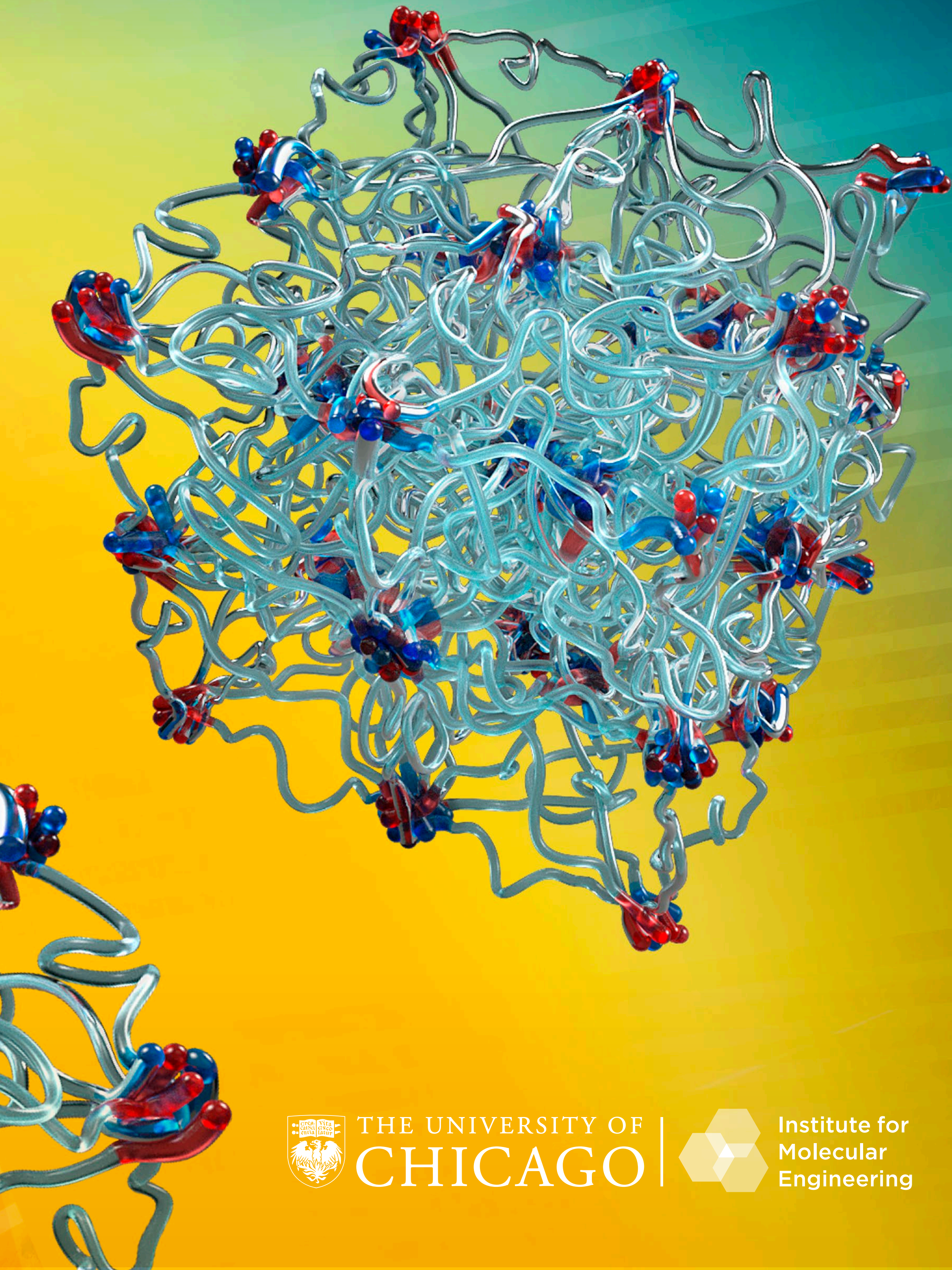
2016 Annual Report

IME's Emerging Coherence and Impact



THE UNIVERSITY OF CHICAGO
Institute for Molecular Engineering

UChicago undergraduates attend an IME lecture course. See the IME Undergraduate Major stories, pp. 12–14.

IME's Emerging Coherence and Impact

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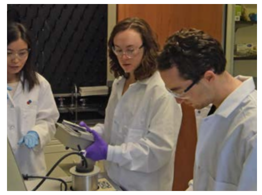


On the cover: Artist's conception of a self-assembled hydrogel network formed by electrostatic interactions. Based on work from the de Pablo and Tirrell research groups.

Emerging Coherence and Impact

Last year, my letter in this space spoke about creating impact. This year, I describe some areas where that impact is being felt. We have been able to generate significant results in as little as five years by concentrating our efforts on prominent research themes in molecular engineering.

One example comes from the IME's theme of quantum information and technology. Our faculty in this area now number five, with a few additional hires expected in the near future. At the same time, major developments in this field are moving forward nationally and internationally, and IME faculty members are steering them. David Awschalom spoke at a White House Office of Science and Technology Policy meeting on the future of Quantum Information, one of several such events in 2016 organized by the Department of Energy, the National Science Foundation, and other agencies. (story p. 28)

In April 2016, AbbVie and the University of Chicago announced a five-year collaboration to advance cancer research. Jeff Hubbell was selected to lead one of the major projects within this collaboration. (story p. 25) He's been developing a type of immunotherapy that triggers the body's immune system to kill tumor cells. It has the potential to be more powerful than chemotherapy but with fewer side effects. Our immuno-engineering area now numbers four faculty with one offer outstanding.

The Danisco Foundation selected Juan de Pablo as the recipient of the DuPont Nutrition and Health Science and Excellence Medal for 2016 for his work that led to optimal processes to stabilize live bacteria for survival and extended stability performance after freeze-drying.

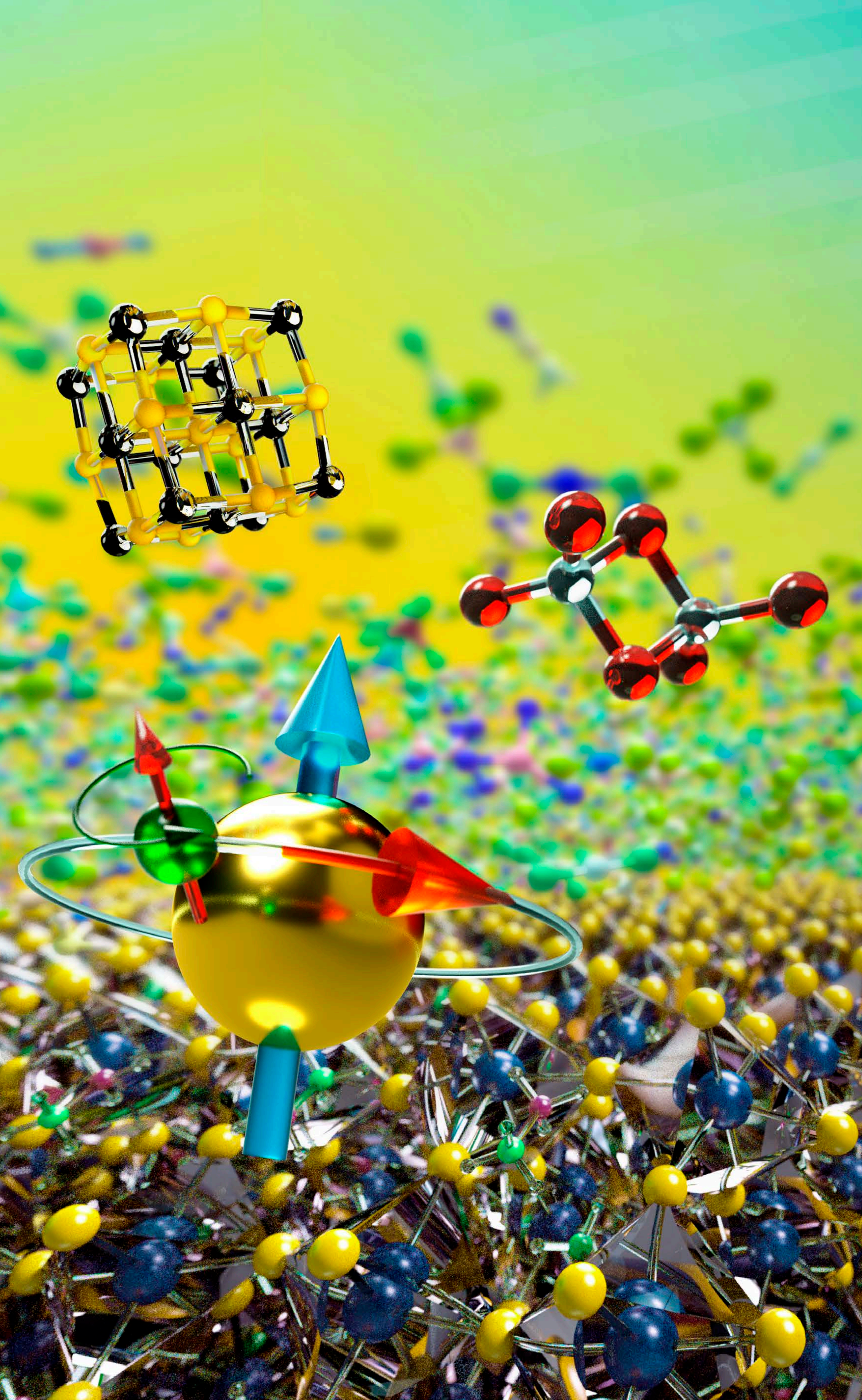
Paul Nealey, working in our soft materials group, was honored by the Semiconductor Industry Association (SIA)—an organization that represents U.S. leadership in semiconductor manufacturing, design, and research. The SIA presented him with their University Research Award, stating that Professor Nealey has "led research efforts that have advanced semiconductor technology and strengthened America's global technology leadership," and it recognized him for his "landmark accomplishments."

The IME's Water Research Initiative is gaining strength and impact. Our new colleague, Jim Skinner, joined us in January 2017, and was appointed to the Crown Family Professorship, empowering him to focus on leading this research effort. (stories pp. 8, 20–23) Jim and I, as well as a half-dozen Argonne scientists participated in a Department of Energy Basic Research Needs workshop (which I was asked to chair) in early January to set priority research directions for basic energy science at the Water-Energy Nexus—the intersection at which energy production and water systems converge.

We continue to build a unique education program for our undergraduate and graduate students, tapping into the University of Chicago's "innovation ecosystem." In 2016 the IME launched the University's first engineering degree in its 125-year history: the undergraduate major in molecular engineering. (stories pp. 12–14)

I believe it is evident from these few examples—and from a glance at the rest of this report—that coherent capacities, resources, and influential themes are emerging within the IME. And there are plenty more to come.

Matthew Tirrell
Pritzker Director and Dean
Institute for Molecular Engineering



Institute for Molecular Engineering

By the Numbers

Statistics for 2016 reflect the advancement and growing coherence of the IME's facilities, faculty, researchers, and programs of study—including the new undergraduate major in molecular engineering. The Institute will continue to attract preeminent scientists from around the world by engaging in collaborative work that fulfills its mission: to translate discoveries in physics, chemistry, biology, and medicine into innovative solutions to address some of society's most pressing problems, and to create a research and teaching environment to enhance and transmit these capabilities to future generations.

62
Researchers at Argonne

15
IME Faculty

3
Faculty positions open

33
Percent of new grant proposals funded

48
Percent of total grant funding from non-federal sources

29
Undergraduates majoring in molecular engineering

184
Undergraduates enrolled in IME courses

92
PhD students

31
Doctoral students and postdoctoral scholars launched independent careers

203
Total IME faculty, staff, postdocs, and grad students

62
Postdoctoral researchers

33
Percent females among total graduate student enrollment

80
New publications

13
Invention disclosures filed in preparation for patent filing

Three New Faculty, One Research Professor Join IME in 2016

Alexander High

Assistant Professor in Molecular Engineering

Alexander High's research lies at the interface of quantum optics, metamaterials, nanophotonics, and excitonics. It focuses on the experimental realization of a visible frequency hyperbolic metasurface using single-crystal silver nanostructures defined by lithographic and etching techniques. The results of this research will help realize efficient, ultra-compact, and broadband integrated optical metacircuits and will have wide-ranging applications in areas from imaging and sensing to quantum optics and quantum information science.

High received his undergraduate degree in physics from the University of Pennsylvania and his doctorate at the University of California, San Diego. Before coming to the IME, he was a post-doctoral researcher at Harvard University.

Shrayesh Patel

Assistant Professor in Molecular Engineering

Shrayesh Patel's group concentrates on functional polymers for energy conversion and storage applications. Batteries and thermoelectrics are the current focus. The group's expertise lies in the characterization of polymers, which allows them to understand charge transport and electrochemical and morphological properties. They frequently leverage synchrotron x-ray scattering and spectroscopy techniques to advance understanding of functional polymers at the molecular, nano-, and micro-scale.

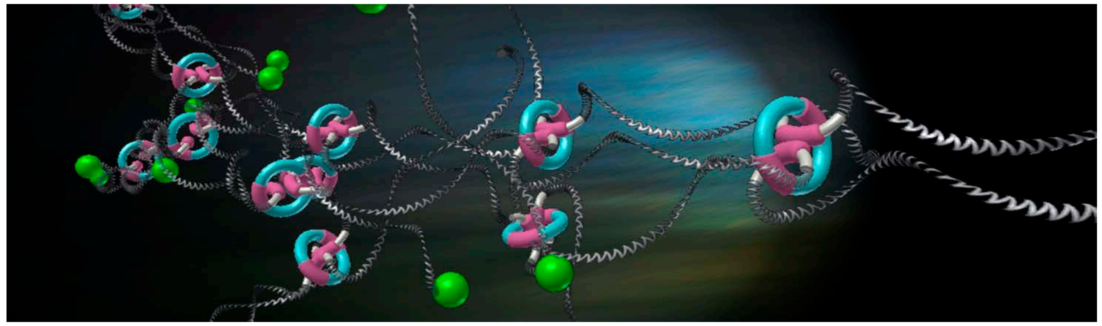
Patel completed his undergraduate degree at the Georgia Institute of Technology in Chemical and Biomolecular Engineering in 2007 and received his PhD in Chemical Engineering from the University of California, Berkeley, in 2013. Before joining the IME as an assistant professor, he was a postdoctoral research associate in the Materials Research Laboratory at the University of California, Santa Barbara.

Stuart Rowan

Professor in Molecular Engineering

Stuart Rowan, a prominent soft materials scientist who hails originally from Edinburgh, Scotland, has been appointed to a full IME professorship with a secondary appointment in the Department of Chemistry. He comes to the IME most recently from Case Western Reserve University, where he was the Kent H. Smith Professor of Engineering in the Department of Macromolecular Science and Engineering with secondary appointments in Biomedical Engineering and Chemistry. He was also director of the Institute for Advanced Materials.

Trained as a polymer chemist, Rowan focuses on the design and synthesis of new soft materials. The Rowan group is developing "adaptive" materials—materials that change properties in response to their environment, such as those that mimic the stiffness of tissue to enhance biocompatibility when implanted in the body. Rowan is also an expert in the development of self-healing materials and his group is working on new classes of adaptive interlocked polymers. Given IME's focus on water purification and battery research, Rowan will work on developing switchable and adaptable membranes with applications in those areas.



Credit: Katie Greenman, graduate student at IME

Monisha Ghosh

Research Professor in Molecular Engineering

Monisha Ghosh, a fellow of the Institute of Electrical and Electronics Engineers, has joined the IME faculty as a research professor with an adjunct position in the Department of Computer Science. Her work focuses on wireless communication networks and signal processing, particularly with respect to spectrum-sharing for cellular systems, agricultural sensors, and healthcare analytics. Ghosh also addresses challenges posed by the need to bury

low-power agricultural sensor networks one foot or more underground to measure moisture, nitrate levels, and other aspects of soil conditions. Ghosh has worked extensively in industrial research and development at Interdigital, Philips Research, and Bell Laboratories. She received her PhD in Electrical Engineering from the University of Southern California and her bachelor of technology degree in Electronics and Electrical Communications Engineering from the Indian Institute of Technology, Kharagpur.

James L. Skinner Appointed Director of Water Research Initiative

Crown Family Professor in Molecular Engineering of Water Resources and Director of the IME Water Research Initiative

James L. Skinner, renowned theoretical chemist, has been named IME's Crown Family Professor in Molecular Engineering of Water Resources and the new Director of IME's Water Research Initiative (WRI). Skinner is the world leader in the study of hydrogen bonding in water, one of the most challenging factors for water researchers.

The WRI was launched in 2013 in collaboration with Ben-Gurion University of the Negev and Argonne National Laboratory.

"Professor Skinner is uniquely qualified to guide the Water Research Initiative through its next phase of expansion."
—Matthew Tirrell

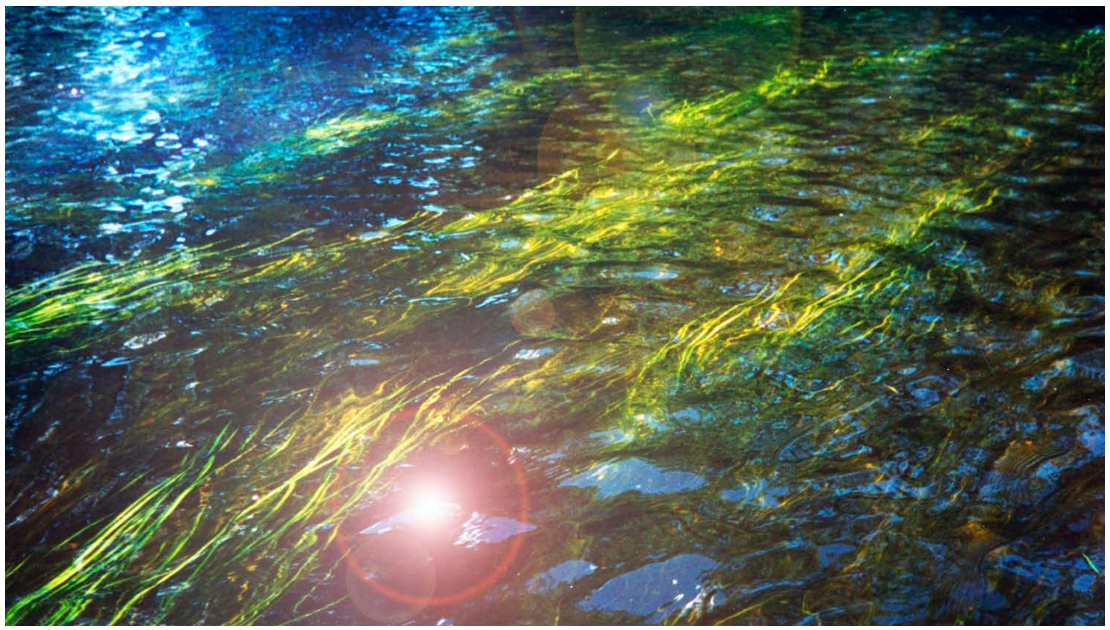
Originally charged with using nanotechnology to create new materials and processes for making clean, fresh drinking water more plentiful and less expensive by 2020, the WRI will now broaden its scope. Skinner will lead WRI development and expansion.

Skinner joins the IME after serving for 26 years as director of the Theoretical Chemistry Institute at the University of Wisconsin-Madison (UW) and for three years as chair of the UW Department of Chemistry, where he was the Joseph O. and Elizabeth S. Hirschfelder Professor of Chemistry. Prior to his work at Wisconsin, he was a full professor at Columbia University.

Skinner's research interests include the theoretical chemistry of condensed phases, non-equilibrium statistical mechanics, chemical reaction dynamics, exciton and electron transport, dephasing and relaxation processes, linear and nonlinear spectroscopy of liquids and supercritical fluids, and amorphous and crystalline solids, surfaces, and proteins.

"Professor Skinner is uniquely qualified to guide the Water Research Initiative through its next phase of expansion," said Dean Matthew Tirrell. "His expertise and a parallel track record of academic leadership at Columbia and Wisconsin will enable him to articulate a coherent vision for the initiative and to successfully recruit new investigators."

(WRI story p. 20)



Update on Facilities: Argonne and the PNF

The IME–Argonne Connection

Demonstrating 'action at a distance'

Separated by 25 miles and two distinct institutional missions and histories, the IME and Argonne National Laboratory are nevertheless inextricably linked—calling to mind the behavior of quantum-entangled particles. Plans and collaborations have been moving forward since IME's inception in 2011. Matthew Tirrell began his tenure in 2015 as Argonne's Deputy Laboratory Director for Science, and IME personnel began steadily moving into Argonne's offices and labs, with IME allotted 7,300 square feet of new laboratory space.

New IME Labs

A nearly 1,500 square-foot lab assigned to Supratik Guha's research is now operational with postdoctoral researchers hard at work. Guha has a joint appointment: IME professor, and Argonne's Director for both the Center for Nanoscale Materials (CNM) and the Nanoscience & Technology Division (NST). His group's investigations focus on new semiconductors and oxide materials and devices for computing architectures, cyber-physical sensing systems, and energy conversion technologies for uses in areas ranging from urban environments to water resources. The new lab may see initial results as early as 2017. In addition, a new state-of-the-art cleanroom lab under construction at Argonne will allow Guha's researchers to create sensors able to detect the smallest amount of energy striking their surface.

3,000 square feet of lab space has been assigned to IME professors David Awschalom and Andrew Cleland. Awschalom, one of the world's leading scientists in spintronics and quantum information engineering, is a senior scientist at Argonne. Cleland, a leader in quantum computing, quantum communication and quantum sensors, is the Director of the IME's Pritzker Nanofabrication Facility.

Increasing Presence and Partnership

The number of IME graduate students now working at Argonne has almost doubled in one year, increasing from 13 to 22. Joint appointments of IME/Argonne principle investigators rose from 8 in 2015 to 11 in 2016. The first undergraduates to study molecular engineering as a major may now work on research projects there.

"IME is forming a new kind of bridge between the campus and Argonne," Tirrell said. "We're bringing talented new faculty with new capabilities to Argonne. The creation of IME is a rare opportunity for both the University and Argonne," he continued. "There aren't many times when a university says, 'we'll invest in 25 new faculty positions and we want the majority of them to develop collaborative opportunities with a national laboratory.'"

"We're Argonne's real partner. Our relationship between campus and Argonne is approaching the best there is. Argonne's 2017 budget is about $800 million, which is up from $760 million the previous year. That's the kind of growth we like to see."

Numbers for IME at Argonne

Position	2015	2016
Staff	1	1
Scientists	2	4
Research Associates	18	24
Graduate Students	13	22
Visiting Scientists	3	3
Joint PI Appointments	8	11
	Total	65

Pritzker Nanofabrication Facility (PNF) Shines in Its First Year

The 10,000-square-foot facility in the William Eckhardt Research Center opens its doors in February 2016.

Getting the PNF off to a bright start, UChicago researchers were the first to take advantage of the facility's state-of-the-art resources. By June, it was accommodating an average of 10 users per day with a growing number of them coming from Northwestern University and the University of Illinois-Chicago to be trained and to utilize the clean room tools. Use of the PNF will continue to increase, fostering new collaborations as more researchers from industry and academic institutions participate.

Shedding Light on Research

Graduate researcher Hung-Shen Chang, who has utilized most of the equipment in the clean room to fabricate quantum integrated circuits, employs an ultra-high performance tool, the Raith electron-beam writer, to focus a beam of electrons that scribe features as small as 1/10,000th the width of a human hair onto the central piece of the circuit. "The PNF has allowed my research to explore approaches that otherwise wouldn't be possible, enabling flexibility and precision in fabricating the samples for experiments," said Chang.

The work of undergraduate researcher Agnetta Cleland also hinges on resources at the PNF. Cleland works on a flip-chip bonding technique to integrate hybrid quantum systems—a step critical to advances in quantum information science. She utilizes photolithography tools to fabricate her prototypes: including a Heidelberg direct writer, plasma etchers, electron-beam evaporator, dicing saw, and scanning electron microscope.

The PNF clean room and equipment have made possible new kinds of research projects and increased the efficiency of the work. Graduate researcher Joel Grebel fabricates devices almost entirely within the PNF, which has tools that allow Grebel to streamline his work and take advantage of in-process opportunities to improve his designs. "This type of work is only possible using tools in a clean room like the PNF," said Grebel.

PNF Staff

To a large extent, the stellar start-up of the PNF can be attributed to the high-caliber technical director Peter Duda and the dedicated PNF staff. According to Chang, nanofabrication can be compared to baking—in the amount of trial and error required to hit upon the correct parameters that allow the tools to work.

The staff collaborates with researchers to develop "recipes" specific to each procedure, advising against pitfalls along the way. When a device fails to produce the desired result, Duda is credited with sitting down with researchers and debugging the process. "We are very fortunate to have in the clean room Peter Duda, Anna [Mukhortova], and Mike [Medina], who have developed a good portion of these recipes for us for each tool," said Chang.

"Our engineering program's small class sizes allow the faculty to spend significant amounts of one-on-one time with our undergraduate students. World-class researchers are doing what they enjoy most—teaching and providing meaningful research experiences to bright and eager individuals, one student at a time."
— Juan de Pablo, Liew Family Professor in Molecular Engineering and Deputy Director for Education and Outreach

Education

IME Pioneers a First for UChicago:

The Undergraduate Major in Engineering

For the first time in the University's 125-year history, in 2016 a group of UChicago undergraduates majored in engineering—Molecular Engineering—taught and administered by the IME.

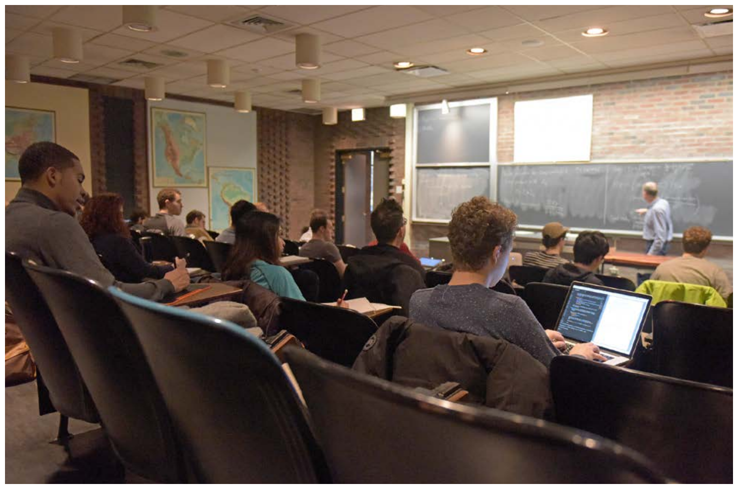
Among majors, UChicago College programs of study, Molecular Engineering ranked as the

9th

most popular for admitted college students—out of 60 majors offered.

The New Paradigm, Implemented

The molecular engineering major represents a new paradigm for both UChicago and engineering education in the broader academic world. Departing from standard engineering education models that teach separate



disciplines of chemical, mechanical, electrical, and other components, the molecular engineering major is a hybrid built on fundamental science education principles yet shaped by unique, applied objectives. It is not bound by UChicago's traditional emphasis on the theoretical side of science and mathematics—it relies on a nano-level focus and a fierce commitment to innovation and interdisciplinary work while inspiring students to direct their invention and design toward solving some of the most pressing problems of our time.

The UChicago Core Meets Engineering

The UChicago Core curriculum is as fundamental to the IME major as it is to all UChicago courses of study. Initially, "there was some concern with how engineering would mesh with the Core curriculum," notes Rovana Popoff, IME's Associate Dean for Education and Governance. "But the major was actually designed to take advantage of the broad training offered through core courses. IME faculty definitely see the value of it." This synergy provides a framework for not only critical thinking but also lifelong inquiry across cultures and disciplines, launching students into career trajectories that promise to converge separate fields of research and yield innovative solutions.

"We're developing the program to take advantage of the strengths and traditions of a liberal arts education," said Paul Nealey, the Brady W. Dougan Professor in Molecular Engineering and Director of IME Undergraduate Studies. "By the very nature of offering a program in the tradition of this University, it will be very different from a standard engineering education, drawing from other strengths on campus—physics, chemistry, and the biological sciences, mathematics, computer science, statistics, and more."

"We're building on the excitement of the first class coming through by conveying this vision."

The Synergy of Double Majors

While the program will prepare undergraduates for a wide variety of careers in technology-focused industries, it also will

prime them for further post-graduate study in other fields such as science, engineering, medicine, business, and law. "The connection to other majors will enable students to pursue molecular engineering degrees with double majors in synergistic fields," explained Nealey. "It offers them more flexibility for individualized trajectories."

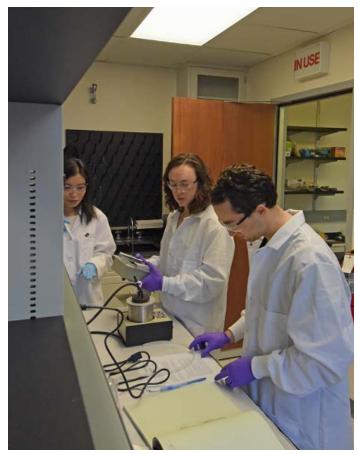
"Our program will attract the super-talented students with diverse interests, students who are risk takers, with a different mindset for putting together their education and for using it."

"Not Your Old, Boring Labs"

The molecular engineering major is composed of three tracks: 1) Chemical & Soft Materials, 2) Biological Sciences, and 3) the Quantum track. An "immersion quarter" in Engineering Design that offers a "capstone experience" will be implemented in Winter 2018. It will give students the challenge of putting their science and engineering knowledge to work on real-world problems and to hone the social skills of teamwork and written and oral communication necessary for operating in contemporary society. Students will learn about and grapple with economic factors, legal and regulatory limitations, and other external constraints on engineering projects.

"Another element of the molecular engineering major that is generating tremendous excitement is the offering of lab sections in conjunction with first courses. One lab section involves an innovative exploration of transport phenomena. Many of the lab modules were designed around micro-fluidics—not your old, boring experiments from 20 years ago!" said Nealey.

"Our aim is also to prepare our students for leadership roles in a technological society. They will be employable in the tech, medical, and consumer products sectors. Post-graduation options include medical school, law school, business administration, venture capital endeavors, entrepreneurship, and public policy positions."



A First Cohort of 29

Twenty-nine undergraduates chose to start on the molecular engineering major in 2016, and this first class will graduate in 2018. Their new courses provide opportunities for developing quantitative reasoning and problem-solving skills; introducing the students to engineering analysis of physical, chemical, and biological systems; and addressing open-ended technological questions across a spectrum of disciplines.

"Our program will attract the super-talented students with diverse interests, students who are risk takers, with a different mindset for putting together their education and for using it." —Paul Nealey

"We have a curriculum in place for those students, but we will continually take stock and assess whether we're training them in the best way that we can," said Dean Tirrell. "Our approach focuses not on the narrow slices of traditional engineering disciplines, but, rather, on major societal issues such as health care, energy, information technology, and water scarcity—issues that a broad spectrum of engineering skills can help address," said Tirrell.

From Minor to Major

The IME's major is the culmination of planning efforts that began with the introduction of an IME minor program in 2014. By 2015–16, 184 undergraduate students were enrolled in IME courses focused on technologies for solving challenging problems.

A new undergraduate course, taught by IME Senior Associate

(continued next page)

Undergraduate Major (continued)

Dean Sharon Feng and Professor Supratik Guha, ***Molecular Engineering 20100: Turning Science and Innovation into Impactful Technologies***, concentrates on "the process of turning science into working technologies for the public good." It asks students to consider "How does one take an innovation or a discovery and perform the due diligence required to identify application areas, assess market potentials, protect intellectual property, evaluate competitive landscapes, and then develop a business plan to produce a reliable, affordable product?"

The course also features distinguished guest speakers who outline their experiences as industrial leaders turning basic research into technology. The students sharpen their newly acquired skills by working on team projects based on real technologies developed in IME laboratories. Their works this past year were presented to and judged by a group of innovation professionals that included tech transfer professionals, venture capital fund representatives, and successful entrepreneurs.

Pipeline for Attracting Students

UChicago and Zhejiang University agree on undergraduate student exchange for study and research

At the University of Chicago's Beijing Center, Dean Tirrell and his Chinese collaborator, Zhikang Xu, Chair of the Department of Polymer Science and Engineering at Zhejiang University, signed an agreement to formalize the IME–Zhejiang relationship and arrange for an undergraduate student research exchange program. The agreement grew out of a day-long workshop on water: "Water Treatment Technologies for a Better Tomorrow," moderated by Tirrell and Xu. (story p. 22)

"Through this kind of global outreach, we are building pipelines for attracting the best students to the IME from all over the world," said Senior Associate Dean Sharon Feng.

Exporting IME Undergraduate Research

Summer water research program for undergrads blooms in the Negev Desert

The IME's Water Research Initiative sponsored its second annual summer program designed to send IME undergraduate students to study and research in Israel at Ben-Gurion University of the Negev. Kwan Wong worked on a water filtration and desalination project. Clare Singer investigated 3-D printing as a means of improving chemical change processes on membrane surfaces treating waste water.

Claire Liu: Profile of an IME Undergraduate Major

Claire Liu is one of the first undergraduate students to major in molecular engineering. Working in the Nealey Group, she researches ways to engineer a robust biomaterial capable of driving and enhancing peripheral nerve regeneration.

Liu is excited to be in on the ground floor of the new major. It affords her the opportunity to learn the fundamentals of engineering and also hone her critical thinking, analytical, and writing skills through the UChicago Core curriculum.

"The wonderful thing about this program is that you have all the traditional sciences combined with technology, design, innovation and industrial aspects," said Liu. "It makes the whole college experience that much more fun. This major is one of the main reasons I chose the University of Chicago."

Beyond her coursework, Claire is the co-president of Benzene, the undergraduate chemistry club. She is also a University Ambassador for Lyric Opera of Chicago, the IME's social media coordinator, and a Frank Sinatra aficionado.

The IME Graduate Program: Acceleration from 0 to 92

The graduate education component of IME's mission rapidly advances in 2016

Just two years ago, the University of Chicago had no engineering students. By the fall of 2016, it had nearly 100 PhD candidates in molecular engineering. "The sheer size of the program—and the speed with which it has achieved that size—is an extraordinary accomplishment," observed Juan de Pablo, Liew Family Professor in Molecular Engineering and Deputy Director for Education and Outreach.

The IME graduate student program is expanding at an astonishing rate. Twenty PhD candidates joined this year, and many more are expected in the wake of 2016's highly successful recruiting season.

IME grad students are receiving high-profile fellowships, including those awarded through the Fulbright programs, National Science Foundation, and U.S. Department of Energy. Several students have published their work in the most prestigious scientific journals, including *Nature*, *Science*, *Physical Review*, *ACS Central Science*, and *Science Advances*. And after only three years, the track record for IME graduates' employment is impressive. They are highly sought-after researchers and practitioners, and they are finding desirable jobs in esteemed educational institutions and companies.

"At the IME we stress the 'future practical.' This means that we pursue research in a problem-focused way. It also means that our students are prepared to communicate the results of their work to a broad audience and to take the lead in developing applications for their research," said de Pablo.

Matt Tirrell and a few IME graduate students visit in one of the William Eckhardt Research Center lounges.

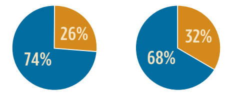
IME GRADUATE ENROLLMENT

	2015–16	2016–17
Total IME Graduate Students	37	50

Percent by Gender

■ FEMALE

■ MALE



An IME Alumnus Puts His Institute Experience in Perspective: Hyo Seon Suh

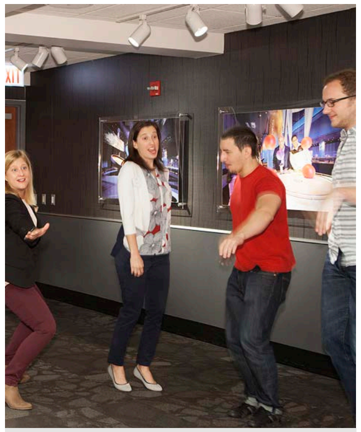
In 2016, Hyo Seon Suh accepted a position as Directed Self-assembly Engineer with International Medical Equipment Collaborative (IMEC), a renowned nanoelectronics research institute based in Belgium.

As one of Professor Nealey's researchers, he investigated self-assembled patterning of nanoscale materials on computer chips—a promising set of technologies that may enable increased memory capabilities on ever-smaller processing chips.

Suh says that his time at IME "was very valuable. It was a completely new institute, and that is a very rare thing." Suh was able to accomplish much of his IME research as a result of the connection to Argonne National Laboratory's clean room and its Advanced Photon Source (APS). "IME's partnership with Argonne was critical for me," he said. "Everyone wanted to work with us when the IME started up. And without Argonne, I would not have been able to conduct the highly detailed work for my research."

IME Advances the Cause of Science Communication

Effectively communicating science is more essential than ever before—for our nation and global community. The IME is developing and collaborating on powerful programs to strengthen students' skills for communicating, not only with other scientists, but also with the general public and within the realms of business, government, and the arts.



The IME–MSI Science Communication Program gets graduate students out of their shells and moving toward new capacities in communicating their science.

Innovative Training in Public Engagement

In 2015, IME Professor Juan de Pablo contacted Rabiah Mayas (pictured below), the Museum of Science and Industry's Director of Science and Integrated Strategies, and asked for her ideas and assistance in fulfilling IME's goal of developing "a really modern twenty-first century graduate student in the sciences."

This novel request for collaboration between the IME and the Museum (MSI) was in response to a National Science Foundation grant requirement: include a public engagement component in the graduate students' experience and training. The innovative IME–MSI Science Communication Program is the result, a powerful example of the high priority the Institute places on teaching effective communication skills.

At the Museum: "You want us to do improv?"

That was the question on the minds of many of the IME graduate students at their first session in the Science Communication Program. Yes—they were asked to "do improv" in a series of workshops aimed at developing their capacities to form and deliver relatable messages about science to non-scientists. "Many students were visibly skeptical from day one—but that changed," said Mayas. "The workshops gradually get students to show up with their voices and their personalities," she continued, "and that helps them find compelling ways of conveying the complexities of their work."

In 2015, the program became official, and two cohorts of students are now moving through this very effective science communication boot camp. First year workshops are conducted by MSI Director of Guest Experiences, Heather Barnes, who uses improvisation in the Museum's training of science facilitators to engage with guests; and year two workshops by Mayas, who is passionate about MSI outreach efforts, including helping young Chicagoans overcome barriers to careers in science. The IME graduate students are gaining the capacity and confidence to tailor scientific content, connect with audiences, respond in the moment, make the evidence relevant, and be empathetic and accessible. They learn the skills of science storytelling, the power of personal narratives, and how to create research-based engagement experiences.

IME scientists participate in UChicago's *Discovery Series*, a speaker series designed for a wide audience that invites the public to hear about research and then engage with experts in a Q&A session. (story p. 39)

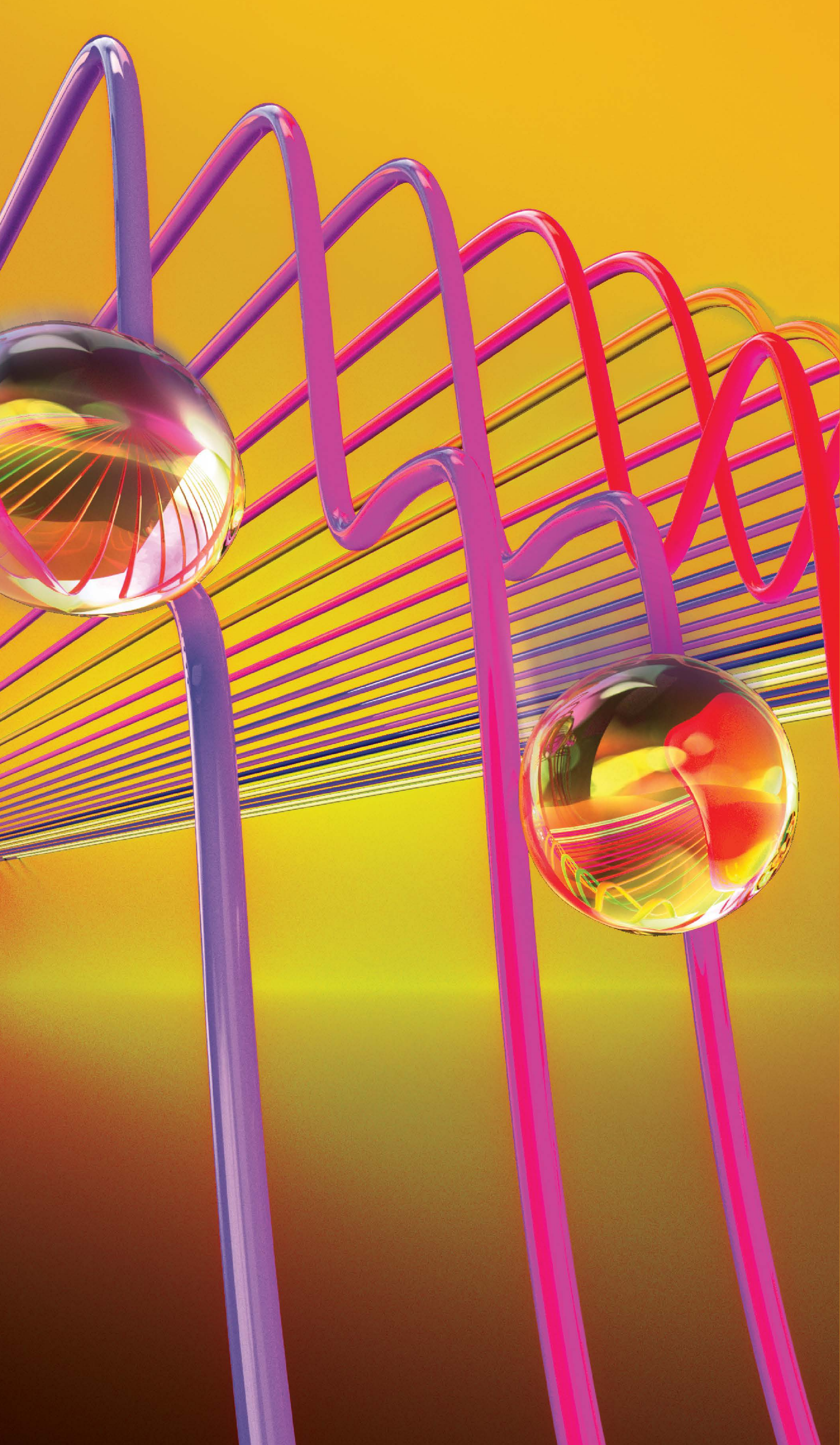
Taking Advantage of the UChicago Innovation Ecosystem

Science communication advances through multidisciplinary inquiry and exchange

IME students are encouraged to collaborate across boundaries and across campus. As a result, they increase their capacity to explain the significance of their work to those outside the field of molecular engineering. The Institute takes advantage of the broader UChicago ecosystem for innovation, entrepreneurship, and public policy understanding to strengthen its communication training programs. UChicago's schools, centers, initiatives, and connections stimulate innovative ideas, teach entrepreneurial skills, and promote collaborative discovery and decision making. The Urban Labs initiative (social sciences), the Harris Energy Association (public policy), and the MERITS initiative (medicine) exemplify UChicago's strategies for promoting cross-disciplinary research, innovation, and scholarship.

Additional IME Communications Programs

- **The STEM Writing Program** helps students anticipate and shape readers' responses to their work, whether those readers are professors, business professionals, or members of the general public;
- **IME Workshops on Teaching Fundamentals** are pre-teaching assistantship courses that help students explore teaching strategies to encourage active learning and problem-solving in STEM classrooms.
- **The IME Science Writing Fellowship** provides opportunities for students to write and publish articles about faculty members' research, new faculty appointments, and major IME events.



"To address significant societal challenges, IME fosters a broad collaborative network of innovators, helping transfer cutting-edge scientific discoveries from campus to marketplace. We collaborate with people from all walks of life, from domestic to international, from academic to industrial, from volunteers to professionals, from government agencies to private philanthropists."
—Sharon Feng, Senior Associate Dean of Budget and Strategy

Collaboration and Impact

Moving to the Frontlines of a Global Effort:

Water Research

In 2016, the IME's water research advanced in its efforts to protect water, to purify it, and to contribute to a shift in thinking—from clean water as a scarce resource to clean water as a global human right.

The IME Water Research Initiative (WRI)

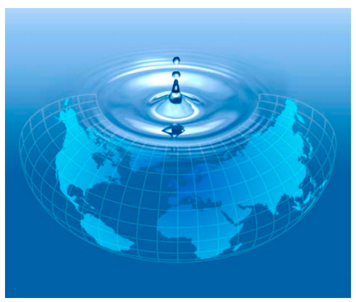
One of the IME's five major research themes—Molecular Engineering of Water Resources—led directly to the creation of the Water Research Initiative in 2013. Entering its third year, the WRI is dedicated to harnessing technological advances in nanoscale science and engineering to develop new tools and processes for water production, purification, preservation, and re-use.

"I'm very excited to join IME. Its world-class researchers have accomplished a very considerable amount in a short period of time, including laying the groundwork for the Water Research Initiative."
—James L. Skinner

The WRI encompasses an expanding range of research projects and opportunities for multidisciplinary, multi-institutional partnerships tackling the critical issues of global water supply. With the arrival of its new director, James L. Skinner (story p. 8), the WRI enters its next phase of expansion and consolidation, forming a coherent, impactful set of programs.

IME collaborations, international events, and research projects outlined below provide an overview of 2016 accomplishments and a glimpse of what's to come in 2017 and beyond.

Water Research Seed Grants Bear Fruit



2016 marked the conclusion of the exceptionally productive round of six seed grants for water research projects. Kick-starting the collaboration among water researchers at IME, Argonne, and Ben-Gurion University of the Negev, a total of approximately $1.5 million dollars was invested by the three partnering institutions. This funded six teams working on diverse technologies to develop materials and systems to make clean water more accessible, affordable, and sustainable. The initiative has involved over 20 research scientists including physicists, chemists, geoscientists, environmentalists, and molecular engineers in this ocean-crossing collaboration.

The teams have already generated 10 publications and one patent, with more to come. Significantly, three teams plan to commercialize their technologies. Two teams have received federal funding from the NSF and from the U.S.–Israel Binational Science Foundation as a result of the work produced. Workshops were conducted—one in the U.S. and one in Israel, each with 20-plus participants. Seven UChicago undergraduates interned during summers in the Negev desert with Ben-Gurion researchers. Technological developments and collaborative relationships formed a solid foundation, enabling the IME to further advance and broaden its Water Research Initiative.

Water: The Fundamental Molecule and Common Bond

The IME organizes three days of events that venture outside the conventional boundaries of nations, sectors, and disciplines.

2016 U.S.–China Forum on Water and Urban Development

As two of the world's top energy consumers and producers, the U.S. and China experience similar challenges in water use, management, and conservation. The U.S.-China Forum on Water and Urban Development was conceived and organized through the IME as an opportunity to gather experts from both countries to share concerns and solutions in managing reliable water resources, particularly with the desire to encourage economic development and growth.

"On topics of water, and energy—broadly speaking—discussions are typically confined within fields: scientists talk with scientists, policy-makers talk with policy-makers, and industrialists talk with industrialists. But viable solutions in this area can only be achieved through shared perspectives and partnership," observed Rovana Popoff, IME Associate Dean. "In organizing this forum, we built on the UChicago tradition of interdisciplinary exchange. Our goal was to foster dialogue and collaboration between scientific, policy, and industry experts to more powerfully address water issues in China, the U.S., and beyond."

The forum was supported by the China–United States Exchange Foundation (CUSEF) in collaboration with the University of Chicago. CUSEF works to create forums that build long-term research collaboration between Chinese and U.S. researchers, and stakeholders in the public sector and industry.

A Diverse Range of Subject Matter Experts

The IME assembled forum participants to explore water issues from every perspective. Industry sector speakers included representatives from GE, True North Venture Partners, IBM, and NALCO Water. Government organizations as diverse as the World Bank and the Metropolitan Water Reclamation District of Greater Chicago were represented. American and Chinese scientists, researchers, and engineers from the IME, Argonne, the Shanghai Urban Construction Design and Research Institute, and several universities participated.

Three Moderated Programs

October 5 – His Excellency He Yafei, former Vice Minister of Foreign Affairs of the People's Republic of China, delivered an opening address on U.S.–China relations and the five pillars of China's foreign policy. "Simply put," he said, "China aims for an international environment that will allow China to develop peacefully and to be a responsible member of the international community that can contribute to the common good of humanity."

A dialogue between He and Paulson Institute Vice-Chairman Even A. Feigenbaum followed and was moderated by Rachel Bronson, executive director and publisher of the *Bulletin of Atomic Scientists*.

October 13 – An address by Deb Frodl, Executive Director of GE's Ecomagination, discussed "Energy at the Nexus of Science, Industry, and Policy."

October 14 – Four Panel Discussions formed a day-long immersion in water issues:

1) U.S.–China Shared Challenges in Water Management and Urban Development,
2) Developing and Implementing Policies to Address Water Challenges,
3) How Are Innovations in Engineering and Technology Helping to Address Water Challenges?
4) Coordinating Perspectives and Expertise to Address Water Challenges in Urban Development.

"We're exploring ways of working together. Everyone's interested. It promises unprecedented progress," IME Senior Associate Dean Sharon Feng commented.

IME, Argonne, and Chinese Experts Explore Water Treatment Technologies

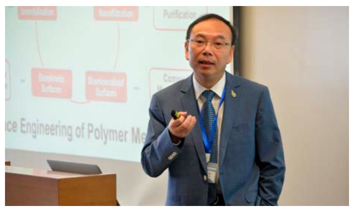
UChicago's Beijing Center is the setting for fruitful workshop

IME's Matthew Tirrell, and Professor Zhikang Xu of the Department of Polymer Science and Engineering at Zhejiang University, moderated a day-long workshop on "Water Treatment Technologies for a Better Tomorrow," held at the University of Chicago Beijing Center.

In addition to scientists from IME and Argonne, industrial experts and top researchers from major Chinese Universities including Zhejiang University, Tsinghua University, and the Harbin Institute of Technology presented their research findings. Speakers focused on new material design for membranes, system and engineering best practices for water purification and waste water treatment, and urban planning for water management.

"This single workshop was the seed for future activities," said Sharon Feng, IME's Senior Associate Dean, who organized and attended the event. "Both IME and our Chinese partners share the same goal of contributing to technological innovation for water sustainability. We're hoping to be able to achieve more collaboration—that's the bottom line." From this workshop came the first joint water research grant application from IME scientists and Zhejiang University researchers. The application was submitted to the U.S. National Science Foundation and the Chinese National Science Foundation. The IME is pleased with these developments, and is confident that they will stimulate more collaboration.

At the conclusion of this workshop, Tirrell signed an agreement to formalize the IME–Zhejiang relationship and arrange for an undergraduate student and research exchange program. (story p. 14)



Thoreau Sensor Network Goes Live on Campus

By utilizing a network of sensors under water, underground, and in other UChicago environments, IME scientists will be able to test a variety of sensor technologies to examine their future viability and application in critical water and agriculture research. Henry David Thoreau's 19th century writings, including his ecological data, inspired professors Monisha Ghosh and Supratik Guha to name it the Thoreau Sensor Network, which went live on campus in 2016.

The network connects to larger networks established by Sigfox, a France-based company utilizing device-to-Cloud connectivity technology to listen to billions of devices broadcasting data. The University of Chicago is one of many local Sigfox partners.

"The network that we are setting up should be usable for all kinds of sensors. This open platform network in the neutral territory of a university will enable its use as a sandbox for research and benchmarking of sensors, hardware, and data science," said Guha.

Monisha Ghosh

Supratik Guha

IME and Argonne Join *Current*—A New Consortium

UChicago brings expertise to regional consortium of water research and tech leaders

The University of Chicago and Argonne National Laboratory have joined *Current*, a Chicago-based consortium of leading research institutions, industry leaders, NGOs, and government organizations launched in 2016 to collaborate on solutions to today's most urgent water challenges.

Chicago's Water Economy

According to *World Business Chicago* statistics, the Chicago region boasts the world's largest water treatment plant (the Jardine Water Filtration Plant) and the world's largest wastewater plant (the Stickney Water Reclamation Plant). Water infrastructure and technology here account for $14 billion in terms of gross regional product, and the region's water industry employs nearly 100,000 people. Chicago's robust water economy is the fourth-largest in the nation.

An Innovation Hub

Making Chicago an innovation hub for water technology is key to positioning the city as a world-wide leader in this field. IME's Sharon Feng, who served on the advisory committee for the formation of *Current*, stressed the importance of developing water technology and assets to attract "water-based and water-intensive" industries. *Current's* partner institutions, which also include Northwestern University and the University of Illinois, form a powerful platform for industry innovation. In addition to IME's cutting-edge research and innovation capabilities, UChicago also brings diverse expertise in the areas of water economics, public policy development, behavioral science, and urban planning to the table, forming a holistic approach to solve today's water challenges. UChicago's close link to Argonne enables it to make progress in areas such as the Water-Energy Nexus—the intersection at which energy production and water systems converge.

A Unique Approach: Access to Testbed Facilities for Technology Development

Often, innovators in the proof-of-concept stage face a daunting challenge: access to adequate facilities to demonstrate the feasibility of a new technology at scales beyond laboratory or even pilot trials. The Chicago area's vast water resources, infrastructures, and commitment to collaboration uniquely position the city to support technological and industrial innovation in the field of water management. With the participation of Chicago's public water sectors such as The Metropolitan Water Reclamation District of Greater Chicago (MWRD) and Chicago Water Authority, *Current* could provide unprecedented access to public facilities for innovators to conduct real-life scale-up trials, and translate laboratory science into technologies that address critical issues of water management and treatment.

The Power of a Multidisciplinary Mission and Culture:

An Emphasis on Innovation Spurs New Ventures

Strong alliances between IME and an array of UChicago schools, centers, and institutes are advancing the process of capacity-building and business development.

Campus-wide Collaboration Brings a Promising Drug Closer to Market

There is no better example of innovation in action than that of the ongoing business development process for a biomedical product through the newly created company, ClostraBio.

Cathryn Nagler is a UChicago Biomedical Sciences Division food allergy professor and research scientist investigating potential drugs to treat childhood food allergies—and she had no plans to step into the world of business. But for Nagler, an encouraging path to company-building was right on campus.

> "Being able to form this company across all of these different parts of the University is pretty amazing." —Cathryn Nagler

Through the Institute for Translational Medicine, the IME, the Polsky Center and its Innovation Fund, the Booth School of Business, and the University's Biological Sciences Division, connections happened, collaborations began, and a compelling vision took shape. "Being able to form this company across all of these different parts of the University is pretty amazing," said Nagler. "I'm just very, very grateful to have this opportunity."

ClostraBio was given a boost when I-Corps, a National Science Foundation program administered at UChicago by the Polsky Center for Entrepreneurship and Innovation, provided grant resources to investigate the real-world commercial potential of an emerging product.

In 2015, she teamed up with Jeffrey Hubbell, the Barry L. MacLean Professor of Molecular Engineering Innovation and Enterprise, to create ClostraBio and further develop drug products that protect against the immune response induced by allergens in cow's milk, peanuts, and other substances.

IME's John Colson Transitions to ClostraBio Leadership Position

While still an IME postdoctoral fellow in chemistry working in professor Nealey's group, John Colson spent his spare time engaged in entrepreneurial activities with Nagler. He collaborated with her on ClostraBio—from an idea on paper to its expansion into a full-fledged company.

In 2016, ClostraBio received an important initial investment of $800,000 to fund the next year of operations. This allowed Nagler to hire Colson as ClostraBio's project manager in charge of business operations: overseeing the scientific progress, developing relationships with potential partners, manufacturers and suppliers, and navigating the realms of insurance and government agency compliance.

Left to right: John Colson, Jeffrey Hubbell, and Cathryn Nagler.

"We've grown infinitely," Colson says of ClostraBio. "I'm grateful that IME and my advisers were so supportive of entrepreneurial activities." He had been active in product and business-forming activities while at the IME, was a senior associate at the Chicago Innovation Fund, and co-founded the IME's Innovation and Commercialization Fellows program.

Colson highlights parallels he sees between entrepreneurship and science: "In many ways, we've undertaken a scientific approach to building a business," he says, observing that his work for ClostraBio requires questioning the science, forming hypotheses and testing them, and building the program in a way that is consistent with previous results.

"I'm excited to be working on a problem so desperately in need of a solution," Colson says. "This is what's so compelling: our long term goal, which is to provide the relief that patients and doctors are asking for."

A Market Leader Expresses Confidence in Innovative Cancer Therapies Being Researched at the IME

Hubbell and AbbVie pursue immunotherapy solutions

Cancer immunotherapies may take on a more significant role in helping patients as a result of IME research that expands commercialization options.

IME, AbbVie Increase Collaborations

Immunotherapy research conducted by professor Jeffrey Hubbell received commercialization support from the newly expanded Polsky Center in 2016. This resulted in a five-year cancer research collaboration agreement between Hubbell's lab and AbbVie, the global pharmaceutical corporation, and strengthened the existing partnership between UChicago and AbbVie. Under the terms of the new agreement, AbbVie will be entitled to license any work produced by the lab during the five-year period.

Hubbell's work in immunotherapy is recognized for the innovative ways it enlists the body's immune system to attack tumors. This kind of treatment promises to be more effective than chemotherapy and less prone to side effects. With support from AbbVie, Hubbell's research and the resulting potential products to help patients will move forward at an accelerated pace.

The Polsky Connection

Consolidating several UChicago innovation and entrepreneurship operations in 2016 (including UChicago Tech and the Chicago Innovation Exchange) into the expanded Polsky Center paves the way for a greater volume and scope of technology and business development activities by:

- accelerating development of commercialized applications of research, including IME's work and its wide network of collaborators;
- streamlining access to UChicago's nationally recognized programs in venture creation and education, technology commercialization, and business incubation;
- supporting new programs such as fellowships to train founding CEOs; and
- providing increased support for alumni entrepreneurs.

Improvisation and Exploration Underway at *STAGE* Collaboratory

With the *STAGE* "collaboratory" space renovation in the Reynolds Club completed in 2016, workshops in the space are erasing the lines between science and the arts for engaged students.

Through *STAGE*, students from IME and other campus entities are gaining the opportunity to participate in the process of generating emotionally engaging theater that is fundamentally integrated with scientific ideas.

"We try to treat every improvisation we do as if it's an experiment, analogous to what might be done in a science lab."
—Nancy Kawalek

These experiences broaden and deepen emerging scientists' understandings of the role and potential of science in contemporary society.

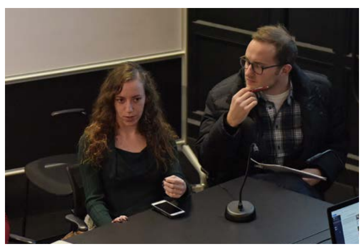
A Two-Year Process of Discovery and Development

Several theater projects are being created through a collaborative, improvisational workshop process that involves the participation of science graduate student researchers, as well as graduate and undergraduate students from various disciplines across the campus. Workshops are also held with professional scientists and artists. Nancy Kawalek is the director, guiding the steps from exploration of an idea to improvisational development of a plot and script to the next iteration of the theater piece.

"We try to treat every improvisation we do as if it's an experiment, analogous to what might be done in a science lab," Kawalek explained. "We explore what we learned from the experiment. This discovery shapes the next round of improvisation and development, which shapes the next, and so on. Finally, in a process that takes about two years, we have a theatrical piece—a performance piece—that has not only been formed at the intersection of science and art, but utilizes aspects of both fields' methods to generate and communicate insights to a broad spectrum of audiences."

STAGE Projects in Progress Include:

- ***The Art of Questionable Provenance*** The lives of a photojournalist, a neuropathologist, an art forensic expert, and a fortune teller intersect around a bizarre crime. A tale of perception that parallels the functions of the brain and explores critical themes emerging from modern neuroscience, *The Art of Questionable Provenance* examines how we piece together the stories—real or illusory—of our selves.
- ***Bend, Fold, Break*** A young scientist, at a critical point in his career, receives notice of a mysterious package left to him by the late mother he never knew. What he finds when he travels to Japan to retrieve his inheritance is much more than he ever could have imagined. Dealing with themes of identity, culture, and heritage, *Bend, Fold, Break* asks how we define ourselves—as scientists and artists, as individuals, and as family.
- ***Symmetry*** A focus on two women, a critical moment in history, and the fundamental principle of symmetry.

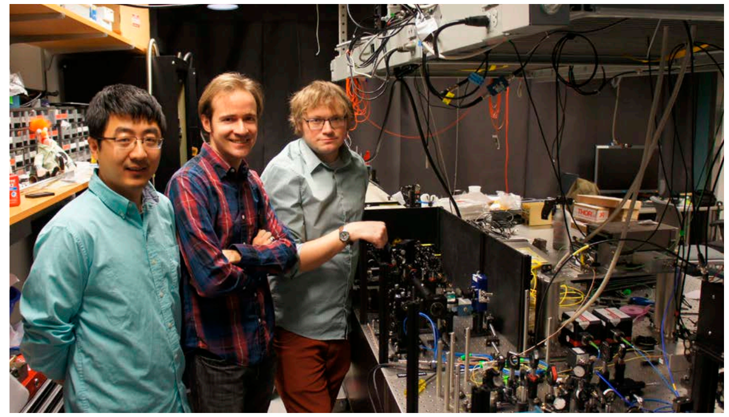


Investigations and Results from IME Faculty and Their Grad Student / Post-Doc Teams:

Research Beyond Boundaries

Quantum Computing Advance: Light 'Lights the Path'

Awschalom Group demonstrates a well-behaved qubit



Scientists in the Awschalom Research Group working with a team at the University of Konstanz have recently demonstrated a way to use light to make a potential qubit (the basic quantum unit of information) behave more reliably for quantum information processing. Their achievement is based on a geometric concept at the atomic level known as the Berry phase and is implemented through entirely optical means within a single electronic spin in an atomic-scale defect in diamond.

Laser Beam—A Way Around Noise

As explained by David Awschalom, Liew Family Professor of Molecular Engineering in Spintronics and Quantum Information, the IME researchers sent a beam of laser light through the atoms in diamond to fully control the path of the electronic spin. Over the past decade, electronic spin states in this system have attracted great interest as a potential qubit. The key to their advance lay in their idea to rotate the direction of the qubit's state along a geometric path, instead of controlling the rotation with traditional fine-tuned, noise-isolating procedures. More common techniques utilize microwave fields, but the use of laser light to fully control the geometric path of the spin state may lead to photonic networks linked and controlled entirely by light. Co-lead author Christopher Yale, PhD graduate of the Awschalom Group and now postdoctoral scholar at Sandia National Laboratories, offered: "Such a photonic network could be a very practical means of processing and transmitting quantum information through robust qubit state manipulation that is resistant to noise and variations in the strength or duration of control."

"Our approach shows incredible resilience to external influences and fulfills a key requirement for any practical quantum technology."
—David Awschalom

To test the robustness of their Berry phase operations, the researchers intentionally added

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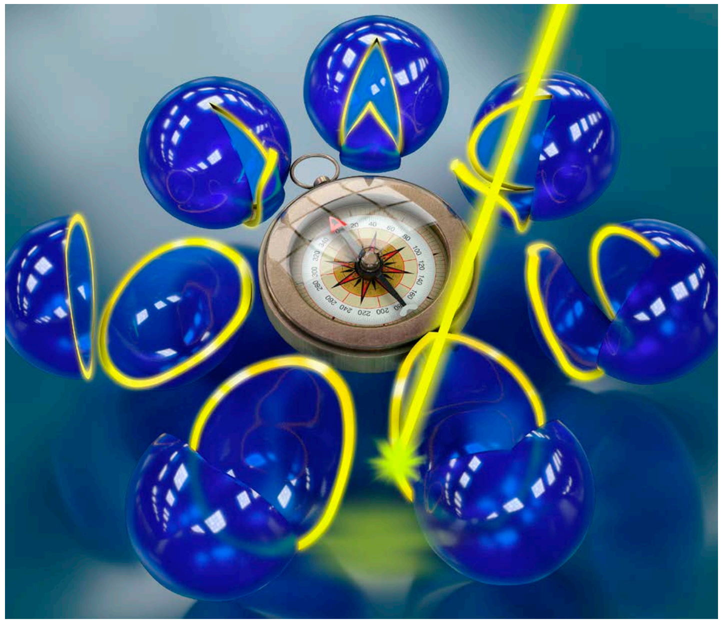
Quantum (continued)

noise to the laser light controlling the path. As a result, the spin state traveled along its intended path in an erratic fashion. However, as long as the total area of the path remained the same, the Berry phase they measured also remained constant.

"We found the Berry phase to be insensitive to fluctuations in the intensity of the laser. Noise like this is normally a bane for quantum control," said Brian Zhou, a postdoctoral scholar in the group and co-lead author.



F. Joseph Heremans, also a co-lead author and now a staff scientist at Argonne, explained: "Imagine you're hiking around a lake but you continually leave the path to take pictures. Once you've finished, you've circumnavigated the lake regardless of the bizarre path you took, and the area remains virtually the same."

"We tend to view quantum operations as very fragile and susceptible to noise, especially when compared to conventional electronics," said Awschalom, who led the research. "In contrast, our approach shows incredible resilience to external influences and fulfills a key requirement for any practical quantum technology."

IME Professor Awschalom Invited to Speak at White House Quantum Information Science Forum

In October 2016, IME Professor David Awschalom traveled to Washington, DC, to participate in a forum on quantum information science (QIS) hosted by the White House Office of Science and Technology Policy (OSTP). Nearly 70 leaders from industry, academia, national laboratories, and government agencies participated.

Awschalom is a pioneer in the field of semiconductor spintronics and quantum information engineering; his research explores the spin of electrons and nuclei for advanced computing, medical imaging, encryption, and other technologies operating at the nanometer scale.

QIS technologies build on phenomena that are unique to quantum interactions and can acquire, process, and transmit information in ways that greatly exceed the existing capabilities of modern digital technologies. QIS promises new levels of performance for sensing and metrology, communications, simulation, and computing that can enable important scientific advances in physics, chemistry, biology, materials science, and other domains. The forum's primary goal was to identify strategic options for addressing the challenges impeding QIS research or commercialization. Many of the presentations were given by QIS leaders in industry and academia who provided their perspectives on potential solutions to those challenges.

Liquid Crystals May Help "Squeeze" Cells to Pinpoint Therapeutic Drug Delivery

de Pablo Group models, then creates a new way to control lipid capsules

How to better target therapeutic drug delivery—that's the question driving a very active field of research. Liquid crystals may hold one of the answers. In 2016, the research group of Juan de Pablo, Liew Family Professor in Molecular Engineering, conducted pioneering work on the cell division process and the means of manipulating it through cell immersion in cooled liquid crystal oil. They found that a splitting-off of cell ends occurred, suggesting a potential means of "squeezing out" medication from those cells to pinpoint delivery.

Engineered in Computer Models, Built in the Real World

"What we've done is reproduce the beginnings of cell division in a synthetic system," said de Pablo. When a cell divides, the spherical cell membrane stretches into an elliptical form, develops a waist in the middle, and then splits into two spherical cells. The scientists built sophisticated computer models of this behavior and then reproduced it in the real world to test their predictions.

"It's the first time that this has been done," said de Pablo. "It's a system that has been engineered at the molecular level using computer models."

In this work, liquid crystals are key: They can flow like a liquid, but they have the orderly molecular structure of a crystalline solid, which can be changed by temperature shifts and harnessed to manipulate the cell division process.

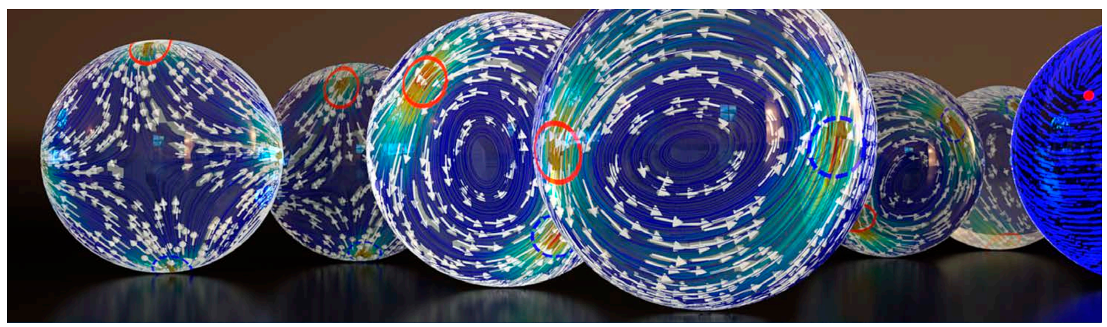
Standing in for cells in the experiments were micron-sized capsules or "vesicles" composed of phospholipids found in real cell membranes. They were immersed in a bath of liquid crystal oil. At temperatures above 97 degrees Fahrenheit, the oil behaves like any other. But when the temperature is lowered slightly, the oil molecules pack tightly against one another like cigarettes and align along a single direction.

"When that happens, the liquid crystal presses on the vesicle more in one direction than in the other, so the vesicle becomes elongated," de Pablo said. "If you squash it more and more, it becomes an ellipsoid, and the two ends become pointier and pointier. There is a point when the molecules around those points separate from one another and create a little gap in the membrane through which things could be squeezed out."

Lipid vesicles are currently used for drug delivery. de Pablo envisions using the liquid crystal technique as a cunning way to control that process.

> "What we've done is reproduce the beginnings of cell division in a synthetic system. It's the first time that this has been done." — Juan de Pablo"

"What we find intriguing is that we have a mechanism that will allow us to take vesicles loaded with something interesting, and by changing the temperature a little bit, we could deform the vesicle and have it squeeze out whatever it has inside without our ever touching the vesicle. And then as we restore the temperature to the original value, the vesicle becomes spherical again."



The Fate of CO_2 in Extreme Conditions

Molecular simulations lead to breakthrough understandings of the nature and behavior of carbon deep within the earth's crust.

Implications for the Modeling of Global Climate Change

The fate of carbon deep within the Earth is linked to that of the planet as a whole. Research results from IME scientists are providing new insights applicable to global climate models as well as fundamental molecular physics.

Giulia Galli, the Liew Family Professor of Molecular Engineering in Electronic Structure and Simulations, and Ding Pan, former IME researcher and now assistant professor of physics and chemistry at the Hong Kong University of Science and Technology, recently achieved a milestone in scientific understanding of the behavior of carbon deep within the Earth, at conditions of extreme temperature and pressure.

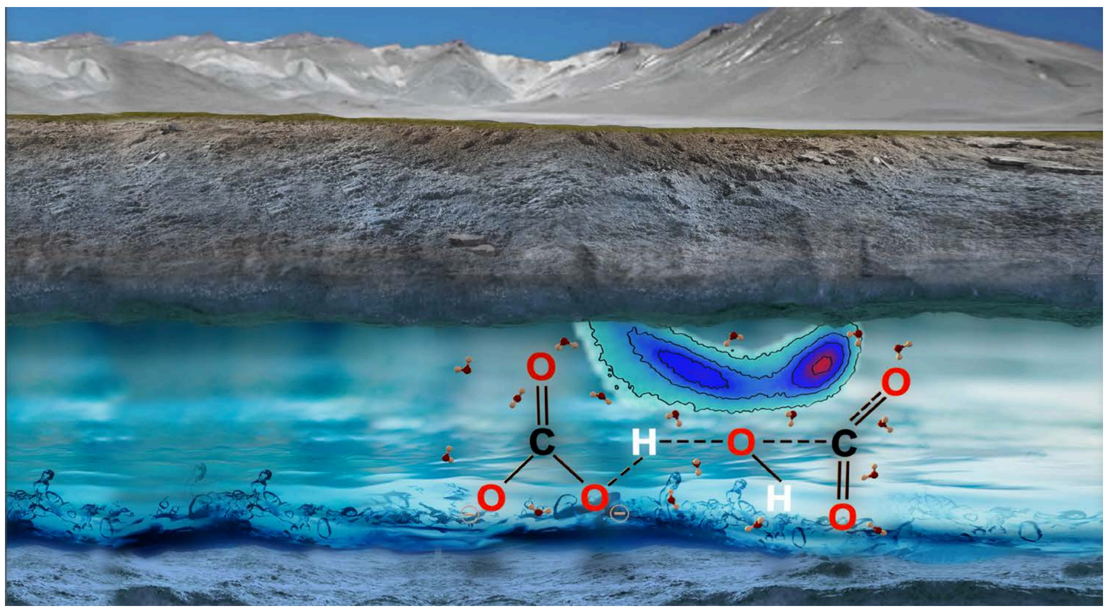
> "Developments in theory and increases in computing power have recently brought ab initio simulation to the forefront of the field." — Giulia Galli

The cycling of carbon through the Earth's atmosphere and near-surface water and land systems is better known than its movement through the planet's deeper mantle. Understanding this deep carbon cycle, as it is called, is critical if scientists are to more accurately model and predict the planetary effects of the increasing amounts of carbon in the atmosphere.

Galli and Pan simulated the fate of dissolved carbon dioxide under the extreme pressures and temperatures existing 400 miles below the surface. In a 2016 paper in *Science Advances*, they described how their research suggests that, contrary to current geochemical models, the carbon dissolved in water-rich fluid at the bottom of the Earth's upper mantle is not in the form of aqueous carbon

dioxide but, rather, it exists in the form of solvated carbonate anions (negative ions). This suggests that CO_2 degassing likely happens close to the surface of the Earth, not deep within its mantle.

"Experiments at these extreme conditions remain very difficult, both in execution and interpretation. Fortunately, developments in theory and increases in computing power have recently brought ab initio simulation to the forefront of the field," said Galli. Powerful simulations of molecular behavior at extreme conditions open the way for concerned scientists to study otherwise hidden geophysical and geochemical processes affecting the planet.



New Immuno-engineering Advances May Help Fight Cancer and Hepatitis

Two IME research teams collaborate to engineer proteins and nanomaterials that trigger immune system responses.

Scientists have just begun to tackle the challenge of developing "therapeutic vaccines" —molecules that create highly specific immune responses to particular diseases already occurring in the body. "The goal is to come up with vaccines for when you're already sick, and not just to prevent sickness," said Jeffrey Hubbell, the Barry L. MacLean Professor of Molecular Engineering Innovation and Enterprise.

> "Collaborations with physicists, with material scientists—all contribute towards the problem of cancer and immunotherapy. It's an area where engineers can solve a lot of problems because of their different approaches and tools." — Melody Swartz

Expanding Boundaries of a Medical Frontier

In March 2016, IME's William B. Ogden Professor, Melody Swartz, and Professor Hubbell and their research teams, published in the journal *Vaccine* the results of a study that expanded the boundaries of this medical frontier. The teams engineered proteins and nanomaterials to trigger a specific immune response that killed both cancer cells and the hepatitis virus in mice.

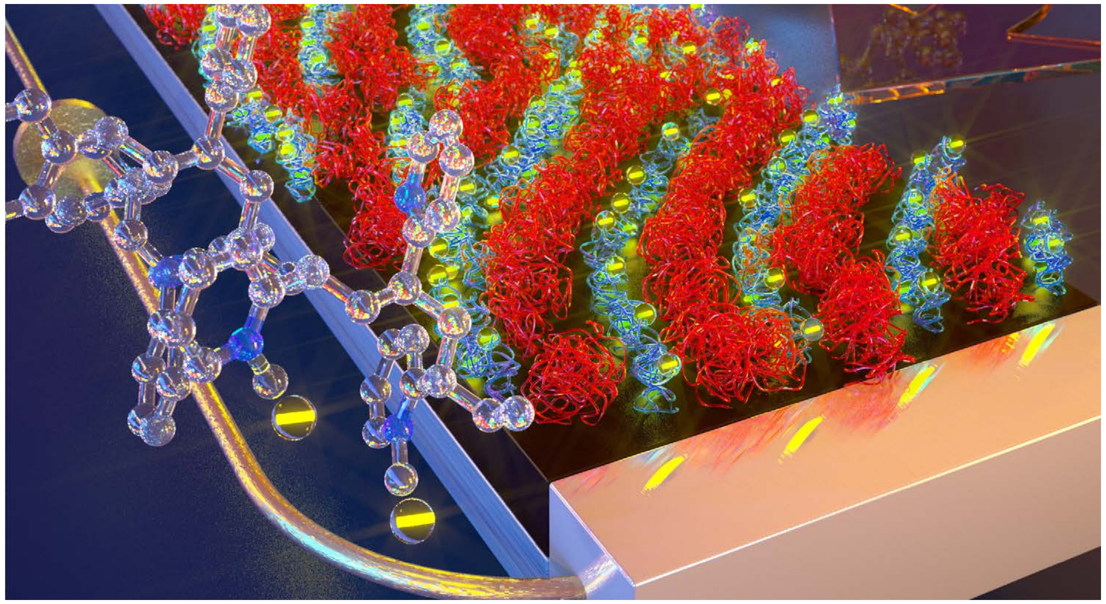
The researchers were able to engineer a protein to stimulate powerful white blood cells, cytotoxic T lymphocytes (CTLs), to kill chronically ill cells such as cancer and hepatitis cells. They also engineered polymer nanomaterials to carry synthetic bacterial DNA sequences through the lymphatic system to trigger an immune response. The nanomaterials, injected into the skin, are so small that "they home to the lymph nodes draining the skin, which are the grand central station for immune detections," said Hubbell. "The nanoparticles carry 'danger signals' along with the molecular characteristics of the tumor cell or hepatitis virus in order to induce specific immunity."

Some other forms of immunotherapy might have the adverse effect of inducing broad autoimmunity, whereas vaccination doesn't induce that. "You stimulate the immune system to turn on very specific immune responses. In principal, therefore, vaccination should be safer than some other forms of immunotherapy," Hubbell added.

IME labs will continue to develop their dual engineered protein and nanomaterial vaccination system in more advanced animal models of cancer and viral disease, he said. "We're refining the technology to try to make it work even better."

After Moore's Law: Still Room for Chip Innovations

New technique patterns atomic-scale transistors more perfectly onto computer chips



Paul Nealey, Brady W. Dougan Professor in Molecular Engineering, along with colleagues at the University of Wisconsin (UW), have found a new, faster, and less expensive way to pattern more transistors into smaller spaces on computer chips—approaching atomic scale. Their work could mean a boost in functionality for semiconductor electronics and in capacity for data storage.

Recognizing the Promise of Directed Self-Assembly

Computer chip makers are always seeking ways to pack more transistors into less space, but as transistors continue to shrink, creating the patterns for circuitry becomes increasingly difficult. Nealey's team addressed this challenge by devising a manufacturing approach utilizing the process known as directed self-assembly, which permits fabrication of intricate, perfectly ordered polymer patterns for circuitry.

Directed self-assembly is a large-scale, nano-patterning technique that can increase the density of circuit patterns and circumvent some limitations of conventional lithographic processes for printing circuits on wafers of silicon and other semiconductors. Conventional chemical techniques are first used to define a pre-pattern or template. Then, when chains of molecules known as block copolymers self-assemble on the pre-pattern, they follow it to form well-ordered features.

Nealey, UW electrical engineer Zhenqiang "Jack" Ma, UW materials engineer Michael Arnold, and their students published details of the advance in 2016 in the journal *Scientific Reports*.

The researchers used a germanium wafer coated with a layer of virtually pristine graphene—a sheet of carbon arranged just one atom thick. They then used electron-beam lithography and a mild plasma etching technique to pattern graphene stripes on the wafer, and they spin-coated the wafer with a common block copolymer called polystyrene-block-poly (methyl methacrylate). When heated, the block copolymer self-assembled completely in just 10 minutes—compared to 30 minutes using conventional chemical patterns—and with fewer defects. The researchers attribute this rapid assembly to the smooth, rigid, crystalline surfaces of germanium and graphene.

Clear Advantages

"These templates offer an exciting alternative to traditional chemical patterns composed of polymer mats and brushes, as they provide faster assembly kinetics and broaden the processing window while also offering an inert, mechanically and chemically robust, and uniform template with well-defined and sharp material interfaces," said Nealey.

The IME's Dean and Founding Pritzker Director Discusses His Research Interests:

Nanotech Meets Medicine

Q & A with Matthew Tirrell

Many of IME's new discoveries and ongoing research projects have applications in medicine. Matthew Tirrell is a pioneering researcher in the fields of biomolecular engineering and nanotechnology. His team is developing nanoparticles called micelles that may be harnessed to help diagnose and treat cancer and heart disease by binding to tumor cells or dangerous plaques that build up in arteries.

Q. What highlights stand out from your IME research in 2016?

A. One of the most satisfying aspects of 2016 for me is the fact that three post-docs from my group graduated and went on to excellent jobs. They're all women, and they received excellent assistant professorships.

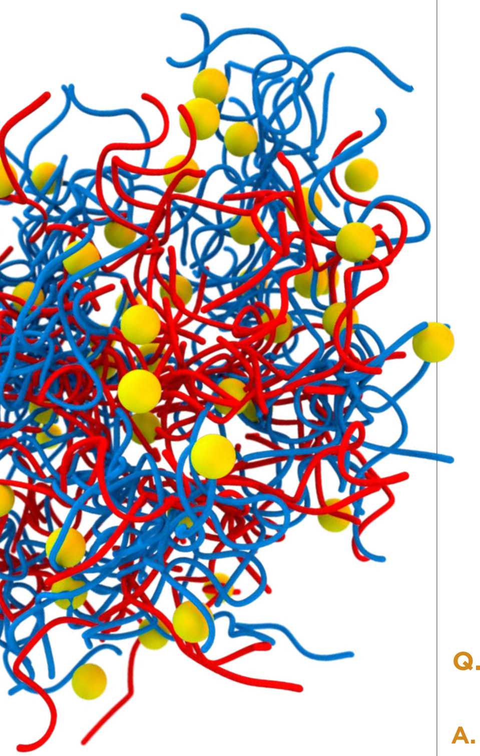
Eun Ji Chung is at the University of Southern California; she helped drive our work on nanoparticle-targeting of atherosclerosis. Blair Brettmann is at Georgia Tech. She was more interested in a fundamental polymer science problem, which is a big effort in our lab: the interactions in charged polymers. Lorraine Leon is at the University of Central Florida. She worked on a variation of that kind of nanoparticle, but she was deeply involved in the physical structure and in understanding the forces that hold these things together and how to make them.

These are great academic jobs—tenure track positions that are very tough. I expect that they will do very well.

Q. A lot of your research examines ways to diagnose and treat atherosclerosis. How did your research this past year move forward on that front?

A. We received a new grant from the U.S.–Israel Binational Science Foundation. Together with Juan de Pablo, we're advising a new grad student on how to use peptide technology for atherosclerosis. That technology has taught us how to remove phosphate from water, which has applications for removing runoff from farms into rivers and lakes. But people can have too much phosphate in their bodies, which can result in the formation of calcium crystals in the walls of blood vessels and severe arteriosclerosis. So we're looking for applications of the peptide technology in the biomedical context.

"The biomedical focus is not our exclusive activity, but it's the direction in bioengineering that we're trying to promote. We're working on engineering the immune system."
— Matthew Tirrell



Nanotech Meets Medicine, Tirrell Q&A (continued)

Q. How do nanoparticles detect arterial plaque?

A. There are diagnostic and therapeutic applications. First, we've figured out how to add imaging capabilities to particles that target plaque. How do you know if you've targeted atherosclerotic plaque? We found a way to inject a fluorescent marker for plaque into the tails of mice that had been fed junk food and had unhealthy cholesterol numbers. We could see that the marker was going to the heart. We couldn't do that in humans—humans are too big—so we found another way to do this. We attached a metal atom so that you could detect plaque in a living human being through nanoparticle imaging diagnostics.

We've also shown we can deliver a nucleic acid therapeutic with one of these nanoparticles. You can use them to deliver therapeutic nucleic acid. In those conditioned mice, we could reduce the size of atherosclerotic deposits.

The biomedical focus is not our exclusive activity, but it's the direction in bioengineering that we're trying to promote. We're working on engineering the immune system. The emphasis has been in large part on cancer, the autoimmune system, and pathogens. But we're also focusing on atherosclerosis, which hasn't received as much attention as it should.

Q. How do these engineered particles stimulate the immune system?

A. In size and shape, nanoparticles are similar to viruses; structurally they have a superficial similarity. Antibodies recognize proteins on the surface of the virus. We know how to engineer particles that look like viruses and stimulate the immune system without exposing people to the possible dangers of injecting viruses.

Q. What's on the horizon for your research in 2017?

A. Pigs are the medical research route from mice to humans. We're going to start moving these atherosclerosis advances into larger animals, and we are thinking of ways to conduct experiments in pigs.

Also, nucleic acids combat inflammation; we have a collaborator who is interested in applying this to injuries to people on intubators, which can cause damage to the lining of the airways that is sometime irreversible. He has made the case that nucleic acids used to treat plaque, which can also arise from inflammation, might be useful for treating lung injuries. So we'll be branching out into other indications for good uses of nanoparticles in 2017.

Faculty: Notable 2016 Honors

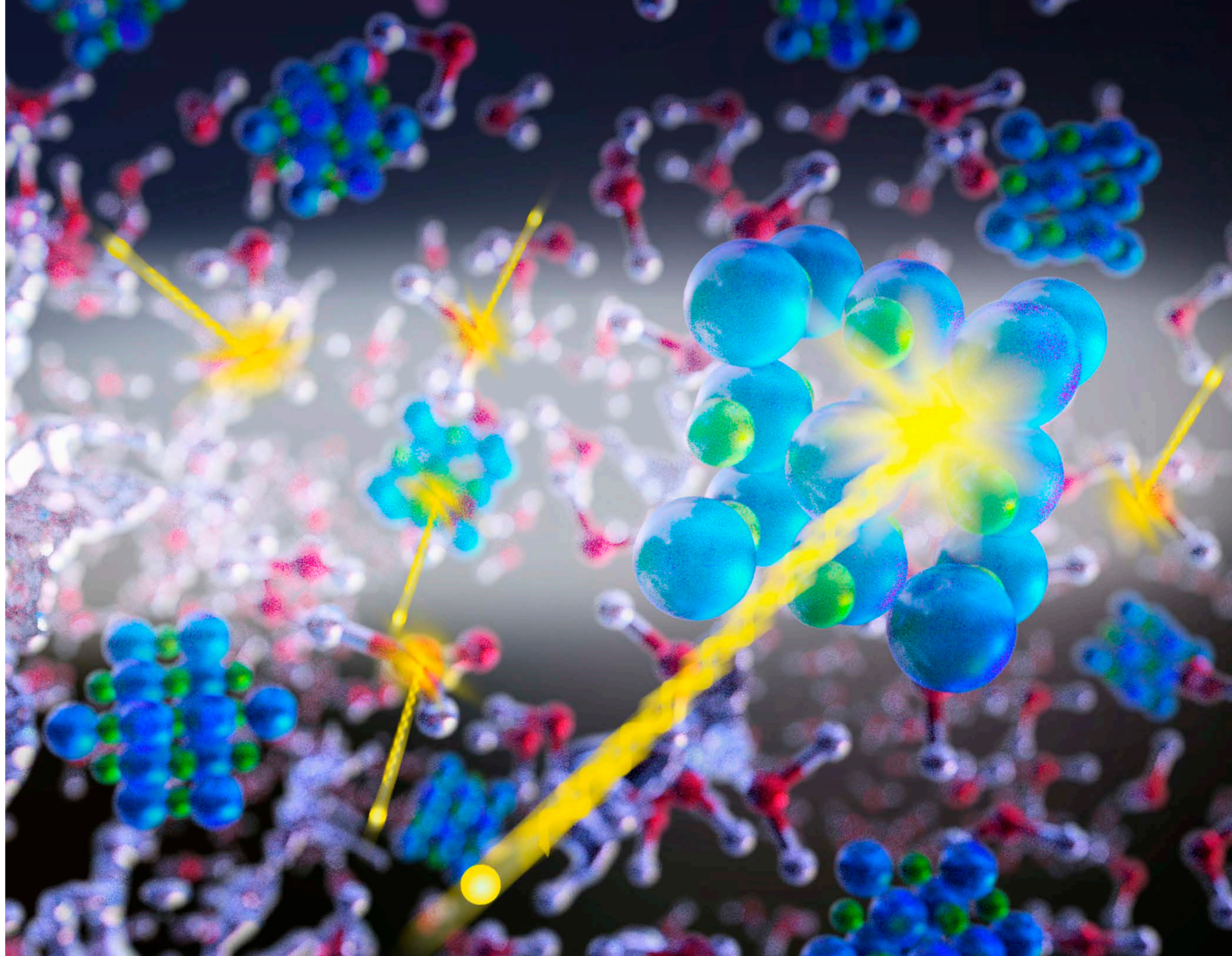
David Awschalom
- Elected Chair of the Section on Physics of the American Association for the Advancement of Science (AAAS)
- Honorary University Professor, Xi'an Jiaotong University
- Thomson Reuters/ISI Highly Cited Researcher
- National Public Radio Golden Mole Award Finalist
- White House Office of Science and Technology Policy Speaker, Forum on Quantum Information Science

Jiwoong Park
- Dreyfus Foundation Postdoctoral Program Award in Environmental Chemistry

Paul F. Nealey
- Semiconductor Industry Association – Semiconductor Research Corporation University Researcher Award

Stuart Rowan
- Selected as an American Chemical Society POLY Fellow

Juan de Pablo
- Election to the National Academy of Engineering for "design of macromolecular products and processes via scientific computation."
- DuPont Medal for excellence in nutrition and health science
- Ralph Peck Lectures, Illinois Institute of Technology

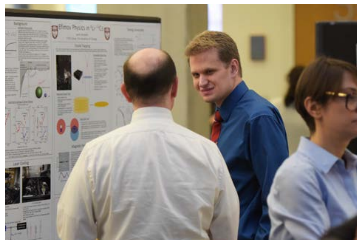


"From the Industrial Affiliates Program that engages members of Industry for research sponsorship, to community outreach events that invite Chicago-area middle school and high school students to discover the benefits of scientific learning and careers—the IME continues to grow its base of interest and support."
—Matthew Tirrell, IME Pritzker Director and Dean

Outreach and Development

Industrial Affiliates Program Hosts Representatives of Tech, Finance, and Manufacturing at Annual Event

Creating channels for industry input, IME output



Representative IAP member companies:

Agilent Technologies

CORNING

DUPONT DANISCO

IBM

SHIMADZU Excellence in Science

Water Intelligence plc

WYATT TECHNOLOGY

In October, the IME and Physical Sciences Division held their second annual Industrial Affiliates Day, beginning at the William Eckhardt Research Center (ERC) with research workshops that highlighted recent scientific breakthroughs on sensors and the new frontier of instrumentation. A luncheon hosted at the Quadrangle Club on campus followed, and then transitioned into a dialog: "Maximizing the Value of Academic-Industrial Collaborations." The session generated discussions among IME administrators, faculty, and representatives of a number of tech industries and companies.

Completing the day's activities was a graduate student research poster session and a reception in the ERC Atrium.

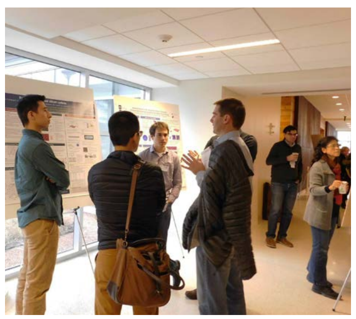
12 Member Companies Now Utilizing the Industrial Affiliates Program (IAP)

In its second year, the IAP grew to 12 members, all of which benefit from:

- managed collaborations,
- access to cutting-edge research,
- early access to talent through recruiting events,
- preferred access to resources and user facilities; and
- an option to serve on the Industrial Advisory Committee.

Second IME Day at Argonne

In February 2016, Argonne National Laboratory hosted its second IME Day. IME faculty, including Professors Matthew Tirrell, David Awschalom, Andrew Cleland, and Supratik Guha, and many IME graduate students presented their research to the Argonne community.



IME Scientists Take to the UChicago Discovery Stage

TED-style presentations viewable as video on IME website

Speaking before an audience of over 150 attendees of all ages at the Reva and David Logan Center for the Arts on April 6, 2016, four IME professors took to the stage to talk about some of the more stunning and promising aspects of their molecular research at the intersection of science and engineering. Titled *Future Science: Small Scale, Big Impact*, this was a *UChicago Discovery Series* event aimed at engaging the community to broaden awareness of the impact of the University's recent research.

The TED-style event, moderated by Dean Matthew Tirrell, energized the IME scientists David Awschalom (quantum information engineering), Supratik Guha (materials science), Paul Nealey (nanotechnology), and Melody Swartz (immuno-engineering) to each present highlights of their own work and some of the potential breakthroughs in their fields.

In attendance were a contingent of IME's "Maroon Kids," the group founded by UChicago alumnus William L. Florida (story p.40), to introduce young people in grades 6 through 12 to science and engineering topics and experiences.

Contributing to UChicago's Collegiate Scholars Program

Through the leadership of Juan de Pablo and Rovana Popoff, the IME established an exciting new partnership with the UChicago's Collegiate Scholars Program, which offers a three-year sequence of courses to prepare talented Chicago Public School students in grades 10 through 12 for admission and success at the nation's top colleges. Professor de Pablo, postdoctoral scholar Xiaoying Liu, and several graduate students from the IME delivered a six-week intensive course for these students that introduced them to molecular engineering concepts, ranging from foundational aspects of precise engineering measurement science, to synthesis and characterization of engineering materials that are commonly used in microchip manufacturing and other industrial processes.

The course was also innovative in that it included collaborating with engineering students from Northwestern University to offer a broad range of backgrounds and perspectives to the high schoolers that participated in this engaging new course. Building on the success of this effort, the IME and Professor de Pablo are planning to offer the course again in the summers of 2017 and 2018.

UChicago Alumnus Bernard J. DelGiorno Names IME Common Areas at ERC

The IME was honored this year by a gift from longtime friend of the University, Bernard "Bernie" J. DelGiorno AB'54, AB'55, MBA'55. Three IME rooms on the second floor of the Eckhardt Research Center have been named in his honor: The Bernard J. DelGiorno Seminar Room (201b); the Bernard J. DelGiorno Collaboration Room (201a); and the IME Dean's Conference Room (299d). Mr. DelGiorno has worked tirelessly to mentor undergraduate students over the years and enthusiastically supports the opportunity for students to pursue a major in molecular engineering at UChicago.

Maroon Kids Get a Hands-on Tour of Argonne, Visit Swartz/Hubbell Labs

Founded by IME Visiting Committee member William L. Florida, AB'87, AM'87, the Alumni Friends of the Institute for Molecular Engineering continued to organize programming for middle school children—the group known as the Maroon Kids—throughout 2016. In January, about 40 students and parents joined scientists at Argonne National Laboratory (Advanced Photon Source) for a tour and a hands-on workshop featuring the research taking place at ANL.

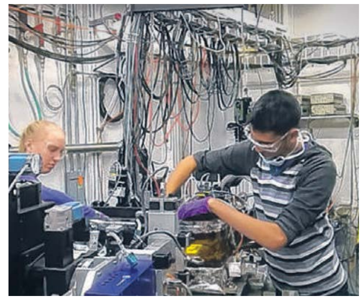
Just before Fall 2016 classes began, students from across Chicagoland visited IME at its home in the Eckhardt Research Center on campus for short lectures from immuno-engineering graduate students.

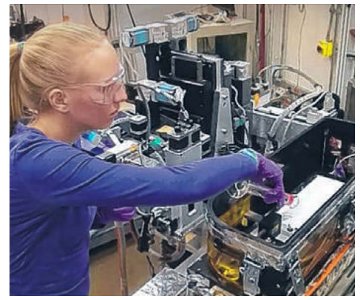
The lectures set the stage for groups of students to tour the Swartz/Hubbell labs and learn about the research intended to change the landscape of therapeutic treatments for cancer and autoimmune disease.

IME Facility at Argonne Puts High Schoolers to Work

Assisting the Hoffman Estates High School's Exemplary Student Research Program

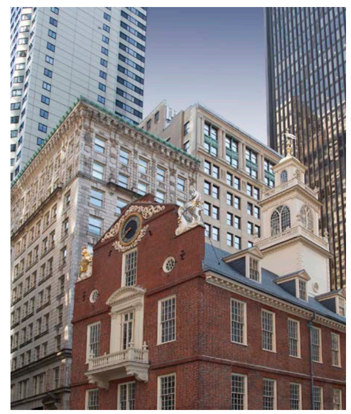
In February, ChemMatCARS, an IME facility led by Dean Matthew Tirrell and located at Argonne's Beamline Sector 15 of the Advanced Photon Source, welcomed 6 students from Hoffman Estates High School's Exemplary Student Research Program (ESRP). They were there for a hands-on synchrotron experimental run, working on a research project they proposed. These students learned all about the synchrotron facilities at Argonne and focused primarily on liquid surface scattering. The high schoolers performed experiments over 3 shifts (24 hours) consecutively, including preparing samples, running scans and retrieving data. They produced high-quality data that ChemMatCARS plans to use for publication in the near future.





Harper Lecture Featuring IME Professor Jeffrey Hubbell Draws 70+ Boston-area Alumni

In Boston to deliver one of UChicago's Harper lectures in May 2016, Professor Hubbell presented advances in molecular-level research and engineering in the immuno-engineering labs at IME. Hubbell's lecture focused on therapeutics for the treatment of Type-1 diabetes, as well as related work in his lab. He also discussed the creation of several start-up biotech companies based on his research. Guests then joined a lively discussion featuring Hubbell and Huntington Willard, President and Director of Marine Biological Laboratory (MBL), covering topics including the interface between the study of characteristics of marine organisms at MBL and their potential translation into new materials and therapies at the IME.



The Institute for Molecular Engineering

Leadership

Now in its second year, the Visiting Committee (VC) to the Institute for Molecular Engineering is a group of University of Chicago alumni and IME friends who support the Institute with professional expertise and philanthropic gifts.

Working in tandem with Matthew Tirrell, Pritzker Director and Dean of the IME, members of the Visiting Committee meet throughout the year to discuss the direction of the Institute, serve as advocates to the University Board of Trustees, and as ambassadors to external communities.

Barry MacLean, a supporter of the IME from its beginnings, chairs the Institute's Visiting Committee.

Visiting Committee

Jack R. Bierig

Keith Lawrence Crandell, MBA'88

William Louis Florida, AB'87, AM'87

Karen Elizabeth Kerr, PhD'95

John Mihn Soo Liew, AB'89, MBA'94, PhD'95

Barry MacLean

Lawrence R. Miller, AB'93

Sylvia M. Neil, AM'05

Laura Elizabeth Niklason, PhD'88

Myrtle Stephens Potter, AB'80

Philip J. Wyatt, AB'52, SB'54

IME Executive Committee

Matthew Tirrell, Pritzker Director and Dean

David Awschalom, Deputy Director for Space, Infrastructure, and Facilities

Juan de Pablo, Deputy Director for Education and Outreach

Jeffrey Hubbell, Deputy Director for Faculty and Staff Affairs

Sharon Feng, Senior Associate Dean of Budget and Strategy

Rovana Popoff, Associate Dean of Education and Governance, Dean of Students

Support the Institute for Molecular Engineering

Acknowledgments

We are very grateful to our donors, whose generosity supports and expands the vision of the Institute for Molecular Engineering. With your help, in the past six years the IME has grown to a faculty comprised of 15 research and scientific thought leaders from across disciplines and around the world. We have formed partnerships and collaborations with several universities, and with numerous corporate entities. The IME continues to further equip and utilize its new home, the William Eckhardt Research Center, a truly collaborative space for scientific inquiry at all levels. The IME is expanding its utilization of facilities and equipment at Argonne National Laboratory and increasing its cooperation with the Polsky Center for Entrepreneurship and Innovation.

This report reflects the IME's progress as it takes steps to tackle big issues, such as the availability of clean water, efficient energy harvesting and storage, improved cancer and medical treatment, and quantum solutions for data storage and security.

The IME is developing new materials that open up possibilities for detecting diseases and delivering medicines—exploring technologies and multidisciplinary approaches that promise to further harness the powers of material interactions at the smallest scales.

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For more information about supporting the research and vision of IME, contact Carolyn Amadon, Director of External Affairs for the Institute for Molecular Engineering, at 773.834.4818 or amadoncaro@uchicago.edu.

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December luncheon with several IME staff and administrators.

Matthew Tirrell (right) meets with the delegation from Shenzhen High-Tech Industrial Innovation Center.

Juan de Pablo (left), in collaboration with others at IME, delivered a summer engineering course to high schoolers enrolled in the UChicago Collegiate Scholars Program. (see story, p. 39)

Above photos: 2016 Admitted Students Weekend in March, with 34 students attending several events including a reception and poster session at the IME, several presentations by faculty, and a dinner in downtown Chicago.

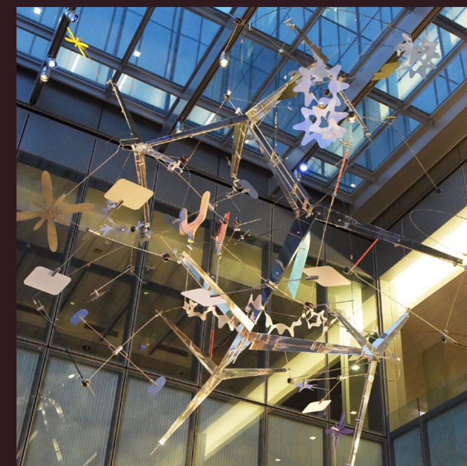
Below: 2016 cohort of graduate students surrounds the IME banner identifying the Institute as one of the University's academic divisions.

In October, Institute of Politics Director Steve Edwards (left) hosted Matt Tirrell for a discussion with students on the impact of public policy on scientific research.

In September, over 100 incoming first-years interested in the Molecular Engineering major/minor listened to Professor Nealey's O-Week information session about IME.

Students take advantage of the lounge spaces on the IME's 2nd floor of the William Eckhardt Research Center (ERC).

The October 26 IAP Day reception and poster session provided opportunities for informal exchanges between grad students and industry representatives. (see story, p. 38)



The Mel Ristau sculpture in the main lobby of the ERC comes to life when late-afternoon light and internal spotlights illuminate the mobile.

Above: The December 2016 Holiday Reception exemplified the growing size, diversity, and energy of the entire IME community. The photo backdrop theme was "You're a shining star, no matter who you are!" Research teams, groups of friends, and parents and kids stopped by the photo booth for portraits as everyone enjoyed refreshments, games, and conversations.

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