundation of Oxnard, CA. This call to scientific arms was made in two complimentary articles: “A unified initiative to harness Earth’s microbiomes” published in the journal Science and Microbiology and “Create a global microbiome effort” published in the journal Nature.

Profound potential

According to the article in Science, the benefits from such a major program could be profound.

• Microbes in the soils and oceans impact the concentration of greenhouse gases in the atmosphere, so have an effect on global warming.
• Manipulating interactions between soil microbes and plants holds promise of increasing agricultural production while decreasing the need for pesticides, fertilizers and water.
• Microbes can be engineered to produce new bio-products ranging from biofuels to antibiotics.
• Management of the microbial communities in and around individuals has the potential for treatment of asthma, diabetes, obesity, infectious diseases, psychiatric illnesses and other common afflictions and is an essential tool for precision medicine.

The authors argue that a vigorous national and global public-private partnership could begin realizing these benefits within 10 years.

New tools needed

“The Kavli Foundation got this high-powered group together for its first meeting,” said Cliffe. “Then they realized that they will need new technology to achieve their goals, so they invited several of us who develop instruments of this sort to participate.”

According to the chemist, the biologists want tools that don’t exist yet: instruments that operate non-destructively at the micron scale, can identify the small molecules that bacteria use to communicate with one another and can observe the methods the bacteria use to control their environments.

“So far most of the research on bacteria has been observational. The biologists want to move from this to a hypothesis-driven approach, where they isolate a subject, perturb it in some fashion and measure how it responds,” Cliffe said. “One problem with this approach is that recent studies have found that certain bacteria in the biome cannot survive in isolation, so the very act of isolation and observation changes the system. As a result, they need the capability to simultaneously monitor the individual activities of the members of entire communities.”

According to Cliffe, his main contribution to the manifesto is its recognition that the analytic challenge involved is the biggest barrier to realizing these goals: Growth of the fledgling field of microbiomics will depend on the rate at which new instruments can be developed with multimodal imaging capabilities that allow scientists to visualize individual microbes along with their chemical interactions with other microbes and their hosts. Until then, the microbial world will remain primarily out of sight and out of mind as it has been in the past.
Richard Neil Armstrong received a B.S. degree in chemistry from Western Illinois University, and a Ph.D. degree in organic chemistry from Marquette University. He was a postdoctoral fellow at the University of Chicago, and a staff fellow at the National Institute of Arthritis, Metabolism, and Digestive Disease, National Institutes of Health, and then joined the Chemistry Department of the University of Maryland. From 1995 until his death, he was professor of biochemistry and chemistry at Vanderbilt University. Armstrong also held a foreign adjunct professorship at the Karolinska Institute in Stockholm, Sweden.

Armstrong’s research at Vanderbilt focused on how enzymes detoxify foreign molecules, including drugs, toxins, and chemicals, through a multipronged chemical, structural, and molecular approach. Armstrong was internationally known for his contributions to understanding detoxification enzymes, proteins that break down foreign and potentially harmful chemicals, drugs, and other molecules. Among other potential applications, his work could lead to new ways to prevent bacterial resistance to antibiotics.

Among many honors and recognitions, Armstrong was elected as a Fellow of both the American Association for the Advancement of Science and the American Chemical Society. He won the ACS Repligen Award, the 2014 Arthur C. Cope Scholar Award, and the Vanderbilt Stanley Cohen Award.

As a teacher, scholar, and adviser, his efforts stood among the very best. Guiding students through the rigors of chemistry and biochemistry, Armstrong emphasized fundamentals through his numerous lectures. He selflessly served the departments and community through committee work, meeting organization, grant reviews, and activities of professional societies. Remarkably, he somehow managed to find time to serve the worldwide community as editor-in-chief of Biochemistry, an honor held by only two other brilliant scientists in the journal’s distinguished 53-year history.

Armstrong, age 66, of Brentwood, died on June 18, 2015, at Vanderbilt University Medical Center, after a brief illness. He was born in Boonville, Missouri, on December 14, 1948.

He was founder and sole instructor of Uncle Ricky’s Fishing School. He was an avid and skilled pie maker, and his dedication to his annual sour cherry crop bordered on the obsessive. An avid, licensed ham radio enthusiast, he enjoyed a parallel identity as KK4MQL.

Armstrong was preceded in death by his mother, Grace, and brother, Clinton Armstrong. He is survived by his father, Ernest Neil Armstrong, and by his wife of 31 years, Mary Frances Clark, J.D.; his children, Kathryn Grace Armstrong and Andrew Clinton Armstrong; and many other family members, colleagues, and close friends.
Jens Meiler, associate professor of chemistry and associate professor of pharmacology—Meiler’s research seeks to fuse computational and experimental efforts to investigate proteins, the fundamental molecules of biology, and their interactions with small molecule substrates, therapeutics, or probes.

Fifteen faculty members hailing from a diverse cross section of disciplines have been selected as the first cohort of the Chancellor’s Faculty Fellows program: Muktar Aliyu (Health Policy/Medicine), Holley Bocklemann (Physics and Astronomy), Stella Flores (Sociology), Scott Guelcher (Biomedical Engineering), Peter Kolkay (Bassoon), Borden Lacy (Chemistry), Jens Meiler (Chemistry), Bunmi Olatunji (Psychiatry), Andrea Page-McCaw (Cancer Biology), Kristopher Preacher (Psychology and Human Development), Bernard Rousseau (Hearing and Speech Sciences, Mechanical Engineering), Sean Seymore (Law), Daniel Sharfstein (Law), Rachel Teukolsky (English), and Sharon Weiss (Electrical Engineering/Physics).

“The strong commitment to education, discovery and care demonstrated by these faculty members is having an enormous impact on Vanderbilt and its mission of serving society,” Chancellor Nicholas S. Zeppos said. “Already proven leaders and innovators in their fields, we have chosen to further invest in them at this critical point in their careers to ensure they have ample resources and opportunities to build their own body of work and to serve as outstanding mentors to post-doctoral scholars, graduate students and undergraduates.”

The faculty members will hold the title of Chancellor’s Faculty Fellow for two years and be supported by an unrestricted allocation of $40,000 a year for two fiscal years to begin July 1, 2015. The funds can be used to support innovative research, scholarship, and creative expression activities that will further propel the career of the awardee.

The Chancellor’s Faculty Fellows will also meet as a group during the course of their awards to foster exchange of research interests and build a broader intellectual community that advances trans-institutional scholarship.

David Wright, Ph.D., Stevenson Professor of Chemistry and Chairman of the Department of Chemistry, has been elected a fellow of the American Association for the Advancement of Science (AAAS) this year for exceptional contributions to bioinorganic chemistry and its application to infectious disease diagnosis and treatment, particularly in the fields of malaria and RNA viruses.

He is among 401 fellows from around the country selected by their peers because of their “scientifically or socially distinguished efforts to advance science or its applications.”

Vanderbilt now has 106 AAAS fellows among its current and emeritus faculty and staff. More than half of the fellows—59—were elected during the last four years, reflecting remarkable momentum and growth of the university’s academic reputation.

“We are very proud of the contributions of these outstanding faculty to discovery and learning, which enriches the entire university,” Provost and Vice Chancellor for Academic Affairs Susan R. Wente said. “In addition to their remarkable scientific contributions, we’re additionally gratified that several have been recognized for their service to the scientific community, mentoring, and efforts to increase diversity in the sciences.”

The new fellows will be recognized on Feb. 14 at the 2015 AAAS annual meeting in San Jose, California. For more information on AAAS fellows, visit the AAAS website.

VUMC Academic Enterprise Faculty Award Winners Announced

The 2015 Vanderbilt University Medical Center Academic Enterprise Faculty Awards, which were presented during the May 19 Spring Faculty meeting, included awards for Excellence in Teaching and Outstanding Contributions to Research. Award recipients were nominated by their faculty colleagues and chosen by the Academic Enterprise Faculty Awards Selection Committee. Richard Caprioli, Ph.D., Stanford Moore Chair in Biochemistry; professor of medicine, pharmacology, and chemistry; and director, Mass Spectrometry Research Center, was awarded Leadership of a Multi-investigator Team Award for Faculty Working Collaboratively or in a Multidisciplinary Manner to Address Important Biological Processes and/or Diseases.
Nathan Schley was born in Chicago, Illinois, and raised in Sacramento, California. He completed a B.S. in chemistry at the University of California, Davis, in 2007. While at Davis he performed undergraduate research in the lab of Prof. Philip Power on tin hydrides stabilized by bulky ortho-terphenyl ligands.

From Davis he moved to Yale University for his graduate work where he joined the lab of Prof. Robert H. Crabtree. At Yale, Nathan focused on catalysis related to issues of sustainability, including developing catalysts for acceptorless alcohol oxidation and examining the mode of action of a family of iridium half-sandwich complexes as catalysts for water oxidation.

After completing his Ph.D. in 2012, Nathan joined the laboratory of Prof. Gregory C. Fu at the California Institute of Technology as an NIH Postdoctoral Fellow. While working in the Fu group, Nathan studied the mechanism of a series of nickel-catalyzed cross-coupling reactions. In the case of nickel-catalyzed stereoconvergent propargylic arylation, he found evidence for an unanticipated radical chain reaction with a diamagnetic nickel(II) resting state. Radical chain reactions are a well-studied class of reactions that can give rise to new carbon-carbon bonds, but this work for the first time implicated a radical chain in stereoconvergent nickel-catalyzed cross-coupling.

Schley began his independent career at Vanderbilt in 2015 and now leads a research group devoted to developing new, selective catalysts for oxidative transformations of C-H bonds. The aim of the Schley group is the application of organometallic chemistry to unmask latent reactivity in organic substrates. Oxidation of simple hydrocarbons provides functional groups which serve as handles for further transformations, but methods for selective oxidation of C-H bonds are limited both in scope and by the factors which dictate selectivity. Our goal is to meet the challenge of enabling new oxidative, catalytic transformations of C-H bonds by making use of unconventional substrate activation strategies.

Recent developments in transition metal catalysis have shown that ligands that actively participate in chemical transformations have the potential to have a profound impact on the reactivity of metal ion in catalytic transformations. Broadly speaking, ligand participation can include redox non-innocence, involvement in concerted heterolytic bond formation or cleavage, and the ability to engage in activating, secondary coordination-sphere interactions with the substrate. We aim to introduce a diversity of functional ligands as supporting platforms for catalysis that make use of these and other modes of ligand participation in catalysis. Our long-term goal is to capitalize on the ability of functional ligands to define the reactivity of the supported metal ion to develop new non-precious metal catalysts for existing catalytic transformations requiring platinum-group metals.

We can take inspiration from Nature to develop new strategies for approaching many of these goals. Nature has evolved highly specialized metal-containing enzyme active sites for a variety of
challenging transformations, and it has done so primarily through the use of earth abundant transition metal ions rather than rare, platinum-group metal ions. In addition to enzymes containing a single metal ion, bi- and polymetallic active sites are critical to the function of certain enzymes. The use of two similar or dissimilar metal ions in a single ligand platform offers the potential to exploit the resulting reactivity of bridging ligands and intermediates in catalysis. Our studies in this area will center on the production of reactive late-metal μ-hydroxides under aerobic conditions. The reactivity of late-metal hydroxides and alkoxides towards C-H bonds has been attributed to dπ-pπ repulsion between the filled orbitals with π-symmetry in late-metals and π-basic hydroxides, as well as the availability of concerted mechanisms for bond activation. By making use of heterobimetallic μ-hydroxides incorporating one early metal and one late metal, we can modulate the redox potentials and π-basicity of the resulting μ-hydroxides which will allow us to develop new hydrocarbon oxidation protocols.

**David Kort Joins Chemistry Faculty as Senior Lecturer**

David Kort has joined the faculty in the Department of Chemistry as a senior lecturer. In addition to General Chemistry, and Inorganic Chemistry, he will also be teaching Advanced Integrated Laboratory.

Kort received his Bachelor of Science degree from Hope College in Holland, Michigan, in 1991. He earned his Ph.D. from Purdue University in West Lafayette, Indiana, in 1997 with an emphasis in inorganic chemistry.

Kort comes to us most recently from George Mason University where he earned a reputation as a fair and entertaining lecturer. He has taught across disciplines teaching general chemistry and inorganic chemistry as well as many upper-level courses. He also served as director of laboratory services. Kort contributed to the development of the laboratory curriculum, developing experiments and procedures for general chemistry, organic chemistry and transition metal chemistry.

**Alissa Hare Joins Faculty as Senior Lecturer**

Alissa Hare has joined the faculty in the Department of Chemistry as a senior lecturer. She teaches sophomore organic chemistry and physical organic chemistry.

A native of Indiana, Hare earned her bachelor of science degree in chemistry in 2006 from Calvin College, Grand Rapids MI. She attended Yale University for graduate school where she worked under Professor William L. Jorgensen on development of small molecule antagonists for the protein Macrophage Migration Inhibitory Factor (MIF). Hare completed her Ph.D. in 2012 and was awarded the Richard Wolfgang Thesis Prize from Yale University.

For her postdoctoral work, Hare moved to Caltech, where she became a NIH NRSA Fellow with Professor Peter B. Dervan. Her research focused on the development of Py-Im polyamides, sequence specific DNA binding molecules, for the treatment of prostate cancer.
One of the main research thrusts in the lab of Professor Sandra J. Rosenthal involves studying the structure and properties of individual quantum dots. These tiny nanomaterials are promising candidates for improving the energy efficiency of many of the electronics that we use every day, such as televisions, smartphones, tablets, and overhead lighting. Adding to their versatility, quantum dots can be chemically synthesized to absorb and emit any desired wavelength of visible light. This high level of tunability is part of what makes quantum dots unique, and why implementation into commercially available televisions (QDVision) and tablets (Amazon Kindle Fire*) has recently come to fruition.

Even though quantum dots are very small (usually containing hundreds to thousands of atoms) and are typically considered cubic, small variations in size and shape are persistent. A standard synthesis will result in trillions of individual quantum dots—many of which fail to emit light at all, reducing the efficiency of any device made with these materials. Most quantum dot studies investigate the properties of millions of these quantum dots at a time (the ensemble); this gives researchers a good idea of the average properties, but an abundance of information about dot-to-dot variation is not collected. This approach would be similar to assuming that, because the average height of American females is 5’4”, every female you encounter will be this height! Taking a census of the height of a large number of individuals allows resolution of a much more complete picture of the distribution of heights in the country.

In the same way, every quantum dot is unique. The placement and composition of atoms making up these nanometer-sized heterostructures vary due to the nature of the high-temperature synthesis used to create the quantum dots. For this reason,
ensemble characterization techniques are inadequate to provide a full understanding of the fine details dictating extremely important parameters such as quantum yield, photobleaching, and photocharging—factors that must be optimized for quantum dot technologies to compete on a commercial scale.

Although the process of sorting out and measuring single quantum dots sounds daunting, Professor Rosenthal and her group were unfazed by the magnitude of this task, as demonstrated by their work published in ACS Nano this spring (Orfield et al., 2015, 9(1), 831–839). Using high-resolution microscopy, researchers in the Rosenthal group have been able to select a single quantum dot at a time and collect light from it. Subsequent high-resolution electron microscopy (performed with Vanderbilt’s Tecnai Osiris scanning transmission electron microscope) on the exact same quantum dot revealed the structure of the individual atoms that make up that quantum dot, and allowed correlation of the precise structure with the unique light-emitting properties. In this way, the group has been able to study what makes individual quantum dots unique—information that provides new ideas for how to fully control the properties of quantum dots. The database of knowledge that is being acquired will allow future chemists to create even more cost- and energy-efficient quantum dots that will aid in reduction of the nation’s energy consumption.

In a size regime where every atom counts, rational design and synthesis of optimal nanostructures demands direct interrogation of the effects of structural divergence of individuals on the ensemble-averaged property. To this end, we have explored the structure–function relationship of single quantum dots (QDs) via precise observation of the impact of atomic arrangement on QD fluorescence. Utilizing wide-field fluorescence microscopy and atomic number contrast scanning transmission electron microscopy (Z-STEM), we have achieved correlation of photoluminescence (PL) data and atomic-level structural information from individual colloidal QDs. This investigation of CdSe/CdS core/shell QDs has enabled exploration of the fine structural factors necessary to control QD PL. Additionally, we have identified specific morphological and structural anomalies, in the form of internal and surface defects, that consistently vitiate QD PL.
At Vanderbilt, potential collaborators can be found down every hallway. Sometimes, though, the perfect collaborator may be much closer to home. This was the case for graduate students Michelle Mitchener and Erin Shockley, members of the Chemistry Department and the Chemical and Physical Biology program, respectively.

Mitchener, who hails from Troy, Michigan, and Shockley, who comes from Parkersburg, West Virginia, first met while attending Cedarville University in Ohio to pursue undergraduate degrees in chemistry. "Perhaps it was our liberal arts upbringing that first led us to think about various scientific disciplines in an integrative manner," Mitchener mused, adding that she chose to pursue graduate studies through the Chemistry Department at Vanderbilt because of their emphasis on interdisciplinary scientific research.

Shockley entered graduate school at the same time, but through the Quantitative and Chemical Biology admissions program, which accepts students from primarily quantitative science backgrounds who desire to use that knowledge to study biological systems. She cites the program’s emphasis on varied lab rotation experiences as a primary reason for choosing Vanderbilt, saying, "Had I not been encouraged to try very different types of research, I might not have learned that I prefer computational research over wet lab projects."

Shockley and Mitchener moved to Nashville in 2012 to begin their graduate studies and continued to be roommates, just as they had during their undergraduate years. However, each joined very different types of labs; Mitchener joined the Lawrence J. Marnett Lab, an experimental lab that studies the role of bioactive lipids in inflammation and disease, while Shockley joined the Carlos F. Lopez Lab, a computational lab that models complex networks of cancer-related proteins. "Our labs really couldn’t be more different—let
alone our day-to-day research work,” said Mitchener.

Yet, their research paths were to cross only a few years into their respective programs. Mitchener was studying cyclooxygenase-2 (COX-2), a target of the pharmacologic actions of common nonsteroidal anti-inflammatory drugs, including Advil and Aleve. Purified COX-2 metabolizes its canonical substrate, arachidonic acid, and the endocannabinoid, 2-arachidonoylglycerol, with approximately equivalent efficiencies; however, in cells, the COX-2 oxygenation products of arachidonic acid exceed those of 2-arachidonoylglycerol by 500-1000-fold. Previous studies revealed that COX-2, while a structural homodimer, acts as a functional heterodimer, with one subunit acting as a catalytic site and the other as an allosteric site. Thus, Mitchener and colleagues hypothesized that differential interaction between the two substrates for the subunits of COX-2 might account for the disparate product levels observed in cells. After demonstrating an inverse correlation between arachidonic acid levels and 2-arachidonoylglycerol oxygenation by COX-2 in macrophages, Mitchener et al. turned to kinetic studies utilizing both substrates and purified COX-2 in attempt to understand this cellular phenomenon. “We found that no single, classical kinetic model was able to represent the resulting data well,” Mitchener explained, adding, “At that point, I was pretty certain that we were going to need help.”

She didn’t have to look far. “Erin and I usually talk about work over dinner, so I knew the types of projects she was working on and that she might be able to help,” Mitchener said. Shockley, who normally codes complex networks of hundreds of proteins, considered Mitchener’s two substrate-two enzyme subunit system simple by comparison. Shockley encoded the possible substrate-enzyme subunit interactions and calibrated a model to Mitchener’s experimental kinetics data. The result? A computational model that fit the experimental data, revealing that competition between substrates for both the catalytic and allosteric sites results in complex regulation of COX-2 that leads to its preferential oxygenation of arachidonic acid.

“Beyond these immediate conclusions, I think this work will have a broader impact on how scientists study COX-2 in the future; now, research involving substrates, inhibitors, and allosteric modulators must entail considering interactions of these molecules with both the catalytic and allosteric subunits of the enzyme,” Mitchener explained. Shockley added, “The modeling approach we used is also broadly applicable to other multimeric proteins. Unlike traditional kinetic modeling that gives single fitted parameters, the modeling we used here yields a range of possible kinetic parameter values that fit the data and their associated probabilities. This allows us to make more definitive statements about our results, specifically the degree of confidence we can have in each modeling-based assertion.”

The duo has submitted the results of their combined efforts to PNAS and it has been accepted for publication.

This work was supported by the National Institutes of Health under grants CA089450 and GM15431 (to L.J.M.), and K22CA151918 (to C.F.L), the National Science Foundation under grant MCB-1411482 (to C.F.L), and the Edward P. Evans Foundation (to C.F.L). M.M.M. and E.M.S. were supported by U. S. Public Health Services Grant T32 ES007028.
The current global economic and environmental landscape has accelerated research into carbon dioxide (CO₂) technology across a broad range of chemical disciplines. The most notable advancements have been made in the areas of materials chemistry, polymers, and amine-based “scrubbing” system to capture CO₂ pollutants from industrial processes. Although the threat of carbon dioxide accumulation as a greenhouse gas has inspired numerous sequestration strategies, this gaseous reagent holds immense potential value as an abundant and nontoxic C₁–building block for carbon-carbon bond formation and carbon-heteroatom functionalization reactions in chemical synthesis. Unfortunately, the underlying features that contribute to carbon dioxide’s low general toxicity and ease of handling render it relatively inert as a chemical reactant.

Imparting a specific chirality or ‘handedness’ into small molecules is often the key to achieving desirable properties in materials, such as potency and selectivity in drug development. Chemical reactions that achieve this—referred to as enantioselective—have grown exponentially over the past half century, leading to a collection of techniques and approaches that serve as readily accessible tools for organic synthesis. Yet, very few established methods exist incorporating carbon dioxide in such a way. To expand the utility of CO₂ as a chemical reagent in organic synthesis, new mild catalytic reactions are needed to mimic Nature’s elegant enzymatic reactivity and to overcome carbon dioxide’s relative inert properties and narrow synthetic scope. There are highly evolved models within Nature to consider from the standpoint of biomimetic catalysis, including the magnesium and hydrogen bonding-dependent enzyme ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), one of the most abundant protein complexes on the planet. RuBisCO incorporates CO₂ through carbon-carbon bond formation into glucose precursors.

As a member of the Johnston Group at Vanderbilt University, I have dedicated my graduate career to exploring new modes of reactivity using various organocatalysts designed within the group, using...
some of the basic elements of life—carbon, nitrogen, and hydrogen. These catalysts are air and moisture stable solids that can be easily weighed out and used from one reaction to the next. Additionally, these catalysts can be constructed from a readily available chiral diamine backbone, allowing for highly enantioselective reactions. To date, these catalysts have been widely efficacious in the aza-Henry reaction—the products of which can be manipulated into anti-tumor compounds, lead molecules targeting Chagas disease, and non-natural amino acids.

For this current project, we posited that a properly balanced Brønsted acid–Brønsted base organocatalyst could lower the barrier to CO2 incorporation and/or assist in the stabilization of the resulting addition product between a homoallylic alcohol starting material and CO2. Following this critical CO2-fixation step, the transient carbonic acid could then act as an oxygen nucleophile in a subsequent enantioselective iodonium ring-opening reaction and forge a new carbon–oxygen bond in the process. This process is formally known as an iodocyclization, and is an effective approach to creating new chiral centers using an iodine (I+) source and an alkene. If this could be achieved using a metal-free catalyst—an organocatalyst—the virtues of minimalism would apply, suggesting easy implementation and broad impact. We validated this design by developing a carboxylation/alkene functionalization reaction of homoallylic alcohols to produce chiral cyclic carbonates (Vara et al. J. Am. Chem. Soc. 2015, 137, 7302–7305).

Throughout the optimization process, we arrived at highly robust conditions using just a balloon of CO2 (1 atm) and employing a catalyst designed in the Johnston group called StilbPBAM. The chiral diamine backbone (see image) along with the achiral Brønsted acid, triflimidic acid or HNTf2, was found to be essential for high enantioselectivity in this reaction. This Brønsted acid/base catalyst system was able to achieve up to 95% ee (enantiomeric excess; a ratio of 97.5 to 2.5 favoring one enantiomer to its mirror image) in the assembly of the desired iodocarbonates. A more unusual finding during optimization was the implementation of molecular sieves (MS 4A) and its correlation with improved yields. After careful control experiments, we found that the slightest amount of water in the reaction (<1 μL H2O) was a significant hindrance in the progression of the catalytic cycle and ultimately resulted in catalyst poisoning and deactivation. The culprit for this deactivation pathway is hypothesized to be carbonic acid (CO3H2, formed by the addition of water to CO2 in the presence of a suitable base). The formation of carbonic acid fortunately appears reversible, reverting to active catalyst when MS 4A are added. In total, 15 new chiral carbonate compounds were prepared using this novel enantioselective approach.

Since these types of chiral iodocarbonates have never been prepared previously, we wanted to explore various derivatizations of these compounds in hopes of better articulating the use of these unique, CO2-containing molecules. The carbonates show wide utility accessing chiral oxygenated small molecules, some of which are challenging to prepare using other enantioselective methods. Additionally, upon reduction we can arrive at chiral 1,3-diols (see image). CO2 is expelled in the process and is formally reduced to methanol or a methanol derivative. Ongoing efforts in the Johnston Research Group are focusing on additional ways to use CO2 that may ultimately benefit the organic chemistry community.

Research reported in this publication was supported by the National Institute of General Medical Sciences (NIH GM 084333).
Ion Mobility Mass Spectrometry as a separation technique for identifying complex biological mixtures

Mass spectrometry measures a particular compound’s mass-to-charge ratio, or, simply put, its molecular mass. Ion mobility, however, measures a chemical’s three-dimensional shape.

In the McLean Lab at Vanderbilt, our studies explore the potential of utilizing ion mobility mass spectrometry as a separation technique that aids in the identification of complex biological mixtures. The ion mobility cells in our instruments provide a separation in supplemental fashion to information gained by mass spectrometry alone. While both techniques (ion mobility and mass spectrometry) have been around for several decades, these two analytical methods have only been recently employed in a simultaneous fashion.

Part of the beauty of meshing both ion mobility and mass spectrometry is that both techniques measure different chemical properties; and, hence, possess the capability to separate molecules in two dimensions. Mass spectrometry measures a particular compound’s mass to charge ratio, or simply put its molecular mass. Ion mobility, however, measures a chemical’s three-dimensional shape. In general, as a compound gets more massive, the shape also increases. However, as it turns out, for different biological systems of interest (lipids, proteins, carbohydrates, etc.) generally one of those biological classes has a different shape for a given mass. Ion mobility allows us to separate compounds that the mass spectrometer cannot differentiate alone due to this varying size/shape ratio.

One of our most recent publications aims to discuss various ways to improve the ion mobility device and optimize operating conditions in order to resolve (distinguish) between compounds with similar masses. In this light we have explored the main metric of quantifying how well our ion mobility device functions, commonly termed as an ion’s resolving power. Resolving power is a general term that describes the sharpness of a peak in a given spectrum. The term itself is taken from mass spectrometry, but, is similar to the idea of number of theoretical plates in liquid chromatography. Basically, a higher numerical resolving power instrument will give you more chances to separate one component from another in a given mixture. This selectivity allows for more complex samples to be analyzed in a given mixture while preserving identifiable components.

The two main components that affect an ion’s resolving power in our instrument are the drift voltage and the ion gate width. The drift voltage is an applied field that pushes our compound of interest through the neutral drift gas. Smaller ions travel faster under a given applied field, and larger ions travel slower. This process is similar to size-exclusion chromatography or a gas phase gel electrophoresis. The gate width is essentially the size of the ion pulse that is sent into the instrument at a given time. Smaller ion packets typically have smaller Columbic repulsive forces, but they also yield a smaller signal. This effect generally results in the typical analytical tradeoff between sensitivity and selectivity.

To begin our analysis we needed to select a compound to test which provided strong...
signal in a consistent fashion in order to alter each of the instrumental parameters and still possess usable data. Ultimately, we decided to analyze a tuning mixture provided by our instrument designer, Agilent Technologies, which is commonly used to set the mass calibration for our mass spectrometer. Not only does this mixture of fluorinated nitro-carbons ionize readily, but in the mixture we can measure about 10 molecules or so for one given analysis. This allows data to be collected from one sample run with information about multiple peaks.

After selecting our control mixture, we set out on varying our experimental parameters. During our testing we varied the drift tube voltage from 7-21 V/cm. We noticed that our peak width was optimized with the retention time in the drift tube at about 14 V/cm. It seems this setting provides an adequate compromise between ion transmission, peak width and drift time. Also, the gate width was varied from 100-500 µs and the resolving power was recorded. An optimum setting of about 150-200 µs for this parameter was chosen to provide improved ion transmission with minimal losses given to peak width.

Next, to ensure the robustness of our findings, we tested other chemical compounds to see if routine samples would follow these trends. We chose various biological classes (carbohydrates, peptides, and salts) to see if the new parameters were applicable to other compounds as well. In short, most chemicals analyzed on this instrument so far agree with our findings. Larger complexes such as proteins like myoglobin and ubiquitin may not follow these trends in correlation to their massive size, and are currently being studied by other members of our research group.

Our study also applied our resolving power data to the current theory in the field to see if our results matched the expected values predicted from equations generated from first-principles. It turns out that most of our data did indeed line up for routine conditions, but current theory in our area still needs refinement for extreme areas of very large and very small chemical compounds (proteins and metabolites, respectively). In our analysis we provided a detailed adjustment to some of the proposed equations that will more closely agree with current data.

In short, our study was able to effectively analyze two of the key components that detail an ion mobility spectrometer’s efficiency, and provided insight into how some of these instrumental components should be handled. This study allows other researchers in the field to use our findings to provide more accurate data in a more time efficient manner. Hopefully we have paved the way for other like-minded scientists to apply our findings and optimize their instruments for analyzing biologically relevant samples. A full version of our paper is published in the Analyst journal and is available for view online. The title is: "Broadscale resolving power performance of a high precision uniform field ion mobility-mass spectrometer." The authors are: Jody C. May, James N. Dodds, Ruwan T. Kurulugama, George C. Stafford, John C. Fjeldsted, and John A. McLean.

Support for this research came from the National Institutes of Health National Center for Advancing Translational Sciences (NIH-NCATS Grant 4UH3TR000491-3) and the National Science Foundation (MRI CHE-1229341).
**Katherine Chong, Sulikowski Lab**

Natural products contain novel scaffolds and further our understanding of biological phenomena through their use as selective chemical probes. In fact, three fourths of small molecule anticancer drugs are natural product based, with almost half of those molecules being natural products themselves or derived therefrom. Despite their vast utility, recent efforts have moved away from the use of natural products in drug screenings due to their challenging total syntheses and subsequent derivation. As typical "low hanging fruit" is scooped by current drug discovery methods, we begin to traverse an area of pharmaceutical research in which we must move into new chemical space. The demand for new scaffolds is ever increasing, to produce selective therapeutic agents in drug discovery—the "holy grail" in the industry being the ability to discriminate disease states from healthy cells. To do so, requires an in-depth understanding of fundamental biological phenomena. Glycosylated natural products have long been explored for their excellent antitumor activity. We have found apoptolidin to have sub-nanomolar activity against tumor cells when glycosylated. When the sugars are removed, the aglycone loses activity (> 10 μM, H292 cells, human lung cancer). Accessing variants of apoptolidin as a function of glycosylation state will enable us to examine the role deoxy sugars play in the cytotoxicity profile of the apoptolidins against varying cancer cell types. As each cancer cell type displays a unique metabolic profile, and notably distinct from healthy cells, we hope to use our toolbox of apoptolidin glycovariants in the quantification of cellular uptake, localization, and subsequent activity as a function of glycosylation state of the apoptolidins and metabolic state of each cancer line. To access our apoptolidin glycovariants, we aim to combine techniques utilizing chemical synthesis, precursor directed biosynthesis, and biosynthesis. Herein describes our efforts toward the chemical synthesis of apoptolidinone C and preliminary results utilizing phospho-specific flow cytometry to measure cellular uptake and response of the apoptolidin glycovariants.

**Anna Davis, Cliffel Lab**

Organ-on-a-chip (OoC) systems are designed to more realistically mimic in vivo cellular responses than traditional two dimensional tissue culturing platforms (such as well plates and culture flasks). The Vanderbilt Institute for Integrative Biosystems Research and Education (VIIBRE), in collaboration with other institutions across the country, have been working to develop different OoCs to monitor responses to pharmaceuticals or environmental toxins. For meaningful information to be determined from long term studies on OoCs, the health of the cells needs to be monitored to observe real-time toxicological events and ensure the viability of additional results produced. Previous work has been done in the Cliffel lab using modified screen printed electrodes in a 26µL chamber to detect changes in cellular glucose metabolism; however, the volume of effluent produced from smaller OoCs require lower sample volumes for real-time analysis of cellular energetics. Additionally, gas permeable materials used to produce OoCs introduce the possibility of evaporation from circulating media, which could result in hypertonic stress causing damage to cellular processes or apoptosis. As water evaporates from the media, the concentrations of ions increase, resulting in increased solution conductivity which can be measured using electrochemical impedance techniques. A nanoelectrode array has been fabricated using electron beam deposition and soft lithography and modified with electrodeposition and ink-jet printing techniques. The modified sensor was utilized to perform electrochemical detection of glucose, lactate, oxygen, conductivity and acidification in a sub-microliter multichannel PDMS sample chamber. Once developed the nanoelectrode array will be used to make automated offline measurements from small volume OoCs.
Amanda Duran, Meiler Lab

AIMS: Genetic variations can predispose humans to a number of diseases including cystic fibrosis, long-QT syndrome, and Alzheimer’s disease. Many single nucleotide variations have been linked to loss of function. This is likely because the variations cause a small change in the protein structure which can affect its thermodynamic stability. We propose to use the Rosetta Molecular Modeling Suite to predict whether mutations are destabilizing. Furthermore, the computational models can be used to understand how the mutations affect the structure of the protein. This information can be valuable for determining which therapies are best suited for the particular protein variant.

METHODS: The focus of this study is for membrane proteins, including multi-meric proteins. Few studies have looked at these systems. Rosetta includes both a membrane and symmetry mode which makes it ideal for this study. Existing structures of the wild-type proteins are used to create models with the mutation. The total energy of the wild-type and its respective variants are compared to experimentally reported values for ΔΔG unfolding. Nearly 90 variants of bacteriorhodopsin, rhomboid protease GlpG, and disulfide bond formation protein B were modeled.

RESULTS: The AUC for the improved Rosetta Design protocol was 0.718 which indicates that Rosetta can often correctly predict a mutation to be destabilizing.

CONCLUSIONS: The protocol has only tested a specific system with limited experimental data. Additionally, the protocol has not been optimized for minimizing input structures. We plan to continue to test a diverse set of proteins and their variants to fully benchmark Rosetta Membrane and Membrane + Symmetry for a thorough understanding of how accurately Rosetta can predict the stabilizing effects of mutations.

Alex Geanes, Meiler Lab and Lindsley Lab

In recent years, virtual high-throughput screening (vHTS) techniques have been successfully applied to the drug discovery process. In many cases, these vHTS techniques are leveraged to prioritize subsets of chemical libraries for acquisition and testing in physical screens. However, the chemical space that is relevant to a particular pharmacological target may not be reflected in pre-made compound libraries, and as such it is advantageous to have algorithms which are capable of designing new chemical structures, a process known as de novo design. An evolutionary algorithm was implemented as part of the BCL::ChemInfo suite within the Biochemistry Library (BCL), a C++ library developed in the Meiler laboratory, to iteratively generate sets of compounds for use as focused libraries. At each step of the algorithm, sets of compounds are evaluated for their biological “fitness” using machine-learning based quantitative structure activity relationship models which correlate two- and three-dimensional molecular properties with biological activities. The best-scoring molecular structures are then modified or mixed together to generate a subsequent set of candidate compounds. These steps are repeated until a desired biological activity score is attained. Here we present the results of this focused library design application, BCL::EvoGen.

Drew Kellum, Stone Lab

2´-Deoxyribosylurea (urea) lesions within DNA form from the cleavage of thymine with hydroxyl radicals as a consequence of exposure to ionizing radiation. In addition, urea lesions are formed from oxaluric acid, a lesion results from the reaction of singlet oxygen with 8-oxoguanine, in vitro under salt concentration that are relevant to cells. Previous NMR studies of urea lesions on the nucleoside level showed the equilibration of alpha (α) and beta (β) anomers on the 2´-deoxyribose ring. Here, we investigated a urea lesion within the oligodeoxynucleotide 5´- (CTXA)-3´ (X=urea) in single strand DNA. Reverse phase HPLC revealed the presence of two different species at a ratio of 1:1. NMR spectroscopy corroborated this finding along with identifying the two different species. NMR NOESY and TOCSY experiments were used to assign the resonances of the different nucleotides by a process of elimination method. NOESY experiments confirmed the identity of the two different species as the α and β anomic configurations of the urea lesion. In addition, NMR TOCSY and one-dimensional experiments in water showed that urea lesion remained in the trans conformation between the H1´ and NH amino proton regardless of the anomic configuration. Future experiments will investigate the urea lesion at a primer-template junction as well as in duplex DNA.
Four Chemistry Students Win NSF Graduate Research Fellowship

The National Science Foundation named four Vanderbilt graduate researchers to be recipients of Graduate Research Fellowships. The program is aimed at aiding individuals who have demonstrated notable potential early in their research career. An additional goal is increasing the diversity of the science and engineering workforce, including geographic distribution and the participation of women, underrepresented minorities, persons with disabilities, and veterans.

The NSF GRF provides three years of support within a five-year fellowship period. With a $34,000 annual stipend and $12,000 cost-of-education allowance, the fellowship supports 2,000 graduate students in science and engineering nationwide.

**Jade Bing**

Jade Bing is a second-year graduate student in the Johnston Lab, doing organic synthesis. Bing found that scientific research created an avenue by which she could support, teach and encourage other first-generation, low-income, disabled, or minority students like herself.

As a child, Bing suffered from Guillain-Barre Syndrome, an acute inflammatory demyelinating polyneuropathy that caused prolonged paralysis in her legs and arms. With no known cure for the disease, she engaged in years of physical therapy to regain her ability to walk. This experience motivated her to gain a mechanistic understanding of chemistry and biochemistry to uncover new reactions and apply them in the synthesis therapeutics, particularly for rare diseases. As an undergraduate at Rider University, Bing was a Ronald E. McNair Scholar, Leadership Alliance Fellow, and ACS Project SEED mentor and went on to work as research coordinator and counselor for the McNair program upon graduation.

Bing joined the Johnston laboratory to pursue chemistry that is mechanistically innovative, medicinally relevant, and often aligns well with the principles of green chemistry. Currently, she is working towards the on-demand synthesis of peptides that contain non-natural amino acids. Specifically, she is developing an efficient, enantioselective synthesis of non-natural, electron-rich aryl glycines and tyrosine derivatives. This approach uses bromonitromethane as an unusual precursor to the amide carbonyl. These residues can be used to construct biaryl or biaryl ether bonds, a motif commonly found in peptide therapeutics. However, the aryl glycine residues are known to be racemization-prone when used in traditional peptide synthesis, making them prime candidates to be synthesized by a novel amide bond forming reaction discovered in the Johnston laboratory. Increasingly large peptides have been successfully prepared by this method. Bing will employ stereoselective, organocatalyzed reactions to generate bromonitroalkane donors for use in Umpolung Amide Synthesis (UmAS) to ultimately synthesize peptides for therapeutic development.

**Alex Geanes**

Alex Geanes is a recent recipient of the NSF Graduate Research Fellowship Program award, and is currently pursuing his Ph.D. in chemistry at Vanderbilt University. He is a second-year graduate student in the Jens Meiler and Craig Lindsley labs.

Geanes received undergraduate degrees in chemistry and mathematics with honors from Purdue University in West Lafayette, Indiana. His research career started his freshman year at Purdue in Dr. Tong Ren’s laboratory, where he worked to develop molecular wires and catalysts based around diruthenium paddlewheel complexes. Between his junior and senior years Geanes participated in the Snyder Scholarship program at the University of Illinois Urbana-Champaign. During his time at UIUC he worked under Dr. Scott Denmark, a synthetic organic chemist, to synthesize chiral ligands for use in asymmetric palladium-catalyzed cross coupling reactions. After graduating from Purdue, Geanes spent a year as a student intern at the Pacific Northwest National Laboratory in Richland, Washington, where he performed quantum-mechanical calculations to investigate how oxidizing chemicals interact with components of spent nuclear fuel.

At Vanderbilt, Geanes is co-advised by Dr. Jens Meiler, a computational structural biochemist, and Dr. Craig Lindsley, a medicinal and organic chemist. His graduate research focuses on the development and application of ligand-based computational algorithms to aid the drug discovery process. The research consists of a computational portion wherein Geanes writes programs to expedite and inform the drug discovery process, and an experimental component where he uses those programs to direct the chemical synthesis of drug-like compounds relevant to a specific medicinal chemistry project.

Geanes’ GRFP proposal centered around the design and application of a computational algorithm that makes use of a series of biological activity models to generate molecular structures that are likely to exhibit strong interactions with specific biological targets. This proposal was inspired by his current research,
and Geanes plans on pursuing the goals he outlined in his GRFP proposal during his graduate career.

When asked about the best part of receiving the GRF, Geanes said, “It will take a lot of the worry off of my shoulders since now I can focus on research without concern as to where my funding is coming from, and will free up a lot of project money that would otherwise go to paying my stipend and tuition. Also, the access that I will have to the NSF’s supercomputing resources will really help in developing these computational methods since they can require pretty substantial computing power.”

**Laken Kendrick**

Laken Kendrick is a first-year graduate student in the Vanderbilt Graduate Program in Chemistry. She has joined the polymer chemistry lab of Professor Eva Harth.

Kendrick is from Hattiesburg, Mississippi, and obtained her undergraduate degree in polymer science from the University of Southern Mississippi (USM) in June 2015. She discovered her desire to pursue a research career during a summer research experience at USM after finishing high school. Through continued research involvement during her undergraduate career, Kendrick was awarded a Barry M. Goldwater Honorable Mention and a university research grant that funded her senior honors thesis.

Kendrick chose to pursue her graduate education in chemistry at Vanderbilt to explore the use of polymers in biomaterials. She is especially interested in the development of biodegradable polymers for use in biomedical applications, such as drug delivery, medical device coatings, and tissue engineering.

**Melinda Shearer**

Melinda Shearer, a former Vanderbilt undergraduate who earned her bachelor’s degree in chemistry in May 2014, was also awarded an NSF GRF this year. Shearer conducted research in the lab of Professor David Cliffel while at Vanderbilt. In 2014, she was awarded the Donald E. Pearson Award for Outstanding Graduating Senior Majoring in Chemistry at Vanderbilt. Shearer attends the University of Wisconsin–Madison and is pursuing a Ph.D. in materials chemistry. Her research is in synthesizing and characterizing materials for solar cell applications.

---

**Wright Lab Selected as Phase I Finalists for the “Follow that Cell Challenge”**

Wright Lab members Alexis Wong, Joseph Conrad, and David Wright were recently selected as Phase I finalists for the Follow that Cell Challenge, a part of the Single Cell Analysis Program sponsored by the National Institutes of Health. The Single Cell Analysis Program “supports investigators examining the transcriptional signatures of individual human cells in order to measure and analyze cellular heterogeneity and to define specific cell types and/or cell ‘states’ in a given population, work focused on the discovery and early development of exceptionally innovative tools for early stage, high-risk/high-impact projects to enable and improve single cell analysis, and studies that accelerate the integration and translation of technologies to characterize single cells.”

In collaboration with Andries Zijlstra in Vanderbilt University Medical Center’s Department of Pathology, Microbiology, and Immunology, the team proposed to use fluorescent molecular probes based on gold nanoparticle technology to identify and measure gene expression in living cells. As Phase I finalists, the team was invited to continue their work in Phase II of the Follow that Cell Challenge and submit their results for future consideration for funding.

Alexis Wong accepts the Phase I finalist award for the “Follow that Cell Challenge” from Roderic Pettigrew, Ph.D., MD, director of the National Institute of Biomedical Imaging and Bioengineering.
The Society for Advancement of Chicanos and Native Americans in Science (SACNAS) has been launched at Vanderbilt. The Vanderbilt SACNAS chapter represents the growth of this organization focused on encouraging and helping students of all backgrounds and heritages reach their goals in the science community. Vanderbilt SACNAS will offer undergraduate students, graduate students, and post-doctoral researchers of all backgrounds opportunities such as writing workshops, outreach and volunteer opportunities, and educational trips.

I was introduced to SACNAS during my undergraduate education at the University of Texas San Antonio (UTSA). Through SACNAS I was able to present my undergraduate research in a supportive and encouraging environment. At the 2012 and 2013 SACNAS National Conferences, I presented in poster format my research from the lab of George R. Negrete, which focused on the development of an efficient delivery modality for small interfering RNA (siRNA) by utilizing cationic guanidine-derived amphiphiles and bolaamphiphiles to anchor the sugar phosphate backbone of nucleic acids for use in lipoplexes or stable nucleic acid lipid particles (SNALPs).

In 2013, I was a SACNAS Undergraduate Student Poster Presentation Awardee in Chemistry for my presentation of this work. As well, I met professionals in all different career stages and fields who shared common experiences stemming from Chicano and Native American backgrounds. It was gratifying to meet people from similar backgrounds who had been able to achieve careers in science and were willing to mentor rising minority students.

During the 2013 National SACNAS Conference in San Antonio, I took the opportunity to learn about different educational opportunities from the hundreds of exhibits from various post-baccalaureate and graduate training programs. It was at one of these many booths that I found the Vanderbilt Department of Chemistry.

I was immediately impressed by the vast resources at Vanderbilt, as well as the interdisciplinary collaborative efforts between students and faculty, so I chose Vanderbilt to continue my development as a chemist.

After successfully completing my first year in the Vanderbilt Chemistry graduate program, I joined the laboratory of Brian Bachmann, which focuses on chemical biology and antibiotic discovery and research. My work will be focused towards elucidating the biosynthesis of the natural product everninomicin. Through a deeper understanding of how this unique natural product is produced, we hope to be able to manipulate the bacterial machinery to make structural changes to this already potent antibiotic.

The SACNAS community helped me prepare to apply to and succeed in graduate programs and will continue to aid in my development as a scientist here at Vanderbilt. I look forward to being part of the new Vanderbilt chapter and seeing it grow into an impactful organization on campus.

Find out more about the VU SACNAS chapter through their page on Facebook.

Mike Turo Awarded DOE Graduate Student Research (SCGSR) Award

Mike Turo, a fourth-year student in Janet Macdonald's lab, has been selected by the U.S. Department of Energy (DOE) Office of Science to receive an Office of Science Graduate Student Research (SCGSR) award. Since February 2015, Turo has been working at Lawrence Berkeley National Laboratory (LBNL) on his project, X-ray absorption spectroscopy and ab initio study on interfacial charge transfer in CdSe@ZnS nanocrystals. Turo is a native of Slingerlands, New York; he received his bachelor of science from Villanova University in Pennsylvania.

Further details of the DOE Office of Science Graduate Student Research Program are available at www.nsfgrfp.org.
Richard N. Armstrong Award in Chemical Biology
Inaugural Winner Nichole Lareau (McLean Lab)

Each year, the Vanderbilt Institute for Chemical Biology recognizes one student for hard work and success in their research efforts. Thus, the VICB Prize for Research Excellence is awarded to a single student whose research warrants this prestigious honor. To be eligible, applicants must be working toward their PhD or MD/PhD under a professor who is an active member of the VICB. This year, the award has been named in honor of Richard N. Armstrong, and will remain so in perpetuity.

The winner of the 2015 Richard N. Armstrong Award in Chemical Biology is Nichole Lareau, a fourth-year student in the lab of John A. McLean.

2014–2015 Master of Science

Cynthia Berry
Eric Bierschenk
Matthew Bryant
Richard Dempster
Braden Durbin
Jason Gerding

Bryson Howard
Katherine Martin
Any Poynter
Kevin Winter
Jonathan Witt

2014–2015 Ph.D. Graduates

Mariusz Butkiewicz
Leipzig, Germany
Advancing Quantitative Structure Activity Relationship Strategies in Ligand-Based Computer-Aided Drug Design

Kerri Jaye Grove
Andover, Minn.
Imaging Mass Spectrometry for the Elucidation of Lipid and Protein Changes in Diabetic Nephropathy and Assessment of Drug Efficacy

Christopher Peter Gulka
Medway, Mass.
Gold as a Sensing Platform for the Rapid Detection of Explosives and Malarial Biomarkers

Sten Heinze
Leipzig, Germany
Improvements to BCL::Fold de novo Protein Structure Prediction

Stephen Randall Jackson
Paragould, Ark.
DNA-Functionalized Gold Nanoparticles for Enhanced Molecular Sensing

Joseph Daniel Keene
Climax, N.C.
Effects of Surface and Chemical Composition on the Charge Carriers of Alloyed Quantum Dots

Glenna Jean Kramer
Oakdale, Pa.
Pharmacology and Chemical Probe Development of the K-26 Family of Natural Product Angiotensin-1 Converting Enzyme Inhibitors

Liang Li
Tianjin, China
Sequence Dependence of Structural Perturbations to DNA Induced by Aflatoxin B1 Formamidopyrimidine Lesions

Amy Ng
Fall River, Mass.
Characterization of Nanocrystal-Based Photovoltaics: Electron Microscopy & Electron Beam-Induced Current via Scanning Electron Microscopy

Jeffrey Scotten Niezgoda
Hartly, Del.
The Implementation of Quantum Dots in Photovoltaics: From Semiconductor-Plasmon Interactions to Current Visualization

Matthew Charles O’Reilly
Billings, Mont.
Application of Organocatalysis to the Synthesis of Chiral Morpholines, Piperazines, Aziridines, Azetidines, beta-Fluoroamines, and gamma-Fluoroamines; Discovery of Selective Phospholipase D Inhibitors with Optimized in vivo Properties

Jacek Grzegorz Pecyna
Olawa, Poland
Polar and Ionic Liquid Crystals Based on the [closo-1-CB9H10]- and [closo-1-CB11H12]- Boron Clusters

Timothy James Senter
Charlotte, N.C.

Larry Marnett presents the Richard N. Armstrong Award in Chemical Biology to Nichole Lareau.
Beckman Scholars Program awards are institutional, university, or college awards. Each year, the Arnold and Mabel Beckman Foundation selects a number of research, doctoral, master’s, and baccalaureate universities and colleges to be invited to submit applications for the Beckman Scholars Program. Each institution may submit one application for consideration for an award.

Arnold O. Beckman, founder-chairman emeritus of Beckman Instruments, Inc., represents nearly a century of outstanding scientific achievements. Considered one of the top five inventors of scientific instruments, Dr. Beckman created devices that revolutionized the study and understanding of human biology, ultimately saving countless lives around the world.

Vanderbilt Chemistry has been fortunate to participate in the Beckman Scholars Program, with Jeffrey N. Johnston, Ph.D., serving as the Beckman representative and mentor. During the past academic year and summer, Zachary Carter, now a senior at Vanderbilt, is the Beckman scholar, majoring in chemical engineering and chemistry, with minors in biology and neuroscience. Born and raised in Chicago, Illinois, Carter is a Chancellor’s Scholar and continuing resident adviser for The Martha Rivers Ingram Commons living-learning community for first-year students. He is also the Cultural Chair of the Vanderbilt Association of Hispanic Students. Carter took organic chemistry as a freshman and gained research experience through the Department of Epithelial Cancer Biology. In 2014 he began work with the Johnston laboratory in an effort to apply new chemical methods to the synthesis of natural products with interesting biological activity. His postgraduate plan is to attend medical school in pursuit of an MD/PhD dual degree, eventually specializing in neurosurgery.

Professor Jeff Johnston is director of the VU-Beckman Scholars Program for undergraduate research. His research program has been recognized by several organizations, including the Boehringer-Ingelheim New Investigator Award, the Yamanouchi and Astellas faculty awards, an Amgen Young Investigator Award, and an Eli Lilly Grantee Award.

In 2011, he was elected a Fellow of the American Association for the Advancement of Science (AAAS), awarded a Stevenson Endowed Chair, and was a recipient of the Chancellor’s Award for Research. He was a 2013 Japan Society for the Promotion of Science (JSPS) Fellow, and received the ACS Arthur C. Cope Scholar Award in 2014. Johnston obtained his B.S. (Honors) in chemistry (summa cum laude) in 1992 from Xavier University. While at Xavier, he completed his undergraduate thesis research with Professor Robert G. Johnson.
2015 Graduating Chemistry Majors

<table>
<thead>
<tr>
<th>Name</th>
<th>Post Graduation Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alex Jeffrey Anderson</td>
<td>Graduate school in chemical engineering at Univ. of Colorado</td>
</tr>
<tr>
<td>Elizabeth Angel</td>
<td>Job with Coca-Cola Company in Atlanta</td>
</tr>
<tr>
<td>Jackson Mark Bennett</td>
<td>Medical school</td>
</tr>
<tr>
<td>David Lee Burns</td>
<td>Taking a year off and then may attend medical school</td>
</tr>
<tr>
<td>Melissa Simone Charles</td>
<td>Job with the quality department at a food company</td>
</tr>
<tr>
<td>Matthew Chet Cleveland</td>
<td>Medical school at Southern Illinois University</td>
</tr>
<tr>
<td>Michael William Crowther</td>
<td>US Navy, nuclear engineering</td>
</tr>
<tr>
<td>Brett Joseph Doliner</td>
<td>Medical school at the University of Miami</td>
</tr>
<tr>
<td>Banita Giri</td>
<td>Healthcare software company in Nashville</td>
</tr>
<tr>
<td>David Aaron Haynes</td>
<td>Medical school</td>
</tr>
<tr>
<td>Monica Elizabeth Herbst</td>
<td>Healthcare consultant, Dallas</td>
</tr>
<tr>
<td>Natalie Paige Honkala</td>
<td>Teach for America, then medical school at Ohio State University</td>
</tr>
<tr>
<td>Paul Andrew Kempler</td>
<td>Graduate school in chemical engineering, Cal Tech–Material Science</td>
</tr>
<tr>
<td>Alexandra Bahar Khodadadi</td>
<td>Medical school at University of Alabama at Birmingham</td>
</tr>
<tr>
<td>Jabari Hakeem Knight</td>
<td>Research in Nashville then medical school</td>
</tr>
<tr>
<td>Madison Bentley Kommor</td>
<td>Medical school at University of Louisville</td>
</tr>
<tr>
<td>Warren Siang Liang Lam</td>
<td>Medical scribe</td>
</tr>
<tr>
<td>Samuel Marc Lazaroff</td>
<td>Medical school in Ohio</td>
</tr>
<tr>
<td>Sicheng Ma</td>
<td>Research associate for Centers for Disease Control, Atlanta</td>
</tr>
<tr>
<td>Justin Martin</td>
<td>[fall 2014 graduate]</td>
</tr>
<tr>
<td>Akwasi Fofie Opoku</td>
<td>Seeking employment</td>
</tr>
<tr>
<td>Aniruddha Chintan Parikh</td>
<td>Medical school at University of Oklahoma</td>
</tr>
<tr>
<td>Katherine Sumarriva</td>
<td>Medical school at Vanderbilt</td>
</tr>
<tr>
<td>Emily Wang</td>
<td>MS in biotechnology at Johns Hopkins</td>
</tr>
<tr>
<td>Rebecca Marie Wiesehan</td>
<td>St. Louis University for research then medical school</td>
</tr>
<tr>
<td>Zhewen Zhang</td>
<td>[summer graduate]</td>
</tr>
</tbody>
</table>

Undergraduate Awards in Chemistry

- **Donald E. Pearson Award** for Outstanding Senior Chemistry Major
  - Brett Joseph Doliner

- **Outstanding Chemistry Research Award**
  - Natalie Paige Honkala

- **Organic Chemistry Award**
  - Alexandra Bahar Khodadadi

- **Thomas W. Martin Award in Physical Chemistry**
  - Samuel Marc Lazaroff

- **Robert V. Dilts Award in Analytical Chemistry**
  - Jackson Mark Bennett

- **Mark M. Jones Award in Inorganic Chemistry**
  - David Lee Bruns

Research Opportunities for Chemistry Undergraduates

Theresa Miller is a sophomore in organic chemistry at Vanderbilt from Lake Zurich, Illinois. Last year, in addition to General Chemistry, she took Professor Jessica Oster’s first-year writing seminar regarding climate change and human history and began researching oxygen isotopes in cave systems.

At Professor Oster’s suggestion and because of her knowledge of analytical research techniques, Miller spent five weeks in Ayacucho, Peru, this past summer, taking part in cross-disciplinary research. Under Professor Tiffany Tung, a bioarchaeologist at Vanderbilt, Miller analyzed bones from the Wari Empire, tracking signs of trauma and disease in order to shed light on patterns around the time of the empire’s collapse. She also conducted a side project regarding stable isotopes in local water sources. In addition to collecting water samples from three rivers and one rainfall, the team also set up a water-catcher in the city of Ayacucho and organized one to be placed with a school in Pacaycasa, near the dig site at Huari.

Why the interest in the water? “Teeth pick up the oxygen isotope signatures of the water that humans and animals drink throughout enamel formation. By gaining perspective on the modern values, we will analyze them in context with isotope data drilled from the teeth of the Wari remains, allowing for greater understanding of the geographic origin of tested individuals and changes in climate,” explains Miller. Samples will be sent throughout the rainy season for analysis of the oxygen values.

A concurrent case study at Grassmere Plantation (now Nashville Zoo) applies the same methods to Civil War era slave burials and Miller plans to participate.

*Research funded through a National Science Foundation grant awarded to Professor Tiffany Tung, Vanderbilt University Department of Anthropology.*
They get little fanfare, but these staff members are a few of those who have helped make the Chemistry Department run smoothly. They certainly make the students’ experiences at Vanderbilt Chemistry great. Together, they have combined service of more than 100 years at Vanderbilt.

By Sandra Ford

Paulette Lynch
Chemistry Storeroom Manager
46 Years

Paulette Lynch has worked at Vanderbilt for 46 years, overseeing the Chemistry Storeroom operation, making certain that it is well supplied with all of the essential items needed to complete research in chemistry, from gloves to glassware to chemicals. She deals with vendors, assists faculty and graduate students in sourcing whatever they may need, reconciles storeroom ledgers, works on acquiring new customers for the storeroom, and, of course, resolves problems.

Q: What do you enjoy most about your job?
A: I enjoy the daily interaction with the faculty, staff, graduate students, and vendors, assisting others when they need it, and being able to negotiate great pricing for our department.

Q: What is your proudest accomplishment at Vanderbilt University?
A: When I first started in the Chemistry Storeroom in 1971 we kept our inventory manually on index cards with orange tabs to let us know something was on order. Through the years, we kept making changes, and today we have a state-of-the-art computerized inventory system, with barcoding ability and a built-in chemical tracking system.

Q: What has changed at Vanderbilt since you’ve been here?
A: I have seen many changes since I came to Vanderbilt. Many new buildings such as Stevenson Center Building 7 for Chemistry, a new Vanderbilt hospital, Monroe Carell Jr. Children’s Hospital, MRBIII and MRBV. Parking has gone from $5 per year to $408 per year. Last but not least, my hair has turned gray.

Q: What’s the most memorable thing that’s happened at Vanderbilt?
A: My greatest memory is from 1996, when I was awarded the Storeroom Manager of the Year award by the National Association of Scientific Material Managers at the annual conference in Savannah, Georgia. It was a great honor to accept this award.

Clara H. Johnson
Senior Lab Teaching Assistant
36 Years

Q: What do you do in an average day in your job?
A: In an average day in my job, I prepare and test routine laboratory experiments; assist students and instructors; evaluate lab experiments and set up and maintain the Organic laboratories. I also help in keeping the students safe in the laboratories.

Q: What is your proudest accomplishment at Vanderbilt University?
A: My proudest accomplishment at Vanderbilt University is knowing that I had a little part in helping some students accomplish their lifetime goals and future. One of my first students in the Organic laboratory, Dr. Douglas R. Weikert, is now associate professor of orthopedics and rehabilitation at Vanderbilt, and he is my hand doctor. One of the graduate students, Steven Townsend, became an assistant professor of chemistry at Vanderbilt, the first African American faculty member in the Chemistry Department.

Q: What has changed at Vanderbilt University since you’ve been here?
A: The changes that I have seen since I have been here are six chairmen, five African American staff, and one African American faculty member in the Chemistry Department. The football team is winning more games and going to bowl games. The basketball team is getting ranked. The baseball team is going to the championship games. All this would not happen if Vanderbilt University had not moved to a diverse university in the ‘90s. This year I have seen the beginning of the separation of the university and the medical center.

Q: What is the most memorable thing that’s happened at Vanderbilt University?
A: I saw the former President of the United States, Bill Clinton, getting out of his car going to speak on campus.
Tommy Howe
Glassblower
24 Years

Vanderbilt is fortunate to have its own Glassblowing Shop, operated by the Department of Chemistry, to provide scientific glassware design and fabrication. Both custom and standard glassware are available, at significantly reduced prices, for the scientific community at Vanderbilt University and surrounding research and teaching entities. Our resident glassblower for the past 24 years is Tommy Howe. Howe learned the art of glassblowing from a friend in Houston, Cleon Yates. Tommy came to Vanderbilt from Texas in 1987.

Q: What do you do in an average day in your job?
A: An average day at Vanderbilt consists of: repair and fabrication of glassware, checking and ordering materials, assisting grad students and/or faculty in design and needs of glassware. I feel the fabrication or repair of glassware, assisting in the design, along with my knowledge of which type glass is best to use and sources of supply, enable me to reach my goal of making the grad student or faculty member’s job easier. The most important thing I do can be summed up in two words: “provide service.”

Q: What do you enjoy most about your job?
A: I especially enjoy the grad students, seeing them come in each fall, excited to be here, and to hear some of their ambitions and dreams and get to observe them striving to achieve. The joy that comes from feeling, “maybe I have helped them, in some way,” brings a smile inside.

Q: What is your proudest accomplishment at Vanderbilt?
A: When I got here, none of the university glass shops provided standard lab glassware, such as lab kit glassware for the undergraduate labs. I suggested we do this in order to keep as many funds in house as possible.

Q: What’s the most memorable thing that’s happened at Vanderbilt?
A: The most memorable thing that has happened to me at Vanderbilt was the warm reception I received by the then chairman, Dr. Andy Hess, and the entire faculty and staff. Another memorable occasion was having a heart attack at work, the subsequent heart bypass surgery, and the wonderful care given by all involved at VUMC, for which I will be forever grateful.

Department of Chemistry Honors Service Anniversaries

The faculty and/or staff members listed below are celebrating a service anniversary of their hire date at Vanderbilt in the Department of Chemistry. Vanderbilt celebrates these anniversaries in five-year increments. Both faculty members and staff are given a pin with their anniversary year on it. We celebrate and thank our colleagues as they achieve these milestones.

**FACULTY**

35 years Prasad L. Polavarapu  
Professor

30 years Timothy J. Hanusa  
Professor

15 years David E. Cliffler  
Professor

15 years Terry Lybrand  
Professor

10 years Jens Meiler  
Professor

**RESEARCH FACULTY**

15 years Keri Tallman  
Asst. Research Professor

10 years James McBride  
Asst. Research Professor

5 years Amanda Kussrow  
Asst. Research Professor

**ADMINISTRATIVE STAFF**

20 years Shellie Richards  
Administrative Asst. III

10 years Heather Lee Watkins  
Administrative Asst. I

5 years Jeffrey L. Mendenhall  
Computer Programmer

Analyst I

5 years Tracy Johnson Salyard  
Research Asst. II
Construction of New Engineering and Science Building

The new Engineering and Science Building is expected to be complete by summer 2016. Construction began in May 2014 on the seven-story structure, which will connect to Olin Hall. The new building is part of an effort to further strengthen the institution’s growing reputation as a major producer of intellectual leaders, entrepreneurs, and innovators.

The 230,000-square-foot building is designed to foster project teamwork and offer programs, instrumentation areas, and core research space that will promote interdisciplinary work, particularly in engineering and related fields, such as chemistry and nanoscience.

“We want to continue to attract and recruit the best students and provide them with exceptional research experiences at the undergraduate and graduate levels. This new facility will allow for even greater collaboration between students and faculty across disciplines so we can deliver scholarship of the highest caliber to address important societal issues,” Philippe Fauchet, dean of the Vanderbilt School of Engineering, said.

A key feature of the new building is an Innovation Center designed to connect students and faculty with technology transfer and industry mentors to accelerate the transfer of laboratory discoveries and student-developed concepts to the marketplace. Students participating in the center will experience the value of interdisciplinary teamwork and carry this model forward as they become leaders.

A cleanroom and advanced imaging facilities will provide capabilities that students and faculty need to advance discoveries in areas such as nanocomposites, smart materials, advanced energy storage, and nano-bio-technology.

Power Plant Is Now Coal-Free: Smokestack Removed

Vanderbilt’s co-generation power plant burned off its last lump of coal in November 2014, bringing the campus’s 126-year reliance on coal to an end. The plant, which produces 23 percent of Vanderbilt’s electricity, 90 percent of its heat, and 40 percent of its cooling, now runs exclusively on natural gas.

The structure, built in 1962, has been partially powered by natural gas since 1988, but still burned 105 million pounds of coal and produced 15 million pounds of ash waste per year. The environmental benefits of the conversion are significant. Greenhouse gas emissions will go down by as much as 40 percent; emissions of particulate matter will decrease by more than 50 percent; and emissions of mercury, hydrogen chloride, sulfur dioxide, and other air pollutants will be virtually eliminated. Demolition of the power plant’s iconic smokestack took place in June 2015.
The Chemistry Colloquium Series is a mainstay of VU Chemistry, broadening knowledge of emerging science and deepening connections between researchers at all levels.

Following are 2014–2015 speakers.

**FREDERICK LEROY CONOVER LECTURE**

Professor Vicki Wysocki, The Ohio State University, "Mass Spectrometry in Structural Biology: Surface-induced Dissociation/Ion Mobility of Protein Complexes"

**COLLOQUIA SPEAKERS 2014–2015**

Dr. John Anderson, Northwestern University, "From Molecules to Materials: Synthetic Iron Compounds as Constructs to Explore Biological Systems"

Prof. Peter Andreana, University of Toledo, "Diversity in Small Molecule Synthesis and Entirely Carbohydrate-based Cancer Vaccines for Disease Prevention and Treatment"

Prof. Stephanie Brock, Wayne State University, "Nanostructured Architectures for Energy and the Environment"

Prof. Jesse Carrick, Tennessee Technological University, "Experiential Investigations in Organic Synthesis"

Prof. Steven Castle, Brigham Young University, "New Strategies for the Synthesis of Unusual Peptides"

Prof. Andres Cisneros, Wayne State University, "Insights on DNA repair enzymes from computational simulations"

Prof. Cathy Clarke, University of California, Los Angeles, "The CoQ synthome — a complex required for biosynthesis of coenzyme Q"

Prof. Sean Elliott, Boston University, "The Metalloprotein Electric: electrochemical and biochemical studies of multiheme cytochromes c"

Prof. Harry Finklea, West Virginia University, "An Electrochemist’s View of Solid Oxide Fuel Cells"

Prof. Natia Frank, University of Victoria, "Organic-Inorganic Hybrid Functional Materials for Switching, Sensor, and Spintronics Technology"

Prof. Tomislav Friščić, McGill University, "A (new) role for solid-state reactivity in making molecules and materials"

Prof. Vlad Iluc, University of Notre Dame, "Secondary Metal-Ligand Interactions: C-H Activation and Metal-Element Multiple Bonding"

Prof. Jonathan Irish, Vanderbilt University, "High dimensional single cell cancer research and chemical biology"

Prof. Mark Ji, University of Utah, "Hot Spot-Based Design of Small-Molecule Inhibitors for β-Catenin/T-Cell Factor and β-Catenin/B-Cell Lymphoma 9 Interactions"

Prof. Ryan Julian, University of California, Riverside, "Probing Gas Phase Biomolecular Structure via Excitation Energy Transfer"

Dr. Tzu-Pin Lin, California Institute of Technology, "Boryl-Mediated H2 Activation at Metal Centers: Applications in Catalysis"

Prof. James Mack, University of Cincinnati, "Grinding it out: the development of organic reactions using mechanochemistry"

Prof. Charles Melancon, University of New Mexico, "An Integrated Approach to Discover and Bioengineer Bacterial Natural Products"

Prof. Daniel Rabinovich, University of North Carolina at Charlotte, "Synthetic Analogues of Methanobactin"

Prof. Krishnan Raghavachari, Indiana University, "Electronic Structure Methods for Large Molecules and Novel Applications in Nanoscience"

Prof. Sarah Reisman, California Institute of Technology, "From Alkaloids to Terpenoids: New Strategies and Tactics for the Synthesis of Polycyclic Natural Products"

Prof. Jonathan Sachs, University of Minnesota, "Understanding the chemistry and appreciating the importance of methionine-aromatic interactions in protein structure and function"

Dr. Nathan Schley, California Institute of Technology, "From Water Oxidation to Cross-Coupling: A Mechanistic Approach to Catalysis"

Prof. Peter Schmidt, Leipzig University, "The Structure of Neuropeptide Y bound to its G protein-coupled Y2 receptor"

Prof. Kevin Shaughnessy, University of Alabama, "Designing ligands for cross-coupling reactions: Effects of size, flexibility, and electron-donating ability"

Prof. Ryan Shenvi, Scripps Research Institute, "Chemical Synthesis of Secondary Metabolites"

Prof. Masahiro Terada, Tohoku University, "Enantioselective Catalysis by Chiral Brønsted Acids and Bases"


Dr. Nathan West, University of the Sciences in Philadelphia, "Developing Sustainable Chemical Feedstocks by Utilizing Transition Metal Catalysts"

Prof. Mikhail Zamkov, Bowling Green State University, "Engineering semiconductor nanocrystals and nanocrystal solids for renewable energy applications"
3D printing, also known as additive manufacturing, describes various processes used to make a three-dimensional object. In 3D printing, additive processes are used, in which successive layers of material are laid down with inkjet printer heads under computer control. These objects can be of almost any shape or geometry and are produced from a 3D model or other electronic data source. A 3D printer is a type of industrial robot.