COLORADOSCHOOLOFMINES

ENERGY AND THE EARTH

RESEARCH
2013-14

EDUCATION AND RESEARCH AT COLORADO SCHOOL OF MINES

The requirements for the chemistry to work are a bright, curious and hardworking student body and a talented, dedicated faculty at the frontiers of research. We have both.

The role of a university is to educate and generate knowledge. Mines has always been at the forefront of educating first-rate engineers and scientists and focusing on critical areas of research. This issue of our research magazine examines the interplay between the undergraduate and graduate student experience and our research agenda. The requirements for the chemistry to work are a bright, curious and hardworking student body and a talented, dedicated faculty at the frontiers of research. We have both.

Let me choose a few examples of student and faculty activities that show the diversity and fun of participating in a real-world research agenda.

- If we were to single out a department that has made the biggest impact in the coupling of pedagogy and research, it would be physics. Students at all levels engage in research projects. This culture has led to Mines having one of the largest undergraduate physics programs in the country. Indeed, the American Physical Society awarded the department the prestigious 2013 Education Award.

- The Mines summer field camps are famous for hands-on experience. The geophysics camp is a prime example, where in 2012 students from Mines, Imperial College and RMIT mapped the geothermal system of Pagosa Springs.

- One defining characteristic of Mines students is their teamwork and organizational ability. The graduate students organize annually a national research conference on energy and the earth. They have been recognized as the national graduate student organization of the year. Our undergraduates are equally well organized. The Mines chapter of the Society of Women Engineers is the largest in the country and our physics undergraduates hosted the very successful 2013 Conference for Undergraduate Women in Physics.

- The geobiology summer course is an exciting example of frontier activities where graduate students from around the world explore the co-evolution of the Earth and its biosphere.

Students will respond to the research environment when they know that their professors are at the top of their game. There are numerous examples where Mines is leading national and international research activities. It is a tough task to highlight and to select from our many research wins of the past year, but here are a few.

- Mines is the lead university in the Critical Materials Institute with Ames Laboratory heading the Department of Energy initiative for strategic energy security.
- Shale gas is transforming the nation's energy and manufacturing scene. Mines is one of the leading universities in the science and engineering of hydraulic fracturing with numerous research grants from federal and industry sources. Moreover, the Environmental Protection Agency has formed the Hydraulic Fracturing Research Panel of leading experts. Three Mines faculty are on the panel.
- The warming climate has caused the death of some four million acres of lodgepole pine in Colorado and Wyoming due to the pine beetle infestation. The National Science Foundation has awarded Mines a major grant to study the impact of this infestation on the state's water resources.
- NASA has chosen Mines to play a lead role in developing ground-based arrays to facilitate the detection of extreme energy cosmic rays.

It is a great pleasure to have contributions in our magazine from two towering figures in the world of science and academia. Joe Gray, in our discussion, describes his odyssey from a Mines undergraduate to one of the world's leading cancer researchers. His thoughts should be digested by all Mines students. Bob Birgeneau will be retiring as chancellor of Berkeley to lead the Lincoln Project. The public research universities, which have been the backbone of technical education and innovation in this country, are undergoing de facto privatization through lack of state support. The Lincoln Project aims to redress this imbalance. The commentaries of our two distinguished friends should be required reading for all those interested in the future of education, research and innovation in the U.S.

Dr. John M. Poate
Vice President for Research and Technology Transfer

John Poate is an internationally recognized expert in science and technology with a distinguished career in academia and industry. He obtained his PhD in Nuclear Physics at the Australian National University. Most of his research career was pursued at Bell Labs where he headed the Silicon Processing Research Department. Since then he has served as Dean of the College of Science and Liberal Arts at New Jersey Institute of Technology and Chief Technology Officer of a semiconductor capital equipment company. His awards and distinctions include Fellow of the American Physical Society, President of the Materials Research Society, Chair of the NATO Physical Sciences and Engineering Panel, winner of the John Bardeen Award of the Metallurgical Society, and appointment to the inaugural class of Fellows of the Materials Research Society. He is on the board of the National Renewable Energy Laboratory and chairs Lawrence Livermore National Laboratory review committees.

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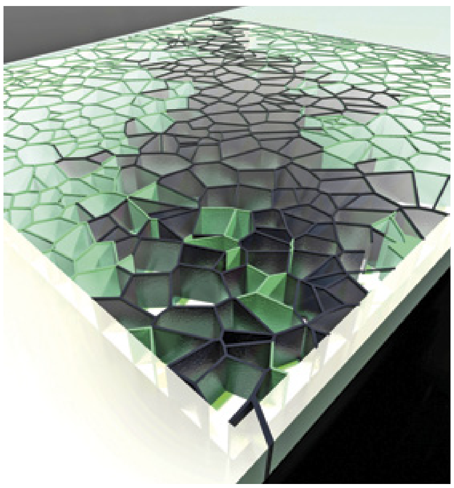
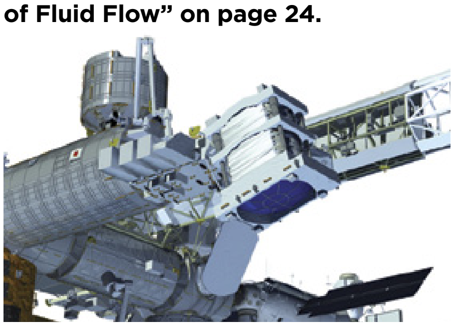


About the Cover: Fluid and solute transport through porous media is critical to applications as disparate as drug delivery and oil extraction. Read about the research being conducted by Mines professors Keith Neeves and Xiaolong Yin in "Rock Grains, Blood Cells and the Principles of Fluid Flow" on page 24.

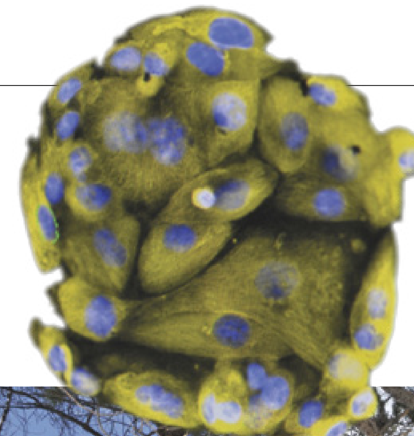


RESEARCH 2013-14

FEATURES

SPECIAL FEATURE

RESEARCH AND EDUCATION



SPRING COMMENCEMENT BY THE NUMBERS

On May 10, 2013, 706 students received bachelor's degrees, 191 received master's degrees and 41 received doctorate degrees at the 139th annual commencement ceremony on the Mines campus.

Not only was it the largest graduating class in Mines history, but also the class with the largest number of women — nearly 25 percent of this year's graduates.

And those weren't the only numbers on the rise this year. Several undergraduate students commanded salaries starting at $115,000.

Congratulations to the 2013 graduating class of Colorado School of Mines!

COLORADO SCHOOL OF MINES

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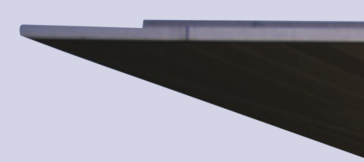

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A MESSAGE FROM THE PRESIDENT

This is a record year for research at Mines, with more than $60 million in research awards.

In this era of decreased federal research budgets, our talented researchers continue to attract grants for a broad spectrum of critical projects involving earth, energy and the environment. More than 40 percent of our research is sponsored by industry, which is vital to the strength and growth of our research portfolio.

While we are proud of our success in securing research contracts, we get the most satisfaction from seeing the quality of our graduates and the results of our research efforts. Our stated mission as a public research university is "to enhance the quality of life of the world's inhabitants." We work every day toward that goal.

—M.W. Scoggins, President, Colorado School of Mines

Nic Lehoux

Marquez Hall designed by Bohlin Cywinski Jackson

Policy matters

It's not surprising that Jason Delborne would call Senator Michael Bennet's office in Washington, D.C. to inquire about a public policy matter.

Delborne, a scholar of science, technology and society in the Division of Liberal Arts & International Studies, is the advisor for Mines' Science, Technology, Engineering and Policy (STEP) minor program and the coordinator of the public policy component of Mines' SmartGeo program.

The surprise was the person who answered the phone. "Dr. Delborne? Dr. Delborne from Colorado School of Mines?" asked the young man working in Senator Bennet's office. Turns out he was a recent Mines graduate who had completed Delborne's Science and Technology Policy course.

"It's a good example of the tight intersection of science and policy. STEP courses expose students to career options they may never have considered. They learn that technical degrees are highly valued in policy circles," said Delborne, who will chair the Gordon Research Conference on Science and Technology Policy in 2016. Almost all Mines graduates will eventually interface with public policy, he added. "Exposing them as students to the mutual influence of science and society will serve them well throughout their technical careers."

Delborne wants his science and engineering students — both undergraduate and graduate — to understand the larger context of their work and to realize their choices make huge impacts on society. He also points out that policy priorities will influence the work they do and how they do it. "They're not separate worlds," he emphasized.

Students in SmartGeo, an interdisciplinary graduate program funded by the National Science Foundation, are studying engineered and natural earth structures and developing systems that sense their environment and adapt to improve performance. Three interdisciplinary teams address Intelligent Earth Dams and Levees, Intelligent GeoConstruction and Intelligent Remediation. The complexity of the science and technology involved in their research is matched by the complexity of associated social, political and ethical issues. So the program, instituted in 2009, incorporates a STEP minor and requires students to devote a thesis chapter to public policy as it applies to their research.

A new course in the McBride Honors Program will focus on energy policy. It will be team-taught in fall 2013 by Delborne and Murray Hitzman, who has extensive public policy experience in the U.S. Senate and White House Office of Science and Technology Policy, and is the Charles Franklin Fogarty Professor in Economic Geology at Mines.

Mines joins mission to detect cosmic rays

Mines will receive $1.7 million in a $4.4 million NASA grant that will help researchers develop a telescope to be deployed on the International Space Station to detect extreme energy cosmic rays.

The Extreme Universe Space Observatory on board the Japanese Experiment Module (JEM-EUSO) is the first mission devoted to detect extreme energy cosmic rays — particles whose origin remains unknown — from space. The telescope, which is expected to be deployed in 2017, will measure the properties of these cosmic rays by recording the UV light produced by their air showers in the Earth's atmosphere.

NASA selected Mines, along with partners at NASA's Marshall Space Flight Center and the University of Alabama, Huntsville, to design and develop a global network of light flashers and lasers. These ground-based light sources will be used to benchmark and monitor the observatory as it orbits the Earth.

The Mines group, led by physics associate professors Lawrence Wiencke (principal investigator) and Fred Sarazin, will help select suitable locations around the world and develop, install and maintain the laser stations of the Global Light System (GLS) array.

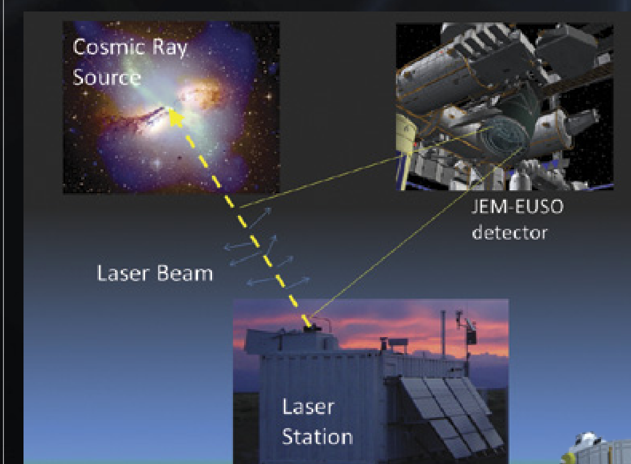
"The energies of these cosmic particles extend more than 10 orders of magnitude beyond the energies of man-made accelerators," said Wiencke. "Understanding the observatory will be key to understanding the cosmic accelerators. This is why the GLS array will be so important. It's also a great match for the Mines group because it builds on our experience with laser techniques and cosmic ray detectors." Wiencke had been in Malargüe, Argentina, with Mines graduate students Eric Mayotte and Carlos Medina leading the upgrade of the central laser facility at the Pierre Auger Cosmic Ray Observatory.

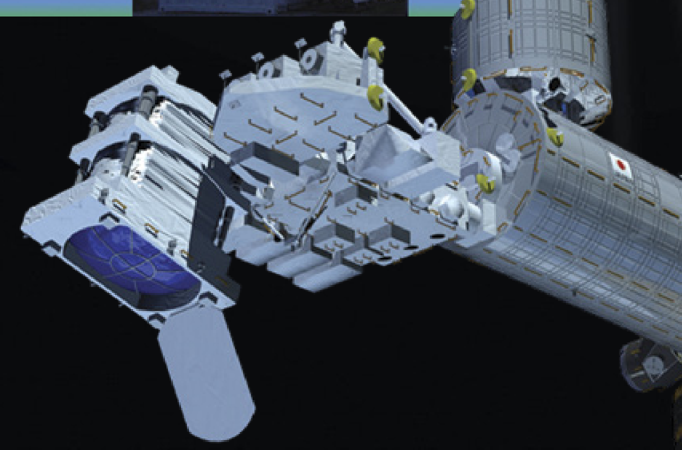
The JEM-EUSO footprint will pass over a GLS unit on average once per near-moonless night under clear conditions over appropriately selected sites, Wiencke said.

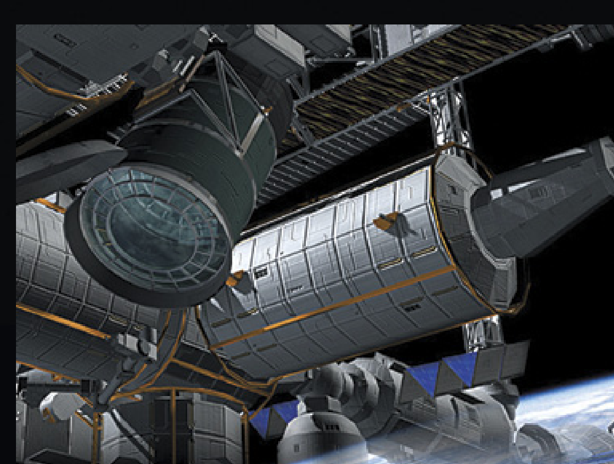
"The GLS locations need to be representative of the different climates around the world, because the development of the air showers depends upon the general properties of the atmosphere where it occurs," said Sarazin.

As part of this grant, the Mines group is developing a laser system that will be flown in an aircraft to test a JEM-EUSO prototype that will be flown in a high altitude balloon in 2014.

Other project partners on this grant include the University of Chicago and the University of Wisconsin, Milwaukee. In all, 13 countries, 77 institutions and as many as 280 researchers are working on this mission.







Working together for children's health

To advance scientific knowledge applicable to children's health, The Children's Hospital — University of Colorado/Colorado School of Mines Collaboration Pilot Awards were established in early 2013.

Under the arrangement, Mines and the Children's Hospital Colorado Research Institute provide seed grants, up to $20,000, for projects that allow researchers to develop the initial data needed to pursue larger grants from the National Institutes of Health. Mines shares the cost equally with Children's Hospital Colorado.

"Children's Hospital is one of the nation's leading medical institutions, and this collaboration will significantly contribute to the advancement of Mines' efforts in biomedical engineering," said Mines Vice President of Research and Technology John Poate.

"There is a growing interest in biomedical research at Mines that would benefit from a connection to patients, animal models and translational research," said Frederick Suchy, chief research officer at Children's Hospital Colorado and associate dean for child health research at the University of Colorado School of Medicine. "Scientists in the Department of Pediatrics recognize the importance of a strategic partnership with a focus on biomaterials, bioengineering, high-end computing and the prospect of engaging graduate students in collaborative research."

From tissue engineering to microfluidic devices and nano-scale drug delivery, engineers develop many technologies that could help doctors treat patients. And many of these technologies are already in development in labs at Mines.

According to Chemical and Biological Engineering Department Head David Marr, "It has become apparent there is going to be a need for much more technology in health care." Ultimately Marr believes cross-disciplinary work such as this will make health care more efficient and, overall, cheaper.

Recipients of the first Collaboration Pilot Awards were announced in March 2013.

- Melissa Krebs, Mines, will collaborate with Karin Payne, University of Colorado, on "Dual Delivery Biomaterial System for the Treatment of Growth Plate Injuries."
- Stephen Boyes, Mines, will collaborate with Sven-Olrik Streubel, Children's Hospital, on "Bone Regeneration Using Biodegradable Polymer Scaffolds."
- Keith Neeves, Mines, will collaborate with Shama Ahmad, University of Colorado, on "Air flow-dependent modifications of airway epithelial basal/progenitor cell phenotype: implications in cystic fibrosis disease pathogenesis."

Exploring gravity map of moon

Twin NASA probes orbiting the moon have generated the highest resolution gravity field map of any celestial body.

The new map — created by the Gravity Recovery and Interior Laboratory (GRAIL) mission — of which Mines Professor Jeff Andrews-Hanna is a guest scientist — is allowing scientists to learn about the moon's internal structure and composition in unprecedented detail. Data from the two washing machine-sized spacecraft also will provide a better understanding of how Earth and other rocky planets in the solar system formed and evolved.

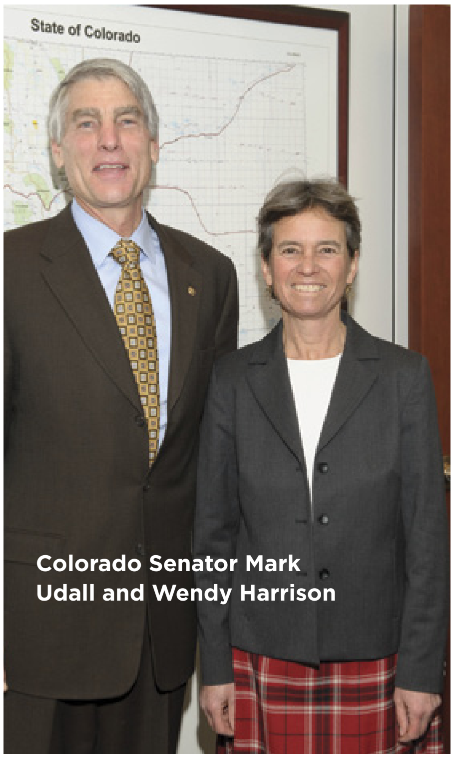
The gravity field map reveals an abundance of features never before seen in detail, such as tectonic structures, volcanic landforms, basin rings, crater central peaks and numerous simple, bowl-shaped craters. Data also show the moon's gravity field is unlike that of any terrestrial planet in our solar system.

These are the first scientific results from the prime phase of the mission, and they are published in three papers in the journal *Science*, with Andrews-Hanna as the first author of one of the papers.

About his analysis of some of the GRAIL data, Andrews-Hanna said, "We used gradients of the gravity field in order to highlight smaller and narrower structures than could be seen in previous datasets. This data revealed a population of long, linear, gravity anomalies, with lengths of hundreds of kilometers, crisscrossing the surface. These linear gravity anomalies indicate the presence of dikes, or long, thin, vertical bodies of solidified magma in the subsurface. The dikes are among the oldest features on the moon, and understanding them will tell us about its early history."

NASA's Jet Propulsion Laboratory in Pasadena, Calif., manages the mission for NASA's Science Mission Directorate in Washington. GRAIL is part of the Discovery Program managed at NASA's Marshall Space Flight Center in Huntsville, Ala.

Inside the beltway



Colorado Senator Mark Udall and Wendy Harrison

During her temporary assignment as director of the Division of Earth Sciences in the National Science Foundation (NSF) in Washington, D.C., Mines Geology and Geological Engineering Professor Wendy Harrison has been impressed by the breadth of the organization's interdisciplinary research endeavors and the efforts made to enable success of early career investigators.

"It is fascinating to see the White House Office of Science and Technology Policy establish national priorities in science, engineering and education and how the National Science Foundation creates new programs for the research community in response," Harrison said.

Harrison's responsibilities include the leadership and management of her division as well as serving as NSF's representative externally in earth science-related activities. Within NSF, she is collaborating with the Division of Atmospheric and Space Geosciences to explore how to interface general atmospheric and oceanic circulation models with terrestrial surface and groundwater models, which would provide policy makers with tools to enable better prediction of the impact of climate change on global problems such as water and food security.

"The results of the research the Division of Earth Sciences sponsors lead to a better understanding of our planet's changing environment (past, present and future), the natural distribution of its mineral, water, biota and energy resources, and provides methods for predicting and mitigating the effects of geologic hazards such as earthquakes, volcanic eruptions, floods and landslides," Harrison said.

She oversees an annual budget of nearly $200 million, which supports fundamental research into the structure, composition and evolution of the Earth and the life it has sustained over the four and a half billion years of its history.

Approximately 58 percent of the division's budget is used to support individuals and small groups of researchers, including early career scientists in core areas such as geomorphology and land use, hydrologic science, geophysics, tectonics, petrology and geochemistry. About 32 percent of the budget goes to instrumentation and facilities.

Increasing emphasis is being placed on providing funds for large interdisciplinary, multi-team projects needed to address more complex problems in earth systems science. Nearly 10 percent of the division's budget is used in this manner.

In the broader community external to NSF, Harrison is bringing together an interagency working group to identify opportunities for collaborative research in energy-related fields with an initial focus on sub-surface science.

Convening next generation of women in physics

One hundred thirty-seven people from 34 institutions across 16 states attended the Rocky Mountain chapter of the Conference for Undergraduate Women in Physics, hosted by Mines in January 2013.

In an effort to increase diversity in the field of physics, the conference was organized by undergraduate students for undergraduate students. Event organizers focused on providing an opportunity for students to learn more about the field of physics and the career prospects it offers, as well as fostering networking opportunities.

Margaret Murnane, award-winning physicist and professor at the University of Colorado-Boulder, delivered the keynote address "Why Diverse Teams Will Meet the Science and Engineering Challenges of the 21st Century."

It was the eighth annual conference for undergraduate women in physics, the first for the Rocky Mountain region and the first year to be formally established under the umbrella of the American Physical Society. A total of six conferences were held simultaneously across the nation.

Summer of research, worlds of experience

What can participants of this summer's Research Experiences for Undergraduates (REU) in Renewable Energy at Mines expect? Research opportunities, of course. Students can synthesize, process and characterize renewable energy materials, as well as perform non-destructive, in-situ microscopy under a range of extreme conditions. Computational investigations and diagnostic studies can also be explored. And the work will be conducted with mentoring from more than 30 top researchers, as well as many staff members, from across the Mines campus.

Participants also attend weekly technical seminars on cutting-edge research topics, including next-generation photovoltaic devices, energy storage materials, the role of catalysts in fuel cells, computational energy science, and biofuels. They take field trips to area companies and research centers, too, including the National Renewable Energy Laboratory (NREL).

"Research is why they come, but there are so many other elements," explained Chuck Stone of the Mines Physics Department and director of the National Science Foundation (NSF) sponsored Renewable Energy Materials Research Science and Engineering Center (REMRSEC) REU. For example, there are also professional development sessions covering topics such as conducting research ethically, making well-crafted and executed research presentations, working across generations, and learning about graduate schools, fellowships and careers.

Special events may include a talk by an expert outside the field of renewable energy. Some will be purely fun — a picnic, a hike, a movie night, a trip to a nearby mountain town — and some will be joint activities with other REU programs at Mines, the University of Colorado and NREL. A joint poster session, with awards given for the Best Technical Achievement and for the Best Presentation, concludes the 10-week program.


Charlotte Evans


Matt Musselman

"When the students first arrive, they need a lot of guidance and direction," noted Stone, who calls himself the ringmaster of the summer's varied activities. "By the end, though, they're accomplished, independent, interdisciplinary researchers."

Kory Riskey was in the program between her sophomore and junior year at Mines. "For me, the REU was an excellent opportunity to do hands-on research and to essentially be a 'grad student' for a summer. After the REU, I knew grad school was for me. And because my peers were studying all different kinds of research, I also was able to make decisions as to what area of study I wanted to pursue," said Riskey. Her REU faculty mentor was REMRSEC Director Craig Taylor. In May 2013 Riskey earned a master's degree in metallurgical and materials engineering, with Taylor as her graduate advisor.

During summer 2012 Mines hosted 21 students from 13 institutions (11 national and two international) with a strong balance in gender, diversity and representation from both research universities and institutions where research opportunities for students are limited. The summer 2013 session expects to host 25 students, with eight funded by the National Science Foundation and the rest receiving support from a variety of programs at Mines.

Research center strong as steel


David Matlock

Why and how do some industry/university research partnerships achieve sustainability, while others do not?

A case study in long-term success, the Advanced Steel Processing and Products Research Center (ASPPRC) has contributed critical answers to this recent NSF-commissioned study. Launched in 1984 with six member companies, the ASPPRC now operates independent of direct federal or state funding and is fully supported by 28 steel-producing-and-using companies from around the world.

According to the report, "Research Center Sustainability and Survival: Case Studies of Fidelity, Reinvention and Leadership of Industry/University Cooperative Research Centers," the ASPPRC has in most respects followed the initial NSF model for industry/university projects.

"However, this center has been particularly adept in making adjustments to a rapidly changing technical and business environment," the report notes. Its authors — Denis O. Gray, Louis Tornatzky, Lindsey McGowen and Eric Sundstrom — point out that the ASPPRC's commendable record has been enabled by:

- A consistently supportive university organization
- An aggressive technology transfer program and an enterprising relationship with industry
- Anticipation of shifts in product needs and the internationalization of the steel industry
- An unusually stable leadership

Housed in the George S. Ansell Department of Metallurgical and Materials Engineering at Mines, the ASPPRC was established by George Krauss and David Matlock. "During the 1984-present period it would be difficult to describe a center that had more wired-in leadership function and a seemingly effortless transition from launch leadership to ongoing direction," the report states.

Krauss continued to participate in ASPPRC well into his retirement. The current center director is Matlock, described in the report as having "an international research reputation, particularly in the areas of mechanical properties of steel." John Speer will take over as the new director during summer 2013.

The center continues to move forward, as evidenced by the announcement in March 2013 of a $1.1 million U.S. Department of Energy grant to Mines and ASPPRC for research into energy-saving technologies. The lead investigator for the new project, "Quenching and Partitioning Process Development to Replace Hot Stamping of High Strength Automotive Steel," is ASPPRC research faculty member Emmanuel De Moor.

Newmont, CIERSE partnership grows

Newmont Mining Corporation, one of the world's largest gold mining companies, recently extended its support of the Center for Innovation in Earth Resources Science and Engineering (CIERSE) at Mines by increasing its total commitment to $2.56 million through 2015.

Newmont, which is headquartered in Greenwood Village, Colo., provided initial funding in 2009 to establish CIERSE, a multidisciplinary center that focuses on educating new professionals and developing innovative solutions to key challenges facing the mineral resource industry. It incorporates expertise and has research projects in several departments at Mines including Mining Engineering, Geology & Geological Engineering, Geophysics, Metallurgical & Materials Engineering and Environmental Science & Engineering.

"Innovation helps resource companies like Newmont overcome the challenges that exist in our industry today, and in the future," said Perry Eaton, Newmont's Group Executive of Global Exploration Solutions. "We are very pleased to support CIERSE and to work closely with the Colorado School of Mines."

To date, Newmont has sponsored 11 research projects through the center focusing on exploration geoscience, mining methods, milling technology, geothermal energy and innovative water treatment. The center is open to and actively seeking new research partners and projects.

Multiple awards for Graduate Student Association

From left, Bebe Onasoga (GSA Social Chair), Amanda Meier (GSA Social Chair), Nikko Collida (GSA Treasurer), Mark Taylor (GSA Vice President), G.C. Murray, Jr. (NAGPS Social Justice Concerns Chair)

The Mines Graduate Student Association has been recognized by the National Association of Graduate-Professional Students (NAGPS) as the 2012 National Member of the Year.

In addition to that top honor, Mines also received the 2012 Western Regional Member of the Year award. The 2012 Individual Member of the Year went to Zach Aman, who earned a PhD in chemical and biological engineering in December 2012.

"We are honored to have received these awards considering the institutions that were in the running for Member of the Year. We are especially pleased that the efforts put forth from our organization have been impactful not only to our community here at Mines, but also to the national network of graduate students," said Cericia Martinez, Mines GSA president.

The other institutions up for Member of Year included the University of Cincinnati, Duke University, Texas Tech and MIT.

Mines' Graduate Student Association is the governing body for graduate students. Founded in 1991, the organization addresses issues of concern to graduate students and organizes research, academic and social functions at Mines.

NAGPS is a student-run nonprofit organization dedicated to improving the quality of life for graduate and professional students across the nation. It was organized in 1987 and serves as the only national organization representing the interests of graduate and professional students in public and private universities at local, state, and national levels.

New supercomputer to focus on energy research

Mines has a new 155 teraflop supercomputer dubbed BlueM. It will allow researchers to run large simulations in support of the university's core research areas while operating on the forefront of algorithm development using a powerful hybrid system.

BlueM's predecessor, RA, has been hugely successful, but Mines has outgrown its 23 teraflops. BlueM will provide a greater number of flops dedicated to Mines faculty and students than are available at most other institutions with high performance machines. Researchers will be able to run higher fidelity simulations than in the past, get more time on the machine and break new ground in terms of algorithm development.

Mines research to be conducted on BlueM includes biomass conversion and the stability of biomass fuels, fuel cells, fundamental battery research, hydrate nucleation, wind energy, hydropower, carbon sequestration, solar cells and material science applicable to solar cells including nanostructures and nanowires, fission reactor design, the environmental impact of the pine beetle infestation, atmospheric scattering effecting climate, interactions between surface and ground water, and seismic modeling.

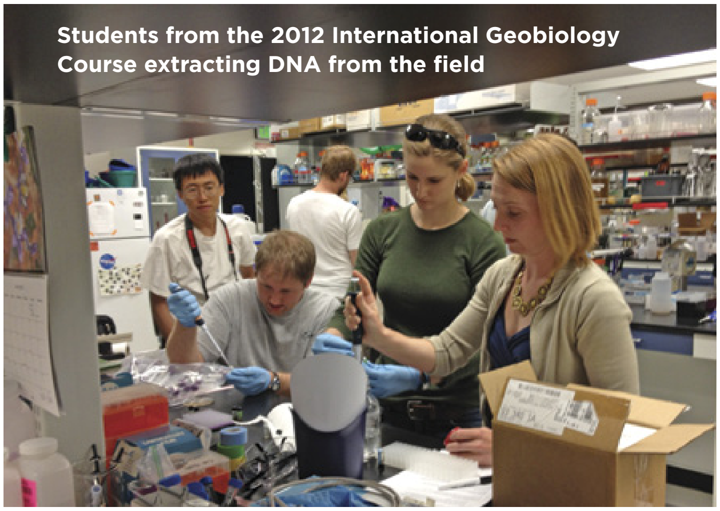
BlueM, is unique among high performance computers in the area. It features a dual architecture system combining the IBM BlueGene Q and IBM iDataplex platforms – the first instance of this configuration being installed together.

The system will be housed at the National Center for Atmospheric Research (NCAR) in a major new collaboration between the two organizations. NCAR is sponsored by the National Science Foundation.

Geobiology course in four states in five weeks

"This course is very unique and very intense," said John Spear, from the Mines Civil and Environmental Engineering Department. A typical course day is 18 hours long with approximately one day off a week. Sixteen graduate students from seven countries have been chosen to participate this year, the 10th anniversary of the course.

Spear co-directs the multidisciplinary, five-week course with Frank Corsetti from the Earth Sciences Department at the University of Southern California. More than a dozen other faculty researchers and as many as 30 guest lecturers help teach the course in this rapidly evolving field, exploring the coevolution of the Earth and its biosphere.



Students from the 2012 International Geobiology Course extracting DNA from the field

The 2013 International Geobiology Summer Course will begin in June with a field trip to the Great Salt Lake in Utah and then head to the Green River Formation in southern Wyoming. Next the group will spend a week at Mines learning molecular approaches to microbial ecology from samples collected during the field trip. Then they move on to Los Angeles where they rotate through the University of Southern California, the California Institute of Technology and the Jet Propulsion Laboratory for study in lipid analyses, geochemistry and petrology, followed by a move to USC's Wrigley Center for Environmental Studies on Catalina Island to bioinformatically interpret DNA data sets obtained from collected samples.

Research results based on work completed during the course are shared with the geobiologic community. In 2012 two abstracts were presented at the Geological Society of America meeting, and three were presented at the American Geophysical Union national meeting.

2012 International Geobiology Course Co-Director John Spear (far right) leading students into "field work" at Gypsum Dunes in western Utah

Petroleum Institute a maturing research partner

Saeed Alhassan, Ali AlSumaiti, Ahmed Al Shoaibi and Mohammed Al Kobaisi, all graduates of Mines now on the faculty of the Petroleum Institute, at the recent 10th anniversary celebration of the collaboration between the two institutions.

In a constantly evolving, across-the-ocean exchange, researchers at Mines and the Abu Dhabi Petroleum Institute (PI) continue to expand knowledge by working together. Consider this milestone in the relationship between the two institutions: There are students from Abu Dhabi who earned their PhD at Mines and are now on the faculty of the Petroleum Institute collaborating with Mines faculty on critical research projects.

"The relationship between the PI and Mines continues to flourish after 10 years from its beginning," said Ahmed Al Shoaibi, who earned his PhD in chemical engineering from Mines in 2008. "This unique collaboration involves research and education projects which are of mutual interest to the two institutions."

Nigel Middleton, Mines' senior vice president for strategic enterprises, agrees. "The PI has a substantial amount of mission overlap with Mines, which is not surprising given Mines' role in the PI's original conceptual design and development. This overlap is pronounced in the energy sector, and demonstrated by our cooperative research projects in carbonate reservoir characterization, materials and equipment engineering for corrosive upstream applications, smart oilfields, chemical processing and power distribution. We also have cooperative activities in engineering education, including advanced pedagogies and global engineering practices,"noted Middleton.

Al Shoaibi is a co-principal investigator with Anthony Dean of Mines on a research project titled "Pyrolysis Reactions of Butene Isomers at Low Temperatures." Dean, who is dean of the College of Applied Science and Engineering, explained, "This joint project focuses on understanding butene pyrolysis at the molecular level. It provides important insights into the details of the reactions that lead to deposit formation and allows us to identify improved approaches to minimize deposits in fuel lines and solid oxide fuel cells."

Middleton said the research agenda for oil and gas-producing countries in the Gulf is huge. "Their conventional fields are aging, and world markets and Gulf state economies are pushing for higher levels of recoverability, demanding more sophisticated know-how and technology in their industry," he said.

"The exploitation of tight gas and oil is on the menu too, as is a commitment to a 21st century practice on environmental sustainability," continued Middleton. "In the United Arab Emirates, the Petroleum Institute is at the very center of these issues through its delivery of engineering and applied science degree programs, and through its development of a research center for in-country and partnered projects with worldwide affiliates. Mines is in a very competitive position to be a major and ongoing contributor in this research arena."

In addition to a strong, productive academic partnership, the two institutions enjoy a rich cultural exchange. Al Shoaibi said, "One of the many perks of pursuing my PhD at Mines was the opportunity it gave me to get to know the American culture and way of thinking. It made me see the world through a different lens and for that I am grateful. Last year, I was able to return the favor. The PI hosted three American undergraduate students from Mines for a semester in our beautiful Abu Dhabi. It was amazing to see my home country through their eyes and to feel the mutual appreciation which developed between them and our students for each other's cultures."

EXCELLENCE IN RESEARCH AND EDUCATION

ALAN SELLINGER

Associate professor
Chemistry and Geochemistry

The Sellinger research group focuses on the synthesis and characterization of organic semiconductor materials for application in flat panel display technology, lighting, solar cells and transistors. They work very closely with scientists at the National Renewable Energy Laboratory who fabricate devices with their new materials and provide invaluable feedback for future materials design and synthesis.

TERRI S. HOGUE

Associate professor
Civil and Environmental Engineering

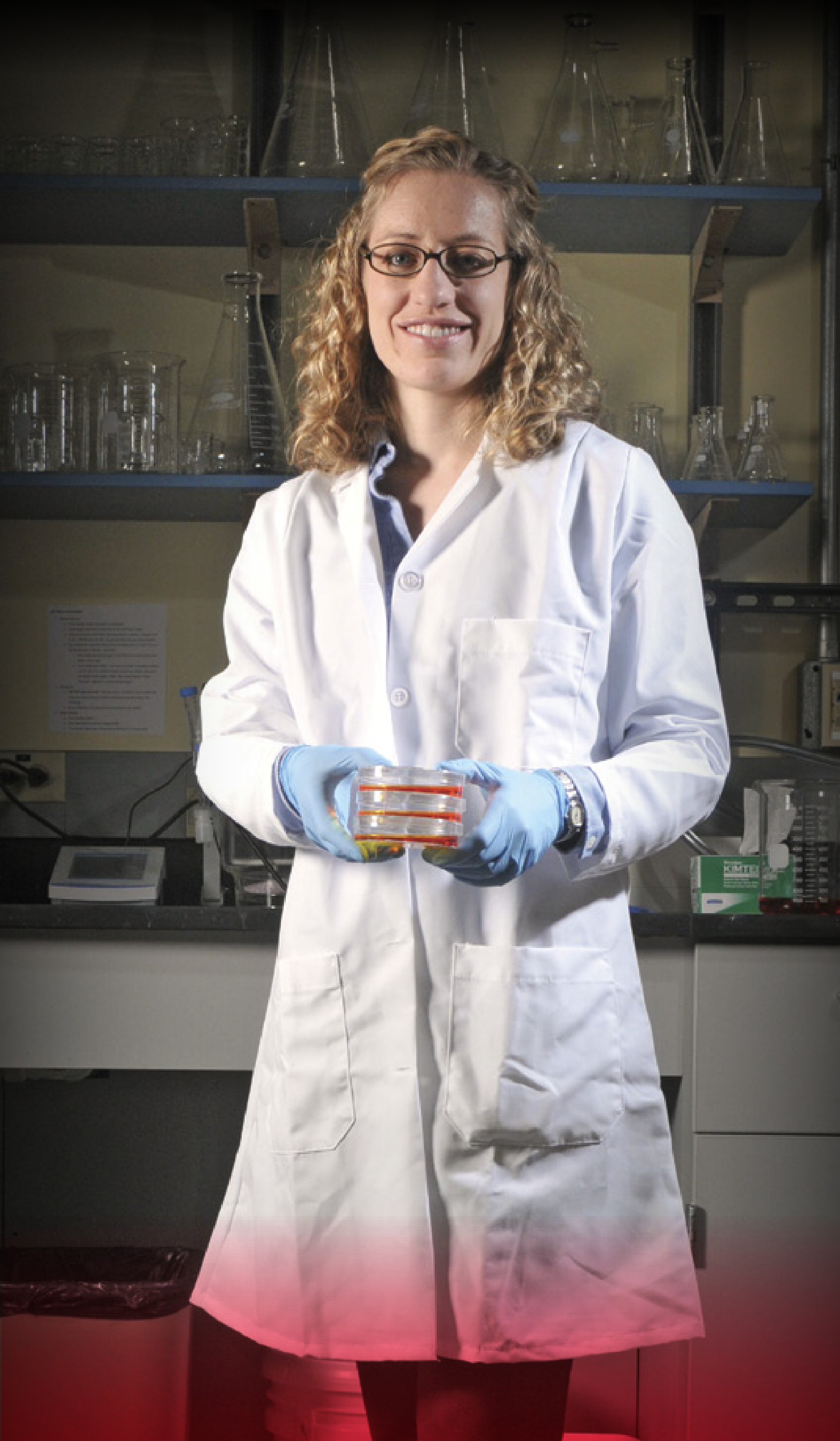
Hogue's research involves assessing human impacts on the environment, understanding natural hazards and hydrologic response, and improving the modeling and prediction of watershed systems. She focuses on urbanization, including determining factors that influence residential water consumption and urban water cycling. Her research team also investigates wildfire effects on both water supply and quality, and the recovery of burned ecosystems.

RANDY L. HAUPT
Department head, professor
Electrical Engineering and Computer Science

Haupt's research area is electromagnetics with specific emphasis on antennas and antenna arrays. He is currently collaborating with researchers in the Mines Physics Department, as well as with industrial partners including Ball Aerospace, Remcom, Inc., Teqnovations, LLC, and Supelec. Haupt is writing his fifth book, *Timed Arrays*. He also writes a popular column, "Ethically Speaking," in the *IEEE Antennas and Propagation Society Magazine*.

KATHLEEN SMITS
Assistant professor
Civil and Environmental Engineering

The motivation of Smits' research is to provide answers to questions of importance to many current and emerging environmental problems including: the management of water resources in dry land, the transport of pollutants through unsaturated soils, understanding the environment in which landmines and unexploded ordinances are placed, and increasing the efficiency of soil borehole thermal energy storage systems.

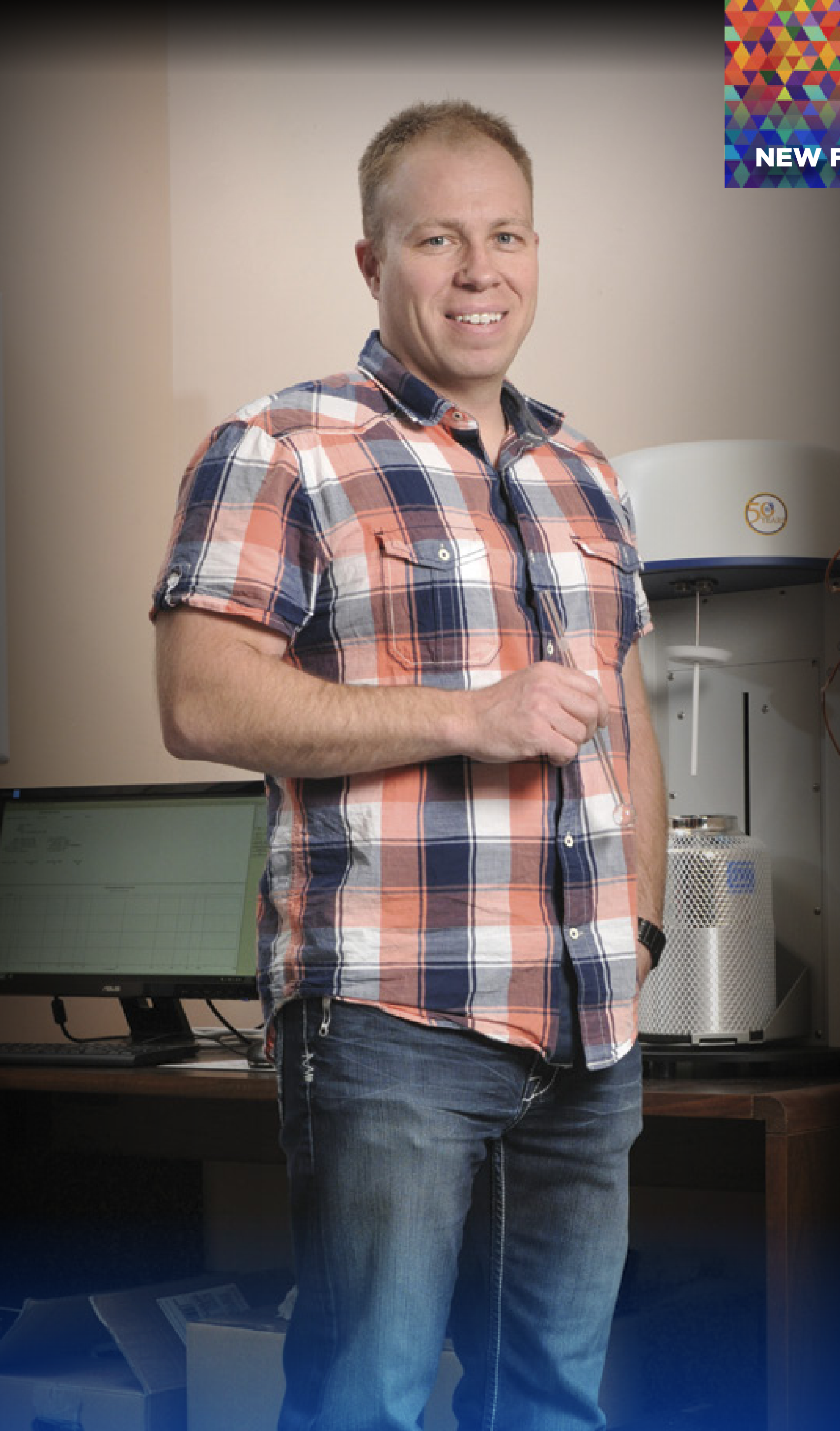


MELISSA KREBS
Assistant professor
Chemical and Biological Engineering

Krebs is focused on tissue engineering and new ways to deliver cancer treatments. Her lab is developing biopolymer systems that will allow the study of cells' interactions with their microenvironment and that can be used for tissue regeneration and therapeutics. She is investigating the controlled delivery of bioactive factors and therapeutics, the presentation of insoluble signals to cells, and the effect of mechanical forces on cell behavior and tissue formation.

ALEXIS NAVARRE-SITCHLER
Assistant professor
Geology and Geological Engineering

To answer questions such as "how does rock turn into soil?" and "what are the impacts of human activities on natural water quality?" Navarre-Sitchler integrates field observation, laboratory experimentation and numerical simulation in the study of geochemical processes in natural systems. She uses tools and concepts from geology, hydrology and materials science to advance the study of water-rock interactions.



BRIAN TREWYN

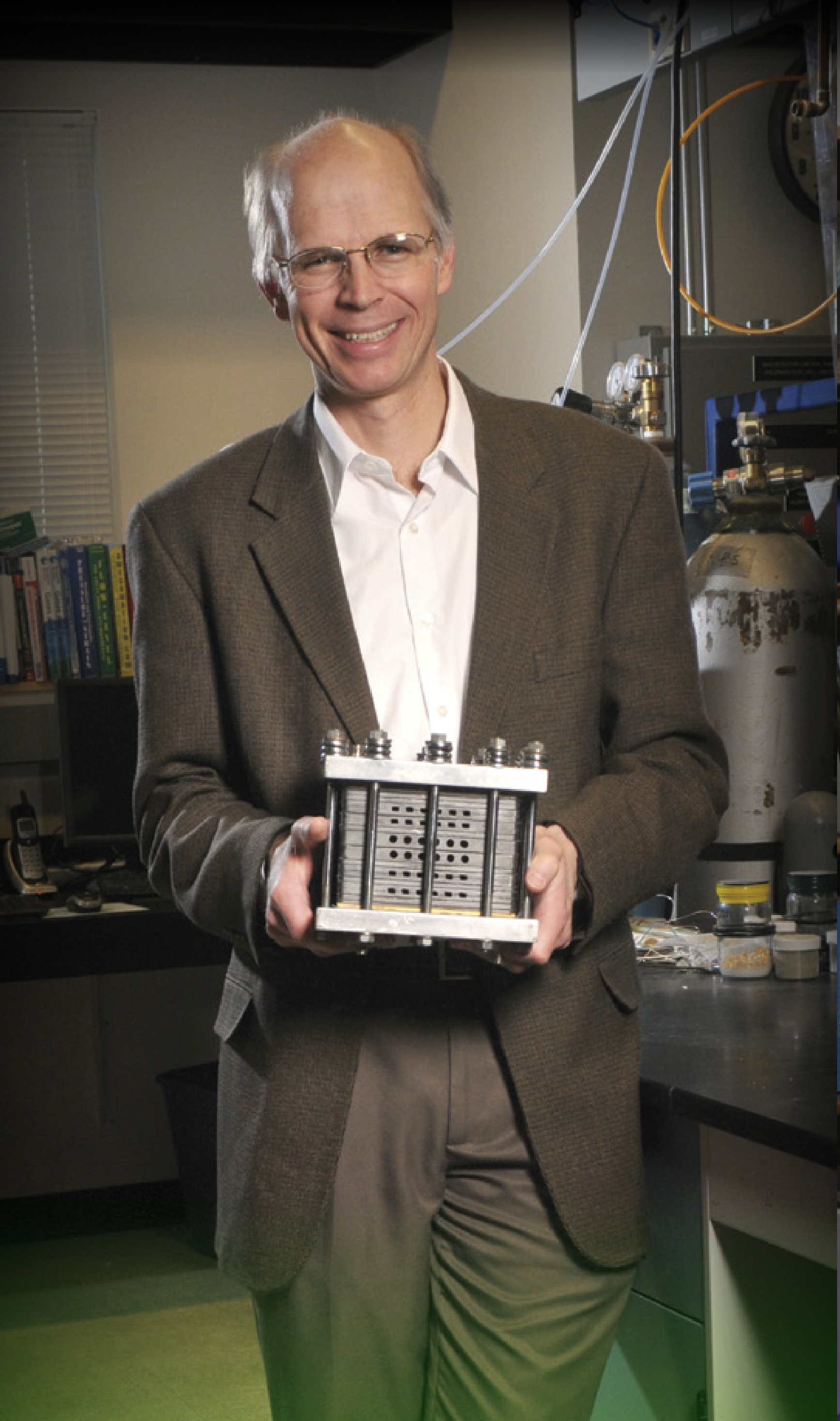
Assistant professor
Chemistry and Geochemistry

In Trewyn's laboratory researchers are investigating the synthesis, characterization, and thermal-, photo- and electrocatalytic applications of high surface area, porous materials. They are particularly interested in looking at the interface between biology and materials/catalysis, morphology controlled synthetic processes, and heterogeneous catalytic systems for tandem reactions. Trewyn strongly supports students working under his guidance to seek new materials with undiscovered applications.

JENIFER BRALEY

Assistant professor
Chemistry and Geochemistry

Acknowledging that nuclear technology needs to be a part of a diversified energy portfolio to meet projected worldwide needs and that safe application of nuclear power requires holistic consideration of proliferation possibilities and disposal concerns, Braley's research is focused on the development of proliferation-resistant reprocessing schemes, new forensics technologies to impede displacement of nuclear materials, and characterizing the environmental chemistry associated with the geological disposal of nuclear waste.



GREG JACKSON

Department head, professor
Mechanical Engineering

Jackson leads a research group with a breadth of activities in solid oxide electrochemical cells, PEM fuel cell systems and electrocatalysis, and catalytic and solar thermal reactors for energy conversion and hydrogen production. His research includes a combination of fundamental experiments and design model development and validation for both the scientific and industrial research and development communities.

KAMINI SINGHA

Associate professor
Geology and Geological Engineering

Singha's research explores processes associated with fluid flow and contaminant transport in porous media and fractured rock as well as groundwater-surface-water interactions. She has collaborated on projects linking water quality degradation and human behavior, imaging moisture dynamics in desert ecosystems, exploring changes in infiltration after fire, and quantifying kinetics of iron reduction given electrical measurements.

FUTURE HELP WANTED:
STEM Knowledge Required

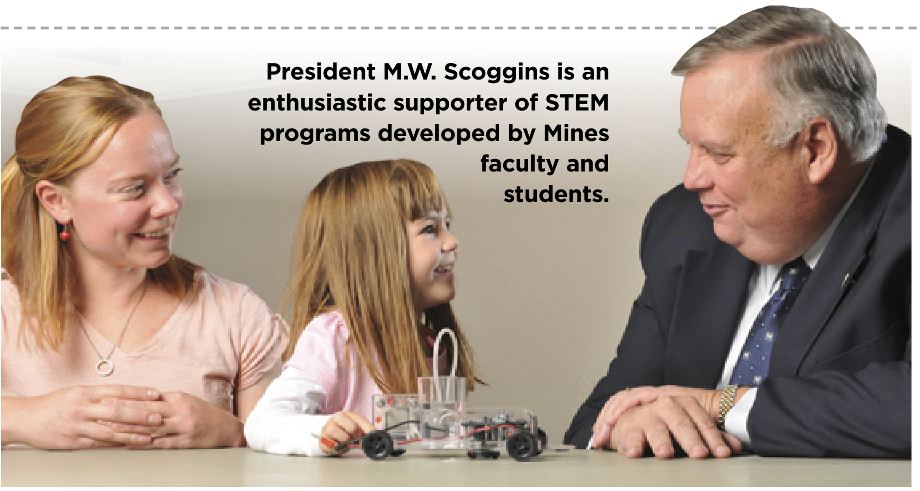
In the center of a clear plastic tub, small rocks formed a mound. With sixth graders gathered around the tub, Lyndsey Wright poured cool water over the rock mound. Next she poked small holes in a paper cup, put some blue food coloring in the bottom, and set the cup in the corner of the tub. Quickly she poured hot water into the cup. And the students observed that the warm water floated to the top and drifted over the pile of rocks, just like a warm front would drift over the top of a mountain range. Then they got their own tubs and supplies to reverse the experiment with warm water over the rock mound and cold water in the cup. They observed, compared and discussed the experiments.

A textbook could have provided an explanation of how mountains affect climate, but this was interactive. This was fun.

Wright is pursuing a master's degree in applied mathematics at Mines. She is focused on a numerical method for solving Poisson's Equation for her research project. And she also said she likes doing "nerdy lessons with kids." Last year, funded by the NSF's GK-12 Learning Partnerships grant, Wright worked with a middle school science and math teacher. This year, funded by the S.D. Bechtel, Jr. Foundation, she is working with a kindergarten teacher to give children an early introduction to science, technology, engineering and math (STEM).

Kelly Lundstrom is a master's student in applied statistics. Her research is related to assessment in education, specifically with the Bechtel Initiative, and she works with Mines Professor Barbara Moskal on assessing data from the program. For the past year and a half, she worked in an elementary school classroom where one of her favorite lessons was a raisin race, teaching students that matter exists as solids, liquids and gases and can change from one state to another by heating and cooling. She also co-ran an after-school science club where students completed engineering design projects. "My favorite part was seeing how excited the students got every time I presented something cool related to STEM," said Lundstrom.

Funded by grants from the Bechtel Foundation and the NSF, kindergarten through eighth grade teachers, Mines faculty and Mines graduate students



President M.W. Scoggins is an enthusiastic supporter of STEM programs developed by Mines faculty and students.

work together to develop problem-centered, interdisciplinary learning experiences for K-8 students in Adams County District 50, Adams County District 12, Denver Public Schools and Englewood Schools. Mines leads a two-week summer workshop focused on mathematical, scientific and engineering content, as well as instructional techniques, for the teachers and graduate students. Then throughout the following school year, the graduate students provide assistance to the teachers in their classrooms.

"Every week elementary and middle school students interact with Mines students — great role models who like science and math and want to work in a STEM field," said Moskal, who directs the Trefny Institute for Educational Innovation and the Center for Assessment of Science, Technology, Engineering and Mathematics at Mines. Her research group examines the effectiveness of existing and new STEM programs and asks: How do you capture the impact of outreach programs on students' learning and attitudes?

One thing Moskal has learned is students want to see the usefulness of STEM subjects. They are motivated when they realize how STEM can benefit their lives and the lives of others. So practical applications are an important element of Mines' STEM programs, which also include the Renewable Energy Materials Research Science and Engineering Center (REMRSEC) K-12 Education Outreach.

Supported by the Bechtel Foundation, BNSF Foundation, ECA Foundation, Northrup Grumman, NSF, Shell Oil Company and The Denver Foundation, this program provides Adams County District 50 and other teachers at the summer workshop with age appropriate lesson plans on energy basics, solar energy, hydrogen and energy efficiency. The Engineering Research Center for Re-Inventing the Nation's Urban Water Infrastructure at Mines also partners with Adams County District 50 to help teachers create compelling lessons and activities for their students during the summer workshop.

The American Society for Engineering Education has honored the Mines programs as "Best K-12 Partnerships" for two consecutive years, and the programs are growing, reaching more teachers and students with increasingly innovative, practical and effective approaches to STEM education. Serving the STEM pipeline from kindergarten to career, Mines is helping the nation build a highly skilled, competitive workforce.

PHYSICS FOR STUDENTS WITH DYSLEXIA

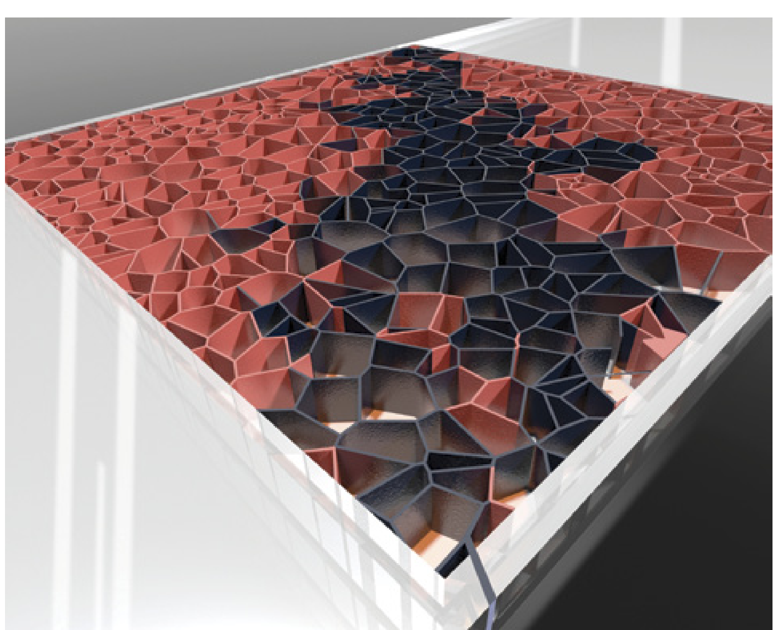
The Rocky Mountain Camp for Dyslexics is Mines' newest STEM partner. The American Physical Society will fund "Children with Disabilities: Physics Outreach to Dyslexic Students," a grant proposed by Moskal and Craig Taylor, REMRSEC director. They will direct the development and delivery of instructional modules in physics for K-6 students. The modules, involving 10 hours of hands-on physics lessons, will be tested on 40 students at the five-week summer camp held in Indian Hills, Colo.

"Dyslexia does not impair students' scientific and engineering reasoning," explained Moskal. "In fact, some researchers believe that dyslexic students have enhanced capabilities in science."

Graduate student Lyndsey Wright has helped in the past with the science unit of the camp. "It is really just a lot of fun," she said. "It allows me the freedom to do the coolest experiments I can possibly think of with a group of kids who genuinely enjoy and have an aptitude for science."

ROCK GRAINS, BLOOD CELLS AND THE PRINCIPLES OF FLUID FLOW

Keith Neeves

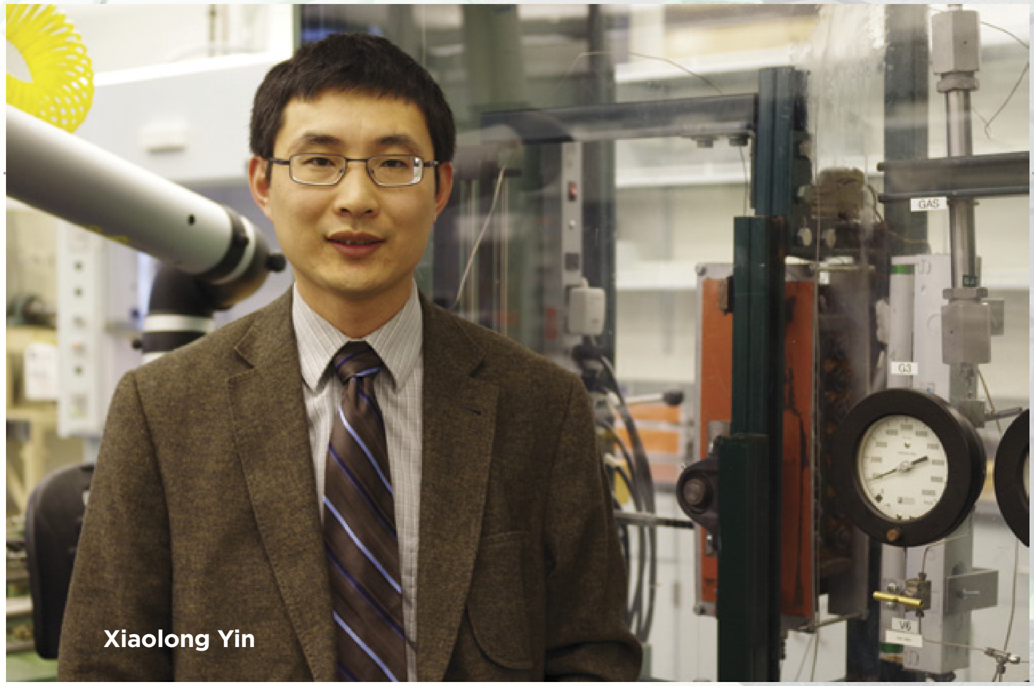


What do oil extraction and drug delivery through human tissues have in common? Their underlying physics.

Biological tissues and geological formations are porous media where fluid flows through a set of connected pores. For example, getting a chemotherapeutic agent to penetrate into a tumor, but not into healthy tissue, is dictated by how fluid moves through the pore defined by the spaces between cells. The ability to predict and direct fluid through these pores cuts across many disciplines including bioengineering, chemical engineering, petroleum engineering, geology and hydrology. Engineers in these fields can derive empirical relationships for a given porous media, but it is difficult to extrapolate these relationships across different types of porous media. Part of the difficulty is due to a lack of model systems that faithfully represent the complex geometry of real porous media.

Xiaolong Yin, from the Mines Petroleum Engineering Department, and Keith Neeves, from the Mines Chemical and Biological Engineering Department, have developed computational and physical pore scale analogs that capture the dynamics of fluid flow in real porous media.

In their recent cover article in the journal *Lab on a Chip*, they describe a model that mimics the size and geometry of a pore network that is characteristic of carbonate rock. The physical analog is fabricated using technology that was developed in the microelectronics industry to define channels ranging from 50 nm to 50 µm. Initial studies focused on simulating oil extraction by water flooding. An advantage of this approach is that the analogs are transparent.

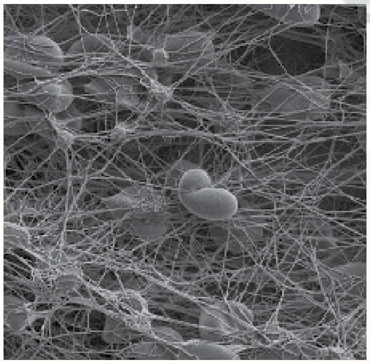

Xiaolong Yin

Therefore the fluids can be observed directly by optical microscopy, which has a higher resolution than imaging methods such as magnetic resonance and X-ray computed tomography.

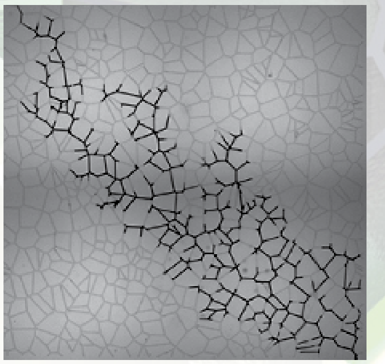
More recently the team has turned their attention to nanoscale pores that are characteristic of shale and biological tissue.

Shale oil and shale gas resources have very low permeability. Hydrocarbons confined in nanoscale pores demonstrate complex rock-fluid interactions and flow/phase behavior that cannot be explained by the theoretical models established for fluid properties at scales of micrometers and above. Nanoscale porous media analog offers an important means to isolate the important physical and chemical effects that are difficult to achieve using natural porous media and also offers a basis for more accurate predictions.

In the researchers' work on biological tissue, these pore scale analogs are being applied to the design of drug delivery strategies for dissolving blood clots. In this case, blood cells called platelets take the place of rock grains, but the principles of fluid flow are quite similar to geological media.



Scanning electron micrograph of a blood clot. The strings are a biopolymer called fibrin that gives the clot structural integrity. Entrapped in the fibrin are platelet and red blood cells. The pore structure formed between the fibrin and cells determines how effective clot-busting drugs can penetrate into the interior.



A transparent analog of sandstone for studying enhanced oil recovery strategies. Here, water (black fluid) is displacing oil (grey fluid) in a corner-to-corner flow. The fractal-like pattern is characteristic of inefficient oil recovery.

Conference for Graduate Students, BY GRADUATE STUDENTS

Participants in past years at the Conference on Earth & Energy Research (CEER) have had the opportunity to compete for a Best Elevator Speech award during a conference lunch. These were their instructions:

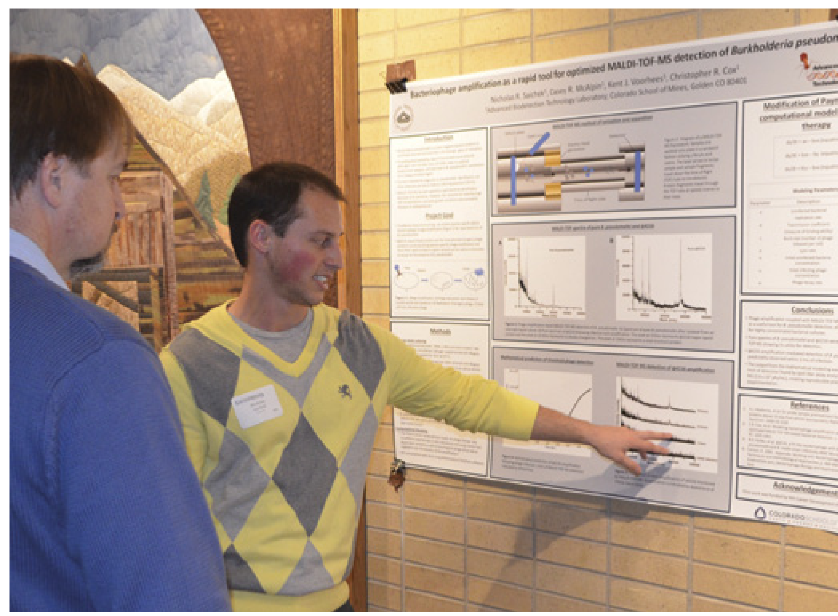
You're in the elevator with a potential employer (faculty, sponsor, etc.). You have two minutes to summarize your research with the goal of them asking for your business card. Go!

For the 2013 conference, the Mines Graduate Student Association (GSA) organizers developed the same type message to concisely explain and market the conference:

CEER is a conference run 100 percent by graduate students, for graduate students. Presenters in both poster and oral sessions get the opportunity to receive feedback on their presentation skills from both faculty and alumni judges, who critique a wide range of areas using an online judging system. A social event is hosted each evening of the two-day conference to foster collaboration and socialization of presenters and judges in a setting outside academia. Prizes are awarded to the top presenters. Over the years, CEER has gained substantial momentum, becoming not only a hallmark event of the GSA, but is also becoming a recruiting tool departments across campus are utilizing for prospective graduate students.

The conference included approximately 115 student presentations from Colorado School of Mines, Colorado State University, the National Renewable Energy Laboratory (NREL), University of California at Berkeley, University of Colorado at Boulder, University of Denver and University of Northern Colorado, according to GSA vice president Mark Taylor, and a record number of faculty and alumni judges, with each presenter receiving feed-back from at least three different judges.

Dr. Dana Christensen, NREL's deputy laboratory director for science and technology, delivered the conference keynote address, "Science and Society: Why Research and Public Policy Depend on Each Other."



ORAL SESSION TOPICS

Characterizing Natural Environments
Innovations in Materials
Advances in Conventional & Clean Fuels
Engineering and the Bio-Sciences
Innovations in Hydrocarbon Techniques
Advances in Structures & Monitoring
Fuel Cell Applications and Innovations
Remediation & Waste Recycling
Earth, Energy and the Human System: Exploring Economics and Policy

POSTER SESSION TOPICS

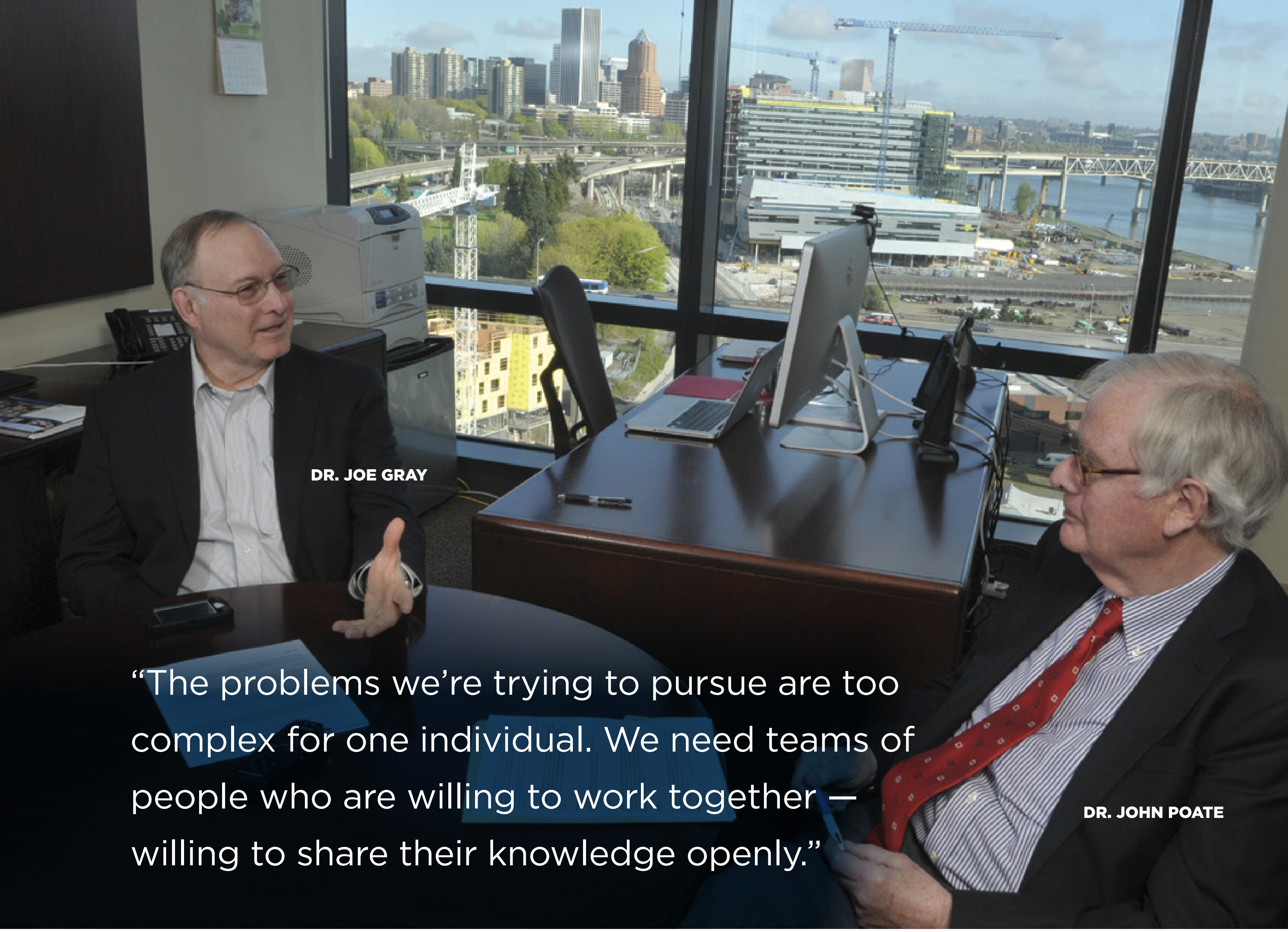
Improving Systems and Structures: Advanced Modeling, Monitoring and Detection
Exploring the GeoStructure: Advanced Modeling & Mineral Exploration
The BioFuels Frontier: Replacing our Conventional Energy Sources
Synthesis of Thin Films: Photovoltaics & Beyond
Natural Disasters & Policy: Mitigating Effects on Humans
Science Below the Microscale: Innovative Methods & Material Behavior
Reducing Environmental Impact: Recycling, Reclamation & Cleansing
Novel Detection of Disease & Environmental Change
Natural Systems: Using Mother Nature to Reduce Our Impact
Innovative Solutions for Fuel Cell Performance

The Odyssey for a Google Map of Cancer

Joe Gray holds the Gordon Moore Endowed Chair at the Oregon Health & Science University (OHSU) and serves as chair of the OHSU Department of Biomedical Engineering, associate director for translational research in the OHSU Knight Cancer Institute, and director of the OHSU Center for Spatial Systems Bioscience. He also holds positions as emeritus professor, University of California San Francisco, and as senior scientist, Lawrence Berkeley National Laboratory.

Gray's work is described in more than 400 publications and in 70 U.S. patents. He is a fellow of the American Association for the Advancement of Science and the American Institute for Medical and Biological Engineering, and an elected member of the Institute of Medicine of the National Academy of Sciences.

Gray earned a physics engineering degree from Mines in 1968 and a PhD in nuclear physics from Kansas State University in 1972. He delivered the keynote address at Mines' December 2012 commencement ceremony. In April he met with Mines Vice President of Research and Technology Transfer John Poate on the OHSU campus.



"The problems we're trying to pursue are too complex for one individual. We need teams of people who are willing to work together — willing to share their knowledge openly."

DR. POATE: You shared three lessons from your incredible career with our December graduates, and those observations correspond nicely with the focus of this year's magazine — the interplay between the research endeavor and the education of graduate and undergraduate students. So I'd like to talk more with you about those three lessons. Let's start with Lesson Number One: Embrace Intellectual Diversity. You have certainly lived that lesson. Tell us about your unique path from physics at Mines to nuclear engineering to being one of the world's leading cancer experts. It's been a great odyssey.

DR. GRAY: Well, it's been a fun odyssey — and productive. When I was at Mines, I was very much dedicated to a career in engineering physics. I was inspired by the Sputnik era and wanted to play a role in furthering our engineering and technical expertise — particularly in the area of physics. It's the fundamental description of nature, so it interested me.

I went from Mines to Kansas State University where I got a degree in nuclear physics — helped build a particle accelerator and was fully engaged. But toward the end of my graduate career there, I was sharing an office with a group of yeast geneticists — not a place you usually put a physics major — but nonetheless, I was exposed to what they were doing. I became fascinated by it. The yeast scientists were trying to prioritize thousands of problems worthy of investigation. I became intrigued by the fact that we knew so little about how these complex organisms of life actually work. About that time there were some job openings at the Lawrence Livermore National Laboratory, where they were trying to build up a program in cell analysis and exploit a laser-based technology — flow cytometry — that had just been invented. You couldn't buy a flow cytometer then. You had to build it.

I talked with the scientists at Livermore about how flow cytometry looked an awful lot like nuclear physics — or particle accelerator physics. I like to say that in biology, the machines are smaller and the nuclei are bigger. It is in essence the same technology. So I went to Livermore to build a flow cytometer.

From a mathematical and analytical point of view, there was a direct transition from what I was doing in physics to what needed to be done to advance the way we study cells. Part of the intellectual diversity here is that somebody who is trained in biology probably would not have been able to make one of these devices, but somebody who had no idea what the problems were knew how to solve them once they had been properly framed.

So my colleagues and I built this gadget, and it worked. Then I became engaged in two studies that took advantage of my physics background. One of them had to do with cancer. I knew very little about cancer, but this was in the day when we were treating cancer with a drug that would cause the cells to pile up in one part of the cell cycle and then releasing them and treating them with a second drug that would kill them later when they got into a sensitive phase. The idea was to do this in a way that synchronized the tumor so that it was in a sensitive phase at a time when normal cells were not — some sort of complex synchrony experiment. It was hard to do this experimentally. So I wrote what turned out to be a huge simulation code — a large set of coupled linear differential equations that described the whole process and actually put together, I thought, a pretty good theory that explained, mostly, that this strategy would require such precise scheduling of drugs that it would not be practical in the clinical setting!

But it got me engaged in cancer research, and as I went along, I became interested in testing some of the models I was developing. And I couldn't get people to test the models for me. So I said, "Fine. I'll learn biology. I'll test them myself." I spent a year or so shadowing some of my colleagues in biology and learning some of their techniques. I became more and more able to do the biology myself, which was important because I needed to understand the nature of the data I was trying to describe.

DR. POATE: **I know you've been inducted into the Entrepreneur's Hall of Fame at Livermore. You've been a great emissary of Livermore – and the University of California San Francisco and the Lawrence Berkeley National Laboratory, too. Is there anything about those institutions you'd like to articulate? They are remarkable American institutions.**

DR. GRAY: They are remarkable institutions, and one of the things that characterizes all of them is the willingness of the faculty and staff to do this exercise of embracing intellectual diversity. They're collaborative in nature. I think — especially in biology today — many of the problems we're trying to pursue are too complex for one individual. We need teams of people who are willing to work together — willing to share their knowledge openly — share their ignorance openly — without being too judgmental about the fact that not everyone is the world's expert in everything — and move forward collaboratively. I think all of these institutions embrace that spirit. And the same is true of the Oregon Health and Science University where I am now.

DR. POATE: **That's a very powerful message to get across, Joe. You were a co-leader of the Breast Cancer Dream Team with the Stand Up to Cancer Foundation, a great organization. It seems to me that cancer is an end game. Down the road, are we going to be at a stage where we get to cancer earlier?**

DR. GRAY: Treating advanced cancer is going to be difficult now and for the foreseeable future. No question about that. There's just too much plasticity and genetic diversity to think there's going to be a magic bullet out there. So you're absolutely right, John. We need to treat the disease a lot earlier in the process — either by prevention or by developing technologies to catch the cancer at a very early stage before it has disseminated in the body. One of the things we discovered is that some cancers are really prone to disseminate and others are not. So I think we're going to be able to develop detection tools that are specifically designed to detect the invasion-prone cancers.

But prevention is, of course, the right way to think about it. Unfortunately, it's the hardest thing we have to do. When you treat a cancer patient, you can be reasonably aggressive about administering drugs that may have some harmful side effects, because the alternative is worse. But when you're dealing with prevention, there are two problems. One of them is the treatment you give has to be very, very non-toxic. And number two is it requires a very long-term study to prove that a treatment actually works. You have to test treatments in a population that is exposed over decades, and we don't have funding mechanisms in this country that will tolerate that kind of persistence.

DR. POATE: **Let's go to Lesson Number Two that you shared with our graduating students. It was: Expose your own ignorance to people who possess the knowledge you need to keep up in a rapidly changing world.**

DR. GRAY: My story — my life lesson in this — was when I had just arrived at the University of California at San Francisco. I had moved there from the Livermore Laboratory and I knew something about breast cancer, but not a lot. I was coming into this intensive and cohesive biomedical environment. We established a seminar series where people — surgeons, oncologists, statisticians and engineers — would gather together weekly and talk. For the first year or so, somebody would make a presentation in a particular area of expertise, and everyone else in the room would just sit there, applaud politely and then leave. After awhile we invited breast cancer advocates to the research seminars. They were women who had breast cancer, so were very interested in the disease, but they weren't scientists at all. They would sit there as I was giving a talk and then I would hear, "Dr. Gray, that's really elegant. Would you say that in English?" And so they took the position that they were not going to let us snow them with jargon. And they started asking questions.

It turns out that when you're talking about engineering, a surgeon probably knows no more about the engineering discipline than the advocates. So when the advocates started to ask me to explain, then everybody else understood. This was originally a 45-minute seminar and now, after 15 or 20 years, it's an hour-and-a-half seminar, and we ask people to prepare only 30 minutes of material because they won't get through any more than that. It's intensely interactive. And it's okay to ask "stupid" questions because the main thing we learned was the questions weren't stupid. If you didn't understand something, there were probably 10 other people in the room who didn't understand it either.

In science I think we tend to always pitch our talks at too high a level. We presume too much on the part of the audience, and as we go deeper and deeper into multidisciplinary science, it's going to be more and more true that your audience is not on the same expertise plane as you are. You're going to have to communicate to the diverse members of your collaborative team in ways they can understand. Teams cannot progress if people don't collectively understand what everybody is talking about.

DR. POATE: **I think that's great, and I'm not sure we're doing it in a lot of fields.**

DR. GRAY: I think we're not doing it in most fields. I would say that the science enterprise we have developed over the last hundred years is really in place to educate small groups of students into a very narrow discipline and to reward people for discoveries in those disciplines. You don't get Nobel Prizes by participating in large teams. The way we reward ourselves is not designed to encourage people to reach out and share information broadly. It's not really designed to solve society's problems. It's designed for what I consider small-scale university science. And I think we have to grow out of that. The physics community did grow out of it. I once talked to Pier Oddone, who is the director of Fermilab, and I asked him, "Pier, how did physics transition from being an academic science to being an international collaborative science?"

He answered, "Well, we had to do it when all of the easy problems were solved." So now they're working together to solve the hard problems, and I think in biomedicine, in particular, we're trying to solve some hard problems. I may be in the minority on this, but I think it's going to require teams — multidisciplinary teams — to do it. We need to develop incentives — in academia, in the private sector and in the scientific community in general — to encourage that to happen.

DR. POATE: You've always been a great pioneer in technology. Tell me about what you're doing with microscopes in your cancer studies. Is it going to bring about a real revolution?

DR. GRAY: Obviously I think it's critically important. The concept of revolutionary is always in the eye of the beholder, but I think what we've been doing in biology is pretty much disassembling biological systems and studying them piece by piece. It's sort of a reductionist approach to biology, and it's been very productive. It's clearly allowed us to identify many of the molecular pathways that regulate cells and tissues. But in the end, you have to understand the whole pathway. By analogy, it's really hard to understand how a computer works by looking at one transistor. You really don't get the whole picture until you put the thing together and watch it operate as a system. That means you need technologies that don't disassemble.

We need tools that allow us to look with molecular specificity at these molecular machines. We need to look at all resolutions to integrate this multiscale biological world. I am convinced that we can now achieve this goal by combining the latest electron and light microscopes. We now have a suite of these tools at OSHU that enable studies of structures ranging in size from nanometers to centimeters. Moreover, the recent major advances in protein labeling enable detection of specific molecular features. The huge advances in high performance computing now allow us to manage this enormous amount of data and analyze it in a new and comprehensive way. It's always been the case that science marches on the back of technology.

We have some very recent results on cellular differentiation based on molecular imaging. We now know that human tumors are heterogeneous in their differentiation state. And since drugs are differentiation status dependent, if you've got a heterogeneous tumor and you don't take that into account, you're pretty much doomed to failure. You'll hit some of the sub-populations and not the others. So this got me thinking that we need to come up with differentiation-heterogeneous-targeted drugs. Let's actually treat the heterogeneity. It's a different way of thinking about cancer. It's very exciting, and it is informed by novel imaging approaches.

DR. POATE I think you're going to have, here at OHSU, the best suite of imaging technologies anywhere.

DR. GRAY: I think that's right.

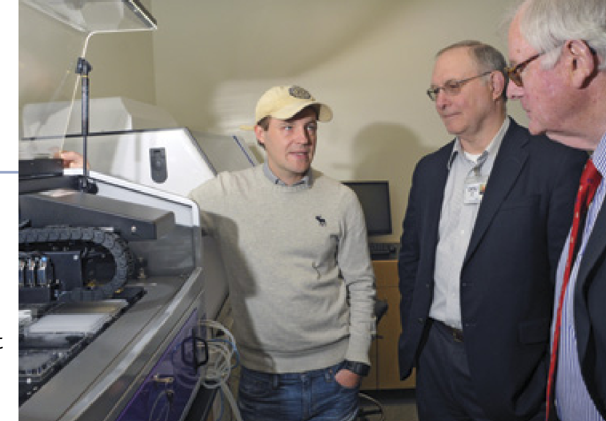
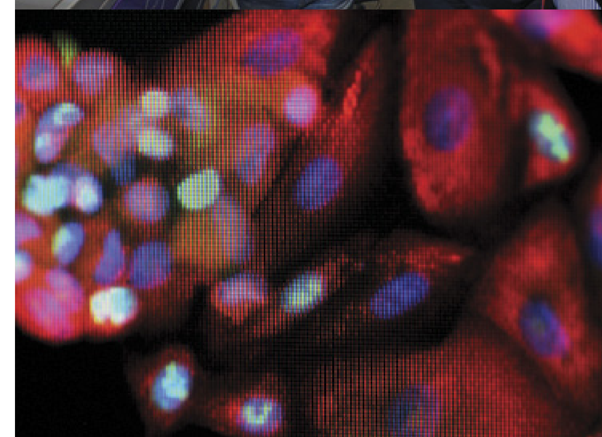
DR. POATE: So I'm wondering about this imaging technology and the big initiative just announced on brain research. What if one of your young, bright researchers said, "Joe, I really want to look at some of this brain stuff."

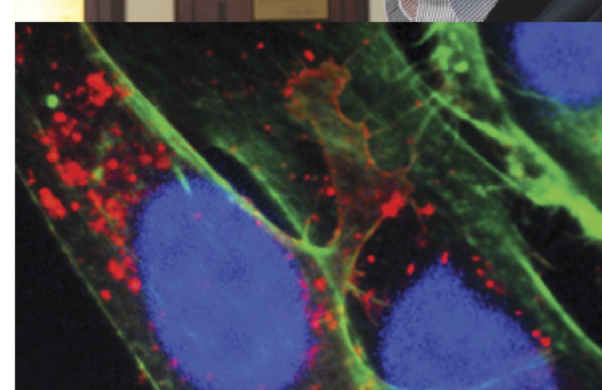
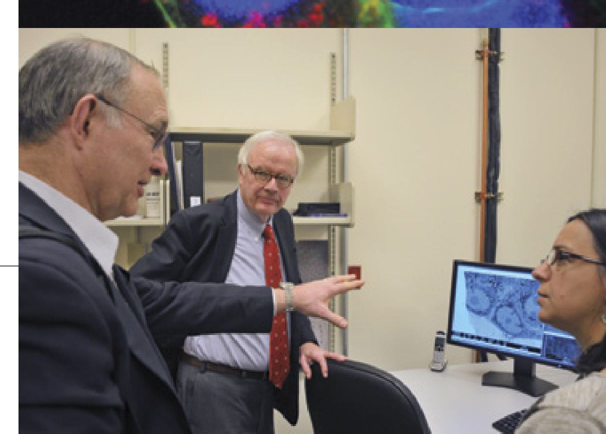
DR. GRAY: Well, as it turns out, the way we're building the center is exactly along those lines. What we want to do is have a world-class group of experts in the technology, but with every expert wearing a technology hat and a biology hat. I'm hoping that as we go forward, we'll coalesce out teams that want to study cancer, which I want to be involved in, and other teams that will coalesce around the study of the brain, and others around cardiovascular disease, and so on. We have a recruitment going on right now for somebody with expertise in electron microscopy, and that's really being driven by the people interested in the brain.

I'm not demanding that all this expertise be focused solely on cancer. That's where I want to take it, but I want other people to take it in different directions. And the different directions sometimes converge. There are people who have learned how to study the brain in ways that are applicable to cancer. There are people who have expertise in cardiovascular disease, and it turns out many aspects of the biology of cardiovascular disease are also involved in aspects of cancer. Here, it's bringing together an intellectually diverse group of people to solve multiple problems.

DR. POATE: Okay, this brings us to Lesson Number Three from your graduation speech. Have the courage to attempt things that others think impossible. So where do you think your research will go next?

DR. GRAY: Well, I think this concept of assembling a Google Earth view of cells and tissues will be viewed by most people as impossible.

DR. POATE: Really?

DR. GRAY: Yes. If you think about this, especially in the area of cancer, we're dealing with extremely complex issues that exist over resolution levels going from angstroms to centimeters. The idea that one would be able to pull together angstrom-level — or even nanometer-level — resolution information on something the size of tissue is an enormous problem in data generation, visualization and interpretation. You have to be able to make the proteins visible in a way that doesn't perturb their function. How do you develop the chemistries to do that? How do you see features when they're sparsely labeled? It's not as if we're going to be able to label every protein so brightly that you can distinctly see it. So there's a lot of work to be done in the chemistry, the imaging, the computer science to make this happen.

DR. POATE: I think your Google Map concept really makes sense.

DR. GRAY: It does make sense, John. The question is, how hard is this to achieve technically? The amount of data we will need to generate may be larger than Google now deals with. They just look at the outside of houses. What we're attempting would be the equivalent of adding to what Google does by looking inside homes at the forks in drawers and then pulling all that together for the world.

DR. POATE: It's a huge challenge.

DR. GRAY: And it's also the case that you don't make progress unless you set a big challenge and then go for it. Think about the human genome program a decade ago — a billion dollars, 10 years for a genome. Tomorrow I can do it in my lab for a thousand bucks. That technological revolution was spawned by clearly stating the goal of being able to sequence the human genome. That inspired people to do it, to make it faster, better, cheaper, more reliable. That caused the technological revolution to happen, and I think the same sort of thing can happen with our project.

DR. POATE: That's exciting. I have another question, Joe. As a member of the Institute of Medicine of the National Academies, you can advise policy makers on the nation's health issues. What are your recommendations?

DR. GRAY: Well, there are several messages that I would want to convey and will convey. One of them is I think that, at some level, we need two National Institutes of Health — one that would be focused on basic discoveries. There's no question we need a strong, vibrant let-a-thousand-flowers-bloom research enterprise. But I think when you start translating this to improve health care, we have to focus. We can't try to solve all problems in parallel. I think it's going to be really important to identify a few key challenges and marshal the resources to solve those problems. Maybe it's early breast cancer detection, maybe it's prevention of a particular disease, maybe it's treatment of pancreatic cancer. There are many ways one can cut this pie, but I think we tend not to be as goal-oriented in the translational science as we need to be. We need to think about what some of the big problems are and empower people to make careers out of trying to solve those problems.

The other bit of advice is I'm afraid we've gotten ourselves into a paper-chasing rat race in sciences where it's difficult to get funding. This causes us to write a lot of small proposals to increase the probability of funding. With small grants you spend an awful lot of time pushing paper, making reports, and doing anything except spending time in the lab thinking about what you're doing scientifically.

I saw this great TV show on the life of Einstein, on how he lived his life. Basically what he did during his day was to think — day after day after day after day. He didn't write grant proposals. He didn't do progress reports. He made a career out of solving the problem he had chosen to solve. I think we somehow need to back away from this idea that it's good to churn paper and try to get people professionally and fully engaged in solving real problems. So I would like to see a move to metrics, see people rewarded for making a real tangible advance in biomedicine or any other aspect of science. Be goal-oriented about it rather than paper-oriented. We're caught in writing these tens of thousands of papers. But to me that's not what should be driving the show. What should be driving the show is whether or not you've solved a real problem.

DR. POATE: Oh, that's excellent. Yes, for the young scientist and young faculty member, it's a real problem. So one of the reasons we're here is that you're a Mines alum and we're very proud of you. One of the things we're pushing is to grow our bioscience and bioengineering. We can't be a first-rate engineering school without our undergraduates being exposed to this field. Give us some advice.

DR. GRAY: I think you've got a great start. To me, the thing that Mines has going for it is its superb engineering and science. And I believe that the biosciences in the future are going to become increasingly dependent on computational science, engineering materials science. Mines is very rich in the engineering disciplines that are going to be needed to understand complex biological systems. And these can be complex biological systems of any type. It could involve medicine or energy, but I think that really understanding and engineering these systems is going to be more and more hard-core engineering. Mines can play a huge role there.

It's always a temptation to try to carve out a separate discipline. My advice would be not to carve out a separate discipline, but rather build it into the engineering programs you already have. Back when I was at Mines, we didn't even discuss biology because there wasn't any. When I was in graduate school, we didn't talk to biologists. If the concept could be developed that there is this set of important things in the world to an engineer, and biology is one of them, I think that would really distinguish Mines as a place where multidisciplinary science is done.

DR. POATE: And that's what we're doing. My final question is about two of your close friends when you were an undergraduate at Mines. Jerry Grandey was CEO of one of the world's largest uranium mining companies. Chuck Hahn is a bit of a rock star in Australia because he's such an innovative brewer. And you are one of the world's leading cancer researchers. You were a remarkable trio. So what brought you together?

DR. GRAY: Well, our attendance at Mines at the same time was coincidental. But we got to know each other well because we were all on the swim team. We were really stressed pretty hard to swim and to excel academically, so this generated a close set of people who would commiserate over the toils of life at Mines. I think the life lesson from that, which Mines should continue to think about, is that Mines made us work really hard. If you look at what all three of us have done, we've pretty much lived the message that sweat equity counts for a lot.

DR. POATE: Yes, you have. I've been privileged to talk with you today, Joe.

DR. GRAY: And I've certainly benefited from my Mines education. It really did start me down the path of an exciting career.

College Research

The evolution of Mines into a broad-based research institution is proceeding at a fast clip. Such an evolution has necessitated the formation of colleges with well-defined identities and missions. The college structure is now in place with three deans overseeing colleges with particular research strengths. These deans are well-established leaders who have enjoyed distinguished academic careers. The colleges are in good hands.

—John Poate, Vice President for Research and Technology Transfer

COLLEGE OF APPLIED SCIENCE AND ENGINEERING

Chemical and Biological Engineering
Chemistry and Geochemistry
Metallurgical and Materials Engineering
Physics

Anthony Dean, Dean: Our vision in the College of Applied Science and Engineering (CASE) is to provide nationally recognized programs of distinction, featuring an emphasis on problem solving and critical thinking that address professional and societal needs. CASE departments are leaders in knowledge creation, recognizing the critical role research plays both in building a dynamic and rigorous intellectual learning community and in the advancement of humankind. This research role connects undergraduates, graduate students, postdoctoral fellows and faculty in the quest for a deeper and broader understanding of nature.

In Chemical and Biological Engineering, research areas include fuel cells, methane hydrates, biofuels, solar photoconversion, membranes, polymers, and complex fluids. Research themes in the Chemistry and Geochemistry Department include energy and materials, geochemistry and environmental chemistry, analytical and biomedical chemistry. Metallurgical and Materials Engineering has research centers in advanced coatings, alloys, welding and extractive metallurgy. The Physics Department research thrusts include sub-atomic physics, condensed matter and applied optics. In addition the college has multidisciplinary research centers in material science and nuclear science and engineering.

COLLEGE OF ENGINEERING AND COMPUTATIONAL SCIENCES

Applied Mathematics and Statistics

Civil and Environmental Engineering

Electrical Engineering and Computer Science

Mechanical Engineering

Kevin Moore, Dean: Research in the College of Engineering and Computational Sciences (CECS) is motivated by the goal of improving people's lives by attacking fundamental problems facing society. Many of CECS's programs aim to enable a better quality of life in the natural and built environment through a focus on livable, intelligent and sustainable infrastructure.

Current and developing areas of expertise include: dynamical systems, inverse problems, wave phenomena, multi-resolution modeling and uncertainty quantification in Applied Mathematics and Statistics; environmental and water resources engineering, structural engineering and geotechnics in Civil and Environmental Engineering; information systems sciences and "big data," electric power and energy, networking and high performance computing in Electrical Engineering and Computer Science; and thermal sciences and energy conversion, mechanics of materials, biomechanics, and robotics, design and automation in Mechanical Engineering. Of particular note are the interdisciplinary efforts that CECS faculty and students are involved in, including the Colorado Fuel Cell Center, the SmartGEO program, the hydrology program and the Underground Construction and Tunneling program.

COLLEGE OF EARTH RESOURCE SCIENCES AND ENGINEERING

Economics and Business

Geology and Geological Engineering

Geophysics

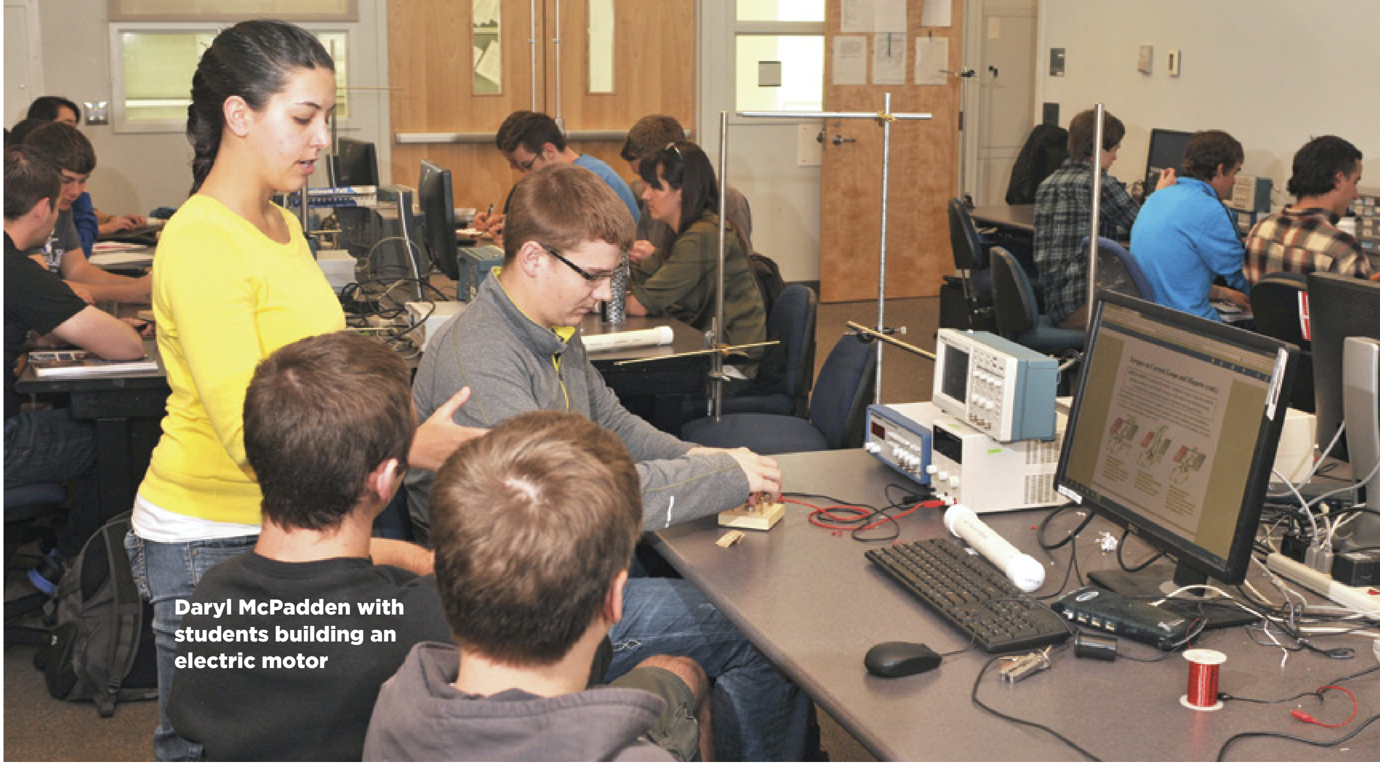
Liberal Arts and International Studies

Mining Engineering

Petroleum Engineering

Ramona Graves, Dean: The seemingly diverse departments in the College of Earth Resource Sciences and Engineering (CERSE) are in reality the correct mix of engineering, physical science and social science. To solve the complex issues in developing earth resources, CERSE has the technical expertise to solve the engineering challenges, the economic expertise to determine if the engineering solutions are economically viable, and the social/public policy expertise to help decide if society is ready to accept these solutions. The research activity in CERSE varies from conventional to unconventional oil and gas development, water resources, critical minerals, operations research, underground construction and tunneling, earth dam and levee sustainability through monitoring science and condition assessment, carbon sequestration, renewable energy (geothermal), geophysical methods for planetary exploration and geophysical hazards mitigation, explosives and blasting applications, and the list goes on. Our challenge as we go forward is to inform our constituents of the amazing group of research teams we have working to solve the world's complex earth resource challenges.

A New Frontier



Daryl McPadden with students building an electric motor

for Physics

Enrollment numbers at Mines suggest it's a hot new field of study, but this is a subject with a long, long history.

We're talking about physics, the realm of Archimedes, Copernicus, Newton, Faraday, Maxwell, Curie, Bohr and, of course, Einstein. Mines saw its number of undergraduate physics majors leap from 114 students in 2001 to 258 in 2012. Since 2006 the school has graduated an average of 56 physics majors a year, placing the program among the four largest in the country, in a league with Massachusetts Institute of Technology, University of California at Berkeley and University of Maryland at College Park.

Indeed, Mines has one of the nation's top undergraduate physics programs, a distinction reflected by its receipt of one of just four American Physical Society's Improving Undergraduate Physics Education awards in 2013.

Perhaps some of the heightened interest in physics has to do with a growing consciousness that the field is humanity's best attempt at decoding the language of the universe. Or perhaps students recognize that a foundation in everything from electrical to gravitational to quantum phenomena can apply to a broad range of fields and even make one a better citizen in a world where numbers are policy. But this wasn't always the case.

Physics II, like Physics I, is a requirement for most Mines students, with about 900 students taking one of the two courses in a given semester. For a long time, it wasn't exactly popular, said Thomas Furtak, head of the Mines Department of Physics.

"Physics II used to be one of the most hated courses here," Furtak said. "It was difficult material, and every student had to take it."

With 40 percent dropping, withdrawing from or failing these classes, Furtak and colleagues in the late 1990s decided to revamp the program. Their goals, expressed in the well-founded buzzwords of the time, were to provide:

- "authentic experiences" with problems that were not merely academic
- something "context rich" and connected to everyday life
- something "experiential" and not just involving working out things on paper
- and something social that involved students arriving at a "negotiated understanding" via mutual explanation and listening

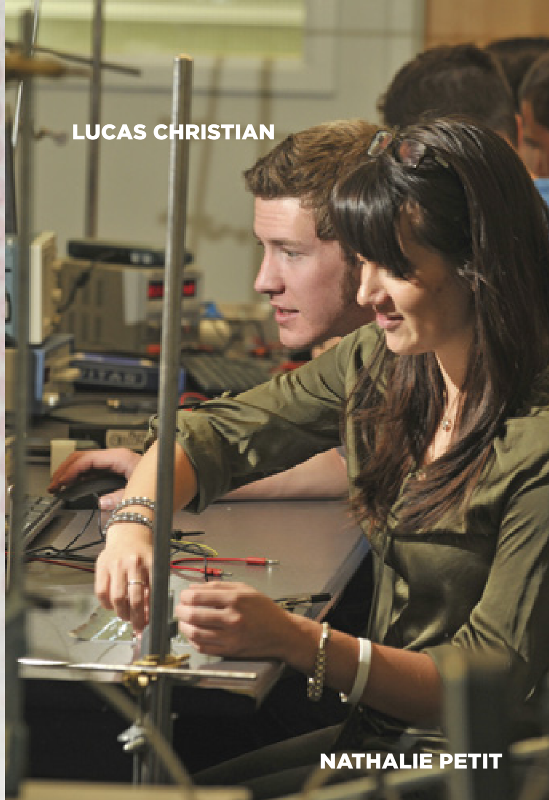
These guidelines and a model pioneered in 1994 at Rensselaer Polytechnic Institute drove a curriculum and classroom development effort that led to an all new "studio physics" approach in Physics I in 2001 and in Physics II in 2006. Both involve a pair of one-hour lectures and two-hour studios per week.

Daryl McPadden, a senior physics major, is a teaching assistant in Physics II, which covers electricity, circuitry, magnetism and optics. On a day designated as "Capacitor Studio," McPadden stood at the fringe of a Computer Commons classroom customized for studio physics. There were eight clusters of tables, each with four work stations. Two or three students sat at each station, outfitted with a flat-screen monitor, digital multimeter, function generator, circuit box, DC power supply, oscilloscope, sensor interface for data collection and small plastic hardware cabinet. Stainless steel bars were vice-gripped at the edge of each station, remnants from a Physics I class that had used dangled weights from springs to study oscillating motion. To all this, students added their scientific calculators, notebooks and papers with circuit diagrams and equations.

"You only get one capacitor," said David Flammer, the instructor. "Don't blow it up. I'm going to show you how to blow one up in a minute."

The experiment involved charging and discharging a capacitor through a thermistor, whose ability to resist current withers with rising temperature. Flammer directed students to a Wikipedia page on resistor color-coding and asked that McPadden and fellow teaching assistants not answer questions for 15 minutes.

"If we hold back as TAs, it helps them problem-solve — as opposed to us fixing it for them," McPadden explained.



Students walked through the exercise, connecting wires and reading meters, discussing possible approaches and next steps. When they ran into roadblocks, they consulted each other or raised their hands. McPadden or another of the five undergraduate TAs on hand then helped.

"Switch it over to five. See what happens? See, you're not actually calibrated to zero," McPadden told a team at table three.

Freshman Katie Schumacher and sophomore Parker Schuster worked together at the next table. On their screen, the online course-management software displayed a page titled "Thermistor Intro."

"Studio kind of gives you a real-world sense of what's going on. It makes it relevant," Schuster said. "And it helps when other students help you, too," Schuster added.

McPadden says the studio courses helped ignite her interest in physics. In general, the rates of those dropping, withdrawing or failing required physics courses have fallen by half, and other Mines programs — including biology and math, are considering the approach. Farther afield, Mines faculty have assisted the faculty of the University of Wyoming and Abu Dhabi's Petroleum Institute in implementing studio courses.

The senior research project has been the other big development in the Mines Physics Department. Launched in 2006, it builds on research skills introduced during a required six-week summer session boot camp Mines students attend between their sophomore and junior years.

"We train students in everything from ultrahigh vacuum techniques to computer numerical-control machining, computer networking and optical technology," Furtak said. "They learn a lot of things that many physics students elsewhere don't know until the end of their first year of graduate training."

The idea of the senior project, Furtak said, is to "merge the research interests of the faculty member and the research activities going on in our graduate program to create an undergraduate experience that is valuable to them."

All 17 tenure-track faculty propose projects, which number in the dozens. In September, seniors choose one they like. McPadden and Mines senior David Bicknase chose one proposed by Furtak and colleague Reuben Collins. Their project: "Passivation and Size Control of Solution-Processed ZnO Quantum Dots."

In a corner of a Meyer Hall lab, McPadden explained that she was interested in renewable energy applications, and that zinc oxide quantum dots could be relevant as a bridge between inorganic and organic solar cells. Each Sunday, she and Bicknase spend several hours in the lab, using zinc acetate and sodium hydroxide to grow quantum dots and then sort out the particles' surface chemistry using a spectrophotometer.

"We're looking at the bandgap energy of the particles," added Bicknase. "The spectrum shifts depending on size, increasing as the particles get smaller."

They've had to be creative at times, such as when their flasks began tipping over after transfer from hot water to ice baths. The solution? A colorful support lattice made from K'NEX construction toys. By the end of their senior year, they will have written the equivalent of a journal article on the topic and presented a poster. A key part of the experience is learning how to communicate their ideas, Furtak said.

McPadden hopes to earn a PhD and specialize in physics education; Bicknase is deciding whether to pursue an academic track or work in industry. Either way, they'll be prepared, Furtak said, because understanding fundamental principles of nature helps physicists explore new frontiers.

"Physicists are really good at that, whether it's exploring black holes or black paint," he said.


Connecting the

Pine Beetle Dots

Forests across the Mountain West have gone orange and faded to gray. Since about the turn of the millennium, the mountain pine beetle's appetite for lodgepole pine has killed off some four million acres of trees in Colorado and Wyoming alone. That the larvae of an insect the size of a grain of rice can bring such destruction is in itself a wonder of nature.

The changes go far beyond appearance, and while questions about the effects of so many dead trees on forest fires may be the most obvious, some of the beetles' biggest impacts lie downstream. Pine beetles are shrinking the snowpack, hastening runoff and parching summer soil. The bugs have affected everything from the molecular habits of soil metals to the makeup of soil microbes. They have changed the chemistry of forest earth and increased the loads of carcinogens flowing through water treatment plants.

It's more than a provincial concern of cabin dwellers and ski condo owners. Mountain runoff into the Colorado and Platte rivers alone sustains 30 million people and 1.8 million acres of irrigated farmland. With a warming climate, the deep freezes that once killed off pine beetles will be fewer, threatening more frequent, longer lasting epidemics affecting the region in ways science is only beginning to grasp. But science will soon catch up. A Mines-led team of hydrologists, microbiologists, geochemists, numerical modelers and social scientists is sharpening the picture of pine beetle impacts below a given dead tree and connecting how those changes trickle out to watersheds and the people who depend on them.

A five-year, $3 million National Science Foundation grant and $375,000 in Colorado state matching funds are fueling the effort. Mines Associate Professor Reed Maxwell, who specializes in hydrological modeling, serves as principal investigator. His Mines office is big and sparse. Its notable features include a high-end road bike outfitted with commuter lights, a wall clock whose arms at noon point to the cube root of 1728, and a 28-square-foot whiteboard, mostly empty on this day.

"The water quality in, say, Lake Granby has a lot to do with a watershed area that's heavily beetle impacted," Maxwell said. "We want to move from tree to plot to hillslope to watershed scale. That's one of the big tasks in our grant, and we're developing the models from scratch. They aren't really out there."

There are plenty of hypotheses, supported — but also contradicted — by a growing number of studies. Combined, the story goes something like this: Pine beetles kill trees, which drop their needles and load the soil with carbon as they break down. Their denuded branches let more snow into the ground, but they also stop less sunlight and block less wind, accelerating melting and runoff. The water moves through the hillslope and watershed faster. That influences how fast it reacts chemically, which in turn affects carbon balance, metal absorption and microbial makeup. At larger scales, the flow paths and speeds of rivulets, creeks and rivers change, too. The sum of the impacts shifts water quality, quantity and timing to new equilibriums, Maxwell said.

But no one knows for sure, which is why the team of eight faculty, eight graduate students and two postdoctoral researchers from Mines and Colorado State University has much to do.

If recent studies are any indication, the pine beetle plot will have many twists. Mines hydrological engineering PhD student Kristin Mikkelson spent three summers doing field work in Pennsylvania Gulch near Breckenridge and Keystone Gulch, where she focused on testing surface waters for copper and zinc. Dissolved organic carbon, more abundant with all the fallen pine needles, latches onto metals and keeps them mobile, boosting their soil concentrations and, one would think, the volume of metals flowing in surface waters. But while soil concentrations of metals have indeed been higher, Mikkelson said, "we're not seeing it in the surface water."

Another curiosity relates to municipal water quality. In a separate Mikkelson-led study, published in *Nature Climate Change* in October 2012, she and Mines colleagues reported that higher concentrations of organic carbon from pine needle pulses react with chlorine-based disinfectants

KRISTIN MIKKELSON

in water treatment plants and produce more carcinogenic disinfectant byproducts. The study compared water treatment plants in five pine-beetle-impacted watersheds with four controls and linked increases in disinfectant byproducts with the degree of pine beetle infestation. The surprise, Mikkelson said, was that one class of disinfectant byproducts, known as trihalomethanes, spiked while others, haloacetic acids, didn't.

"When we saw the jump in only the one, it was clear that the pine beetle epidemic is not only changing the amount of organic carbon, but also its composition," she said.

Mikkelson is following up with experiments in which she percolates artificial rainwater presoaked with brown pine needles through columns of soil. "We're measuring how that organic carbon is changing as it goes through the columns — what parts are partitioning and absorbing into the soil and which metals they're grabbing."

That effort complements Mines hydrology PhD student Lindsay Bearup's work. In a Berthoud Hall lab, Bearup pulled a one-gallon Ziploc® bag from a refrigerator. Its dirt would find its way into jars, and then vials.

"I have jars and jars of dirt — really exciting!" she joked.

Bearup had collected it from a site north of Bear Lake in Rocky Mountain National Park. After hiking the eight miles in, she filled bags of dirt beneath trees in various states of beetle impact — some green and untouched, some orange, some gray. In the lab, she put single grams of soil into 50 milliliter falcon tubes and added chemicals to determine how organic fractions differed and what metals were present. This information, combined with water captured in a rain gauge (to determine precipitation volume and stable isotopes) and other data, may help explain the surface water metal mystery, among other things.

"I'm looking at where metals are associated with soils," she said. "It's interesting because organic matter is changing as trees die."

Those changes probably affect the microbial communities in forest soils, added Jonathan Sharp, a Mines assistant professor who focuses on the intersection of microbiology, geology and hydrology. With the pine beetle work, Sharp is guiding graduate students as they work to determine microbial makeup in soil based on DNA analysis. The theory is that, as trees die, microbial ecosystems face a pulse of needles and lifeless root systems and will evolve accordingly. That, in turn, could ultimately affect the transport of metals and water quality.

"We're trying to look from the millimeter scale all the way up to the watershed," Sharp said.

Maxwell's modeling work will incorporate the team's fieldwork, as well as data from partners at the U.S. Geological Survey and the University of Colorado, to bridge these scales. One aim is to put new information in the hands of water managers and policymakers. Part of the project, Maxwell said, will involve partnering with water municipalities in Colorado and southern Nevada to help them understand how pine beetles may be affecting the quality of their inflows and how they might adjust their water treatment regimes.

"We're seeing real water quality changes," Maxwell said. "At best, this is going to mean an increase in water bills."

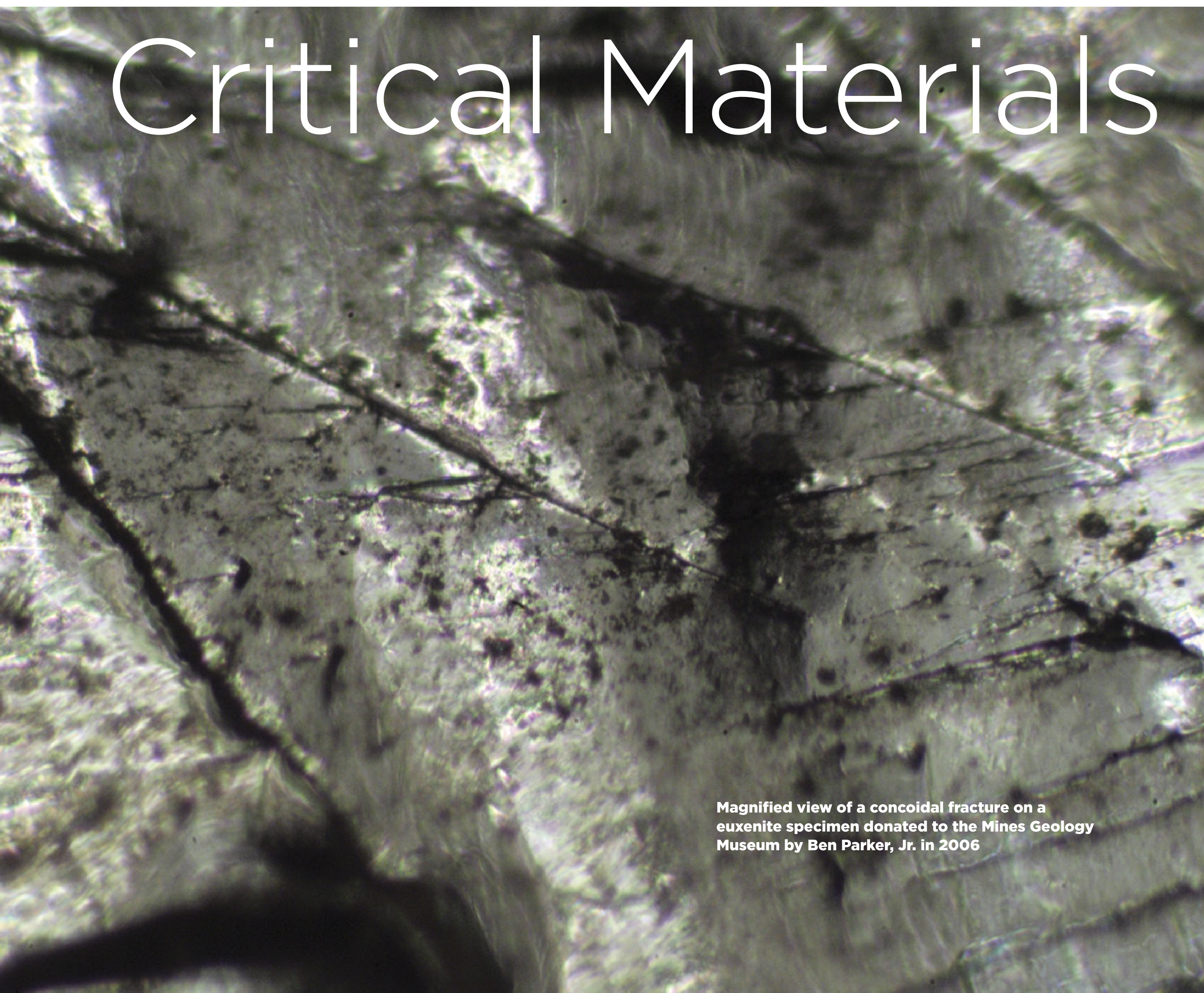
John McCray, a co-investigator and director of Mines' Environmental Science and Engineering Division, said the project's combination of field work, chemical and DNA analysis, and computer modeling could help answer questions well beyond those posed by the pine beetle.

"The processes we're looking at really have to do with any sort of change in mountain and forest hydrology," McCray said. "Those could be changes due to fire, development or climate change."

It's good that the work's happening now, he added. "Pine beetles appear to have significant effects on hydrology and water quality, and we've only had a limited window in which to study this."

Indispensable to Modern Life and Precarious in Supply:

Critical Materials



Magnified view of a concoidal fracture on a euxenite specimen donated to the Mines Geology Museum by Ben Parker, Jr. in 2006

MATT ESQUIBEL

Matt Esquibel held a jagged plate of glass in his gloved hands. A white coating had been scraped off like frost from a winter windshield. But this was no windshield, and that wasn't frost.

Esquibel, a master's student at Mines, had spent the better part of two years working on ways to recycle this white coating and other materials from the glass of flat-panel displays. The coating consisted of many thousands of phosphors that glowed red, green or blue depending on a xenon haze's transmission of electric micropulses. The piece of glass Esquibel held had once been the business end of a plasma TV.

The phosphors earned their name from their behavior rather than their chemistry. They glowed thanks to the combination of rare earth elements gadolinium, europium, terbium and yttrium. These and the 13 other rare earths count among a loose classification of substances known as critical materials, so named because they are both indispensable to the tools of modernity and precarious in supply.

Take yttrium as an example. In addition to its use in flat-screen TVs, it's an indispensable component of medical, industrial and scientific lasers as well as temperature sensors and certain fluorescent lights. No yttrium was mined in the United States as of 2011; three quarters of U.S. yttrium imports came from one country — China. Its price has been unstable, leaping from $16 per kilogram in 2008 to $169 in 2011 before plunging back to $36 in 2012. And that's cheap compared to europium and terbium, which ran $1,550 and $2,050 per kilogram at the end of 2012.

The challenges associated with critical materials span basic science, process engineering and geopolitics. Mines has long been established as a research leader in mineral extraction, processing and recovery. Less well-known has been its expertise in the political and economic aspects of mining. With the announcement of Mines' central role in the U.S. Department of Energy's new Critical Materials Institute, the word is out.

The institute, which launches this summer under a five-year grant of up to $120 million, seeks to:

- diversify supplies of critical materials through innovations in process engineering that facilitate opening up new sources as well as improving the processing of existing ores
- develop critical material substitutes
- improve reuse and recycling
- establish an infrastructure for assessing the economic, political, environmental and social aspects of critical materials-related issues

It's a big effort, involving four DOE labs, seven universities and research institutions, and seven companies as diverse as General Electric and Molycorp. Mines has been a key player from the start, says Alex King, PhD, who leads the DOE's Ames Laboratory as well as the Critical Materials Institute, which will be managed at Ames.

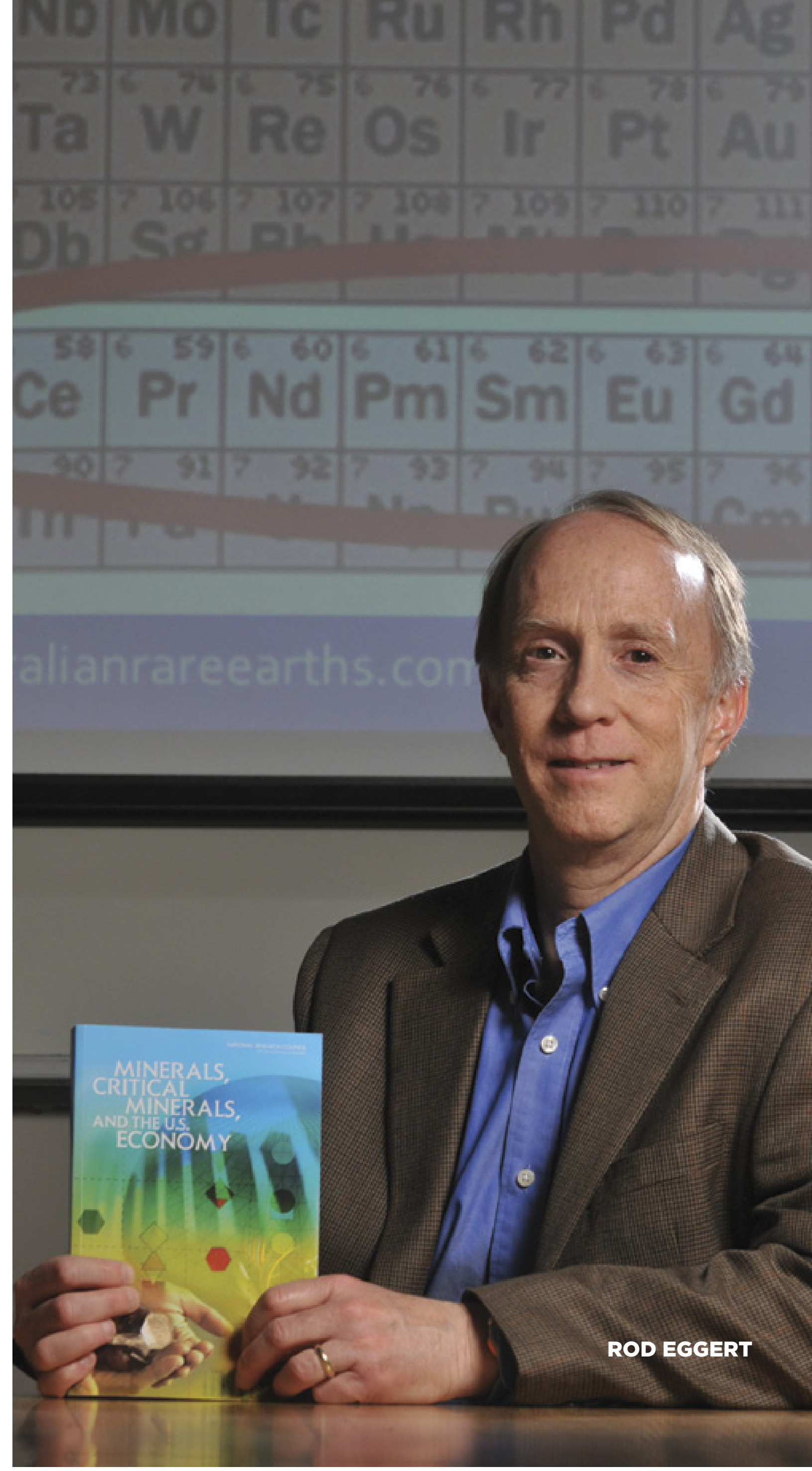
"Mines was the first partner we started working with on this," King said. "They bring just enormous strengths in extractive processes, and Rod Eggert brings a completely unique piece in terms of the economic analysis, which is really essential to what we do."

Eggert, a Mines mineral economist since 1986 and director of the school's Division of Economics and Business, serves as the deputy director of the Critical Materials Institute. Eggert has established himself as one of the world's leading thinkers in critical materials. He has testified on the topic before the U.S. Congress and the European Parliament, and chaired the National Research Council's Committee on Critical Mineral Impacts on the U.S. Economy. The committee's 2008 report helped raise awareness of the issue in Washington, D.C., and beyond, and it served as an intellectual pillar of what would become the Critical Materials Institute.

Eggert's expertise has been vital in helping define the goals and strategic direction of the institute, King said. Critical materials are a diverse lot, from lithium destined for batteries to rhenium destined for jet-engine superalloys. Smoothing U.S.-Bolivia relations may help the lithium supply, but bringing more rhenium to bear might have more to do with boosting extraction yields, developing recycling techniques, improving manufacturing efficiency, or researching potential substitutes. It just depends, Eggert said. The target is always moving, too, he added.

"The elements of concern evolve and change over time," Eggert said, as new materials evolve and companies seek to substitute, cut back on or find new supply sources for materials that put their supply chains at risk.

In addition to helping shape and lead the Critical Materials Institute's direction, Eggert said he will direct the institute's work to "monitor criticality and produce forward-looking economic and technical assessments of what might become the supply risks of the future, both aimed at managing technical risks and avoiding problems before they occur."



ROD EGGERT

Still, Eggert said, the majority of the roughly $14 million Mines will receive over five years will go to nuts-and-bolts science and engineering work of the sort Esquibel was doing with old plasma TVs. Mines professors Brajendra Mishra, Corby Anderson and Patrick Taylor will focus on extractive metallurgy from ores and resource recovery from used hardware such as hard drive magnets. The work at Mines will extend to materials-characterization efforts led by professors John Speer and Michael Kaufman; environmental sustainability work under the direction of Doug Way; and education, training and outreach behind professors Nigel Middleton and Barry Martin.

Taylor, who leads Mines' Kroll Institute for Extractive Metallurgy, says the new grant will more than double Mines' scale in extractive metallurgy and resource recovery, enabling perhaps 10 new master's and PhD student positions and one or two postdoctoral researchers — not to mention $1 million in new equipment such as an inductively coupled mass spectrometer and a wet high-intensity magnetic separator, among other hardware and software.

From Taylor's perspective, the Critical Materials Institute combines the best of basic and applied research, with DOE's Ames Laboratory applying expertise in the fundamental science of critical materials and Mines complementing that with applied research directly applicable to industry. He said industry both within and outside of the institute is taking note. The combination of new funding and more sharp minds focusing on these issues, Taylor said, "has attracted interest in the rare earth/critical materials industry and the mining industry in general."

The institute will benefit from a range of ongoing work at Mines. Eggert and graduate students' efforts to assess future uranium supply for Idaho National Laboratory and that of gallium, indium and tellurium (all photovoltaic panel inputs) for the National Renewable Energy Laboratory have laid important groundwork, he said. On the extraction and recovery side, Esquibel is far from alone in his work on resource extraction and recovery.

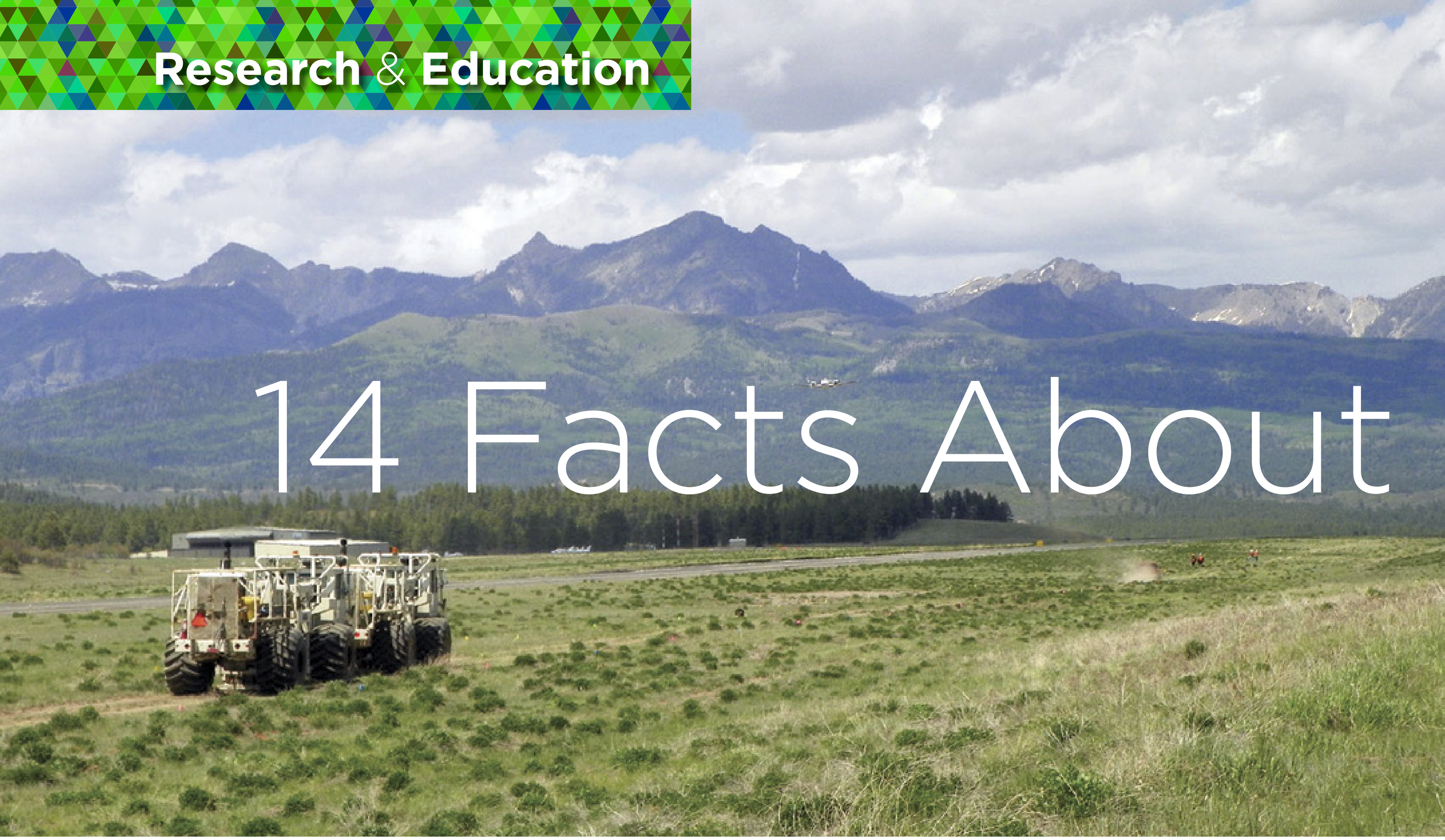
In a Hill Hall hydroelectric laboratory, Mines PhD student Caelen Anderson is investigating the surface chemistry of rare earths using a video microscope connected to a device that measures the charge on particles swimming through distilled water. What does this have to do with mining? Froth flotation enables the extraction of valuable materials from low-grade ores. Flotation depends on understanding mineral particles' electric charge and surface chemistry, which depends not only on a material's fundamental properties, but also on the size and shapes of the particles it's ground into for processing. As Mines Professor Corby Anderson — also Caelen's dad — explained, it enables ores with just 0.2 percent copper content to be mined profitably.

"Without flotation, we wouldn't be able to effectively mine and treat maybe 30 percent of the copper we use in our lights, wires, cell phones and computers," he said.

Master's student James Wright is investigating how to recycle rare earths such as neodymium from computer hard drives and even the motors of Chevy Volts. His work focuses on how one might economically shred, dissolve, melt or otherwise recover and reconstitute critical materials in magnets. Taylor serves as his advisor, but he'll sink or swim on his own, Wright said.

"There are so many different options," he said. "I'm going to try to take a few steps in the direction of each one to see which looks most promising."

And so it will be with the Critical Materials Institute. The institute's steps, its creators hope, will be large enough to clear critical materials hurdles that might otherwise trip up economically vital American industries.



14 Facts About

1 FIELD CAMP ISN'T FOR MINES STUDENTS ONLY.

Thirty students from Imperial College, London, joined 30 Mines geophysics students for field camp in 2012. Together they collected data with the goal of characterizing the geothermal system of the Pagosa Springs, Colo., area. "And every year, it seems, we get 'strays' — one or two students from other schools," said Geophysics Department Head Terry Young. A student from RMIT University in Melbourne, Australia, also participated in the 2012 field camp.

2 IT'S A FOUR-WEEK PROGRAM.

The first half of the session is held in the field and the second half on the Mines campus, where students process and interpret data for a final presentation.

3 ORDINARY CAMPERS DON'T PACK LIKE THIS.

Students at the Pagosa Springs study site needed equipment for geophysical methods such as deep and shallow seismic, gravity, electromagnetics, self-potential, resistivity and ground-penetrating

radar to collect data. The department owns "the doghouse," the trailer that houses the seismic recording system. Brian Passerella, lab and field coordinator, manages all of the department's survey and radio equipment and keeps it in operating condition. It's a full-time job. Equipment for the 2012 camp filled a 20-foot long moving truck from bottom to top.

4 IT'S HELD DURING SUMMER VACATION.

Summer field camps are a longstanding tradition at Mines. But vacation? "Students get up early and stay up late," said Young. "From daylight until dinner they're working in the

Geophysics Field Camp

CG-5 Gravimeter

Pagosa Springs geothermal map

field. After dinner they're working with instruments and getting a first look at data." In addition, they're all thrust into leadership roles, taking turns being responsible as "site boss" for the project.

5 ALL UNDERGRADUATE STUDENTS ATTEND FIELD CAMP, A REQUIRED COURSE, THE SUMMER BEFORE THEIR SENIOR YEAR.

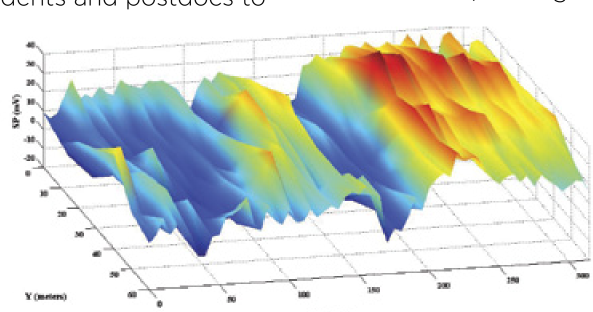
"By then they have a firm educational foundation," said Young. "With this hands-on application in a real world setting, everything clicks into place."

6 GRADUATE STUDENTS ALSO ATTEND.

The Imperial College attendees last summer were primarily master's students. Mines grad students also attend camp if they've had no previous field experience. Mines Geophysics Professor Andre Revil brought grad students and postdocs to camp, where they had a vested interest in gathering data that would help solve their research questions.

7 THE DATA IS IMPORTANT TO MANY.

"I love seeing how energized students get when they realize they're making a difference to communities," Young said. "They really want to make an impact." A good example is the data that Mines researchers made available to residents of Pagosa Springs, who are interested in using geothermal energy to heat their business district, in addition to starting a geothermal greenhouse project and educating their community — especially their students — about geothermal energy. Field camp is returning there this summer to continue studying the geothermal potential of the area. In years past, students have applied geophysical techniques to determine the presence of oil and gas



Representation of SP data at the Warm Springs Site made in MatLab in different areas, or the presence of water in other areas — matters of critical importance to those communities.

8 SAFETY COMES FIRST.

To get acquainted with one another and also to reinforce safety protocols, Mines and Imperial College students held a Geophysics Olympics on campus before departing for Pagosa Springs. "Once in the field, we always start with geology," explained Young. "What are we working with? What can we appreciate from the surface?"

9 MICHAEL BATZLE LEADS THE CAMP.

Young said Batzle, the Geophysics Department's Baker Hughes Chair, "has a unique, natural ability for relating to local ranchers and farmers." Batzle has led the camp for the last six years. "His style opens doors," added Young. "He organizes town hall meetings for locals to hear what and how we're doing." During the 2012 camp Batzle and Revil were interviewed by the local radio station to provide information to residents about the field camp's activities and objectives. Faculty and staff also find opportunities for field camp students to learn about the local culture, geology and history. The 2012 camp agenda included a visit to Chimney Rock National Monument and the Southern Ute Cultural Museum.


Cesium Magnetometer

10 DAWN UMPLEBY MAKES IT POSSIBLE.

"Logistics are an enormous task," noted Young. "Dawn is on site for field camp now instead of handling details from a distance." Program Assistant Umpleby also organizes Science, Technology, Engineering and Mathematics (STEM) outreach for the department by arranging for graduate students to visit area schools and talk with young students — the future workforce. Some visit the work site and get a hands-on lesson about geophysics.


GPS (global positioning system)

11 OTHERS HELP MAKE THE COURSE EXTRAORDINARY.

Many contribute to the experience. For instance, Bob Raynolds, a consulting geologist and research associate with the Denver Museum of Nature and Science, gave a roadside tour on the way to Pagosa Springs that provided context and set a framework for the historic geology of the area. Included in the tour were stops at an alligator

and tilapia farm — only possible in Colorado because of natural thermal heating in the region. In addition, Mines alumni and supporters are often camp visitors, as Jim Payne '59 and Bob Albers were last summer. Industry, too, plays a major role. A great example is CGG, the Paris-based geophysical service company that provides vibroseis trucks and equipment for deep seismic exploration, and its subsidiary, Sercel, which donates a seismic recording system, complete with an expert to work with the system and teach students how to operate it. Mines faculty also collaborate with the U.S. Geological Survey and the Bureau of Reclamation on each summer's location and research pursuit, and often their representatives visit the camp.

12 FORGET ABOUT THE STARVING CAMPER STEREOTYPE.

There's always a barbecue and always the generosity of Mines supporters. For instance, a few years ago the camp traveled to the Estancia Basin east of Albuquerque, N.M., to examine the region for water sources. Vern Woods hosted the entire group on his ranch — with faculty members sleeping in a barn loft. Woods procured a huge barbecue and a smoker, which were used to feed the whole group breakfast and dinner, with lunch supplies also provided daily.

13 IN THE END, SHARING IS THE MOST IMPORTANT SUMMER CAMP LESSON.

"In the past eight years or so, our field camps have taken on a strong research flavor," said Young. At the end of their two-week data analysis back on campus, students publish their work and give a final presentation of their findings. Often clients attend. "This past summer we had a large delegation from Pagosa Springs," said Young. Government agencies — from the Department of Energy, an important sponsor, to the Colorado governor's office — also benefitted from the geothermal study results. "We supply data for free to anyone who wants it," noted Young.

14 IT'S NEVER FORGOTTEN.

"When we conduct exit interviews with our graduating seniors, field camp almost always comes up as a highlight of their years at Mines," said Young. And years and decades later, alumni are still talking about it.

A MESSAGE FROM

ROBERT J. BIRGENEAU

Chancellor of the University of California, Berkeley

Achieving Transformative Advances for Society

Public Research and Teaching Universities

Near the end of World War II, in a study entitled "The Endless Frontier," Vannevar Bush, the true progenitor of the modern research and teaching university, stated that "new products and new processes do not appear full-grown. They are founded on new principles and new conceptions which in turn are painstakingly developed by research in the purest realms of science." With that historic statement, Vannevar Bush provided the rationale for large scale investment by governments in basic research in universities and the concomitant responsibilities that this implied. What followed was decades of accelerated government investment in U.S. research universities and in basic science.

Today ominous clouds threaten this enlightened vision of the research university. The sequester cuts that reduce federal research funding for the next 10 years will seriously impede scientific discovery and innovation. Public research and teaching universities, traditionally reliant on state funding to support their operations, are doubly challenged because of progressive disinvestments by their states. This is particularly true in my state of California and even more so in Colorado.

Research universities are the primary institutions in which basic research, driven by scientific interest irrespective of possible applications, takes place. In particular, the great industrial laboratories such as Bell Labs, IBM Research and Xerox Parc have passed or greatly faded and the national laboratories are progressively more focused on applications. Thus, universities are now the principal institutions that have long enough time horizons to allow researchers to do the kind of research that is revolutionary, rather than evolutionary.

One of my favorite examples to illustrate this point is the Global Positioning System (GPS). The GPS was made possible by the development of atomic clocks, which were first proposed in 1944 by physicist I.I. Rabi. In the 1950s physicists Norman Ramsey and Daniel Kleppner were carrying out research to test Einstein's theory of General Relativity by measuring the effects of gravity on time. This work, which required phenomenal accuracy in the measurement of time, inspired them to invent the hydrogen maser atomic clock. One cannot imagine research which is more basic.

As Daniel Kleppner has noted, "Without atomic clocks there would be no GPS, though at the time the clocks were conceived nobody dreamt of a satellite-based global navigation system." The GPS also required enormous investment to develop a useful new technology, including satellites, microelectronics, time transfer techniques and modern data processing methods. The new GPS technology was initiated in the 1970s by the Navy and taken over in the 1980s by the Air Force, which developed the GPS into an operational navigational system. Today, as we know, the GPS has passed into civilian use and is inexpensively mass produced with enormous impact and benefit to our lives.

The clear lesson is that to achieve transformative advances for society we must invest in long-term basic science and in new technologies, which in turn can be developed into new industries. All three components are needed.

"We must invest in long-term basic science and in new technologies, which in turn can be developed into new industries."

Basic research is overwhelmingly the responsibility of our nation's research and teaching universities. Our great public research and teaching universities are essential to America's research productivity and to educating the next generation of scientists and engineers who will in turn become the innovators and entrepreneurs who will develop new technologies and create new industries. In my view, to guarantee the continuing excellence of our great public universities we must reexamine the basic model that public education is the sole responsibility of the states. We need to look to tripartite partnerships between the federal government, state governments and the private sector, including business, foundations and individual philanthropy for supporting the operations of our public research universities.

I am now leading the Lincoln Project, an initiative of the American Academy of Arts and Sciences, to address exactly this issue. We hope that out of the Lincoln Project's work will come new paradigms for the support of our nation's great public research and teaching universities. The future of our nation and our ability to innovate, create jobs and support a strong economy rests on the health of our research and teaching universities with the public institutions having the additional responsibility of educating a huge fraction of the nation's future scientists and engineers drawn from the population quite broadly. America's competitive advantage in the global economy depends upon their success.

ROBERT J. BIRGENEAU

Robert J. Birgeneau has served as chancellor of the University of California, Berkeley, since 2004. On June 1, 2013, he will step down as chancellor and return to conducting his research in physics. He will also lead the Lincoln Project, an initiative of the American Academy of Arts and Sciences, to advocate for the importance of public colleges and universities as key engines of economic growth, innovation and upward mobility.

Prior to his years at Berkeley, Birgeneau served as president of the University of Toronto and as dean of the School of Science at the Massachusetts Institute of Technology. He is a fellow of the U.S. National Academy of Sciences, the Royal Society of London, the American Philosophical Society and the American Academy of Arts and Sciences.

Birgeneau delivered the keynote address at the December 2007 Mines commencement ceremony and was awarded an honorary degree from the university.

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