It's About Societal Impact

Engineering and Applied Science at Caltech

"We are looking at lifelong education because it is not just about what happens while they are at Caltech, but what happens after they leave."

Mani Chandy, *Simon Ramo Professor and Professor of Computer Science; Deputy Chair for Education*

Societal impact is a glue that binds the seven Departments of the Caltech Division of Engineering and Applied Science (EAS). In the words of the Deputy Chair for Education, Professor Mani Chandy, "Societal impact is a driving force for an engineer and applied scientist. Applying fundamental science to societal problems is a key characteristic of our Division." To better understand how this approach to research and education is created and strengthened, *ENGenious* met with the leaders of the seven academic Departments.

Greater Impact Through Collaboration

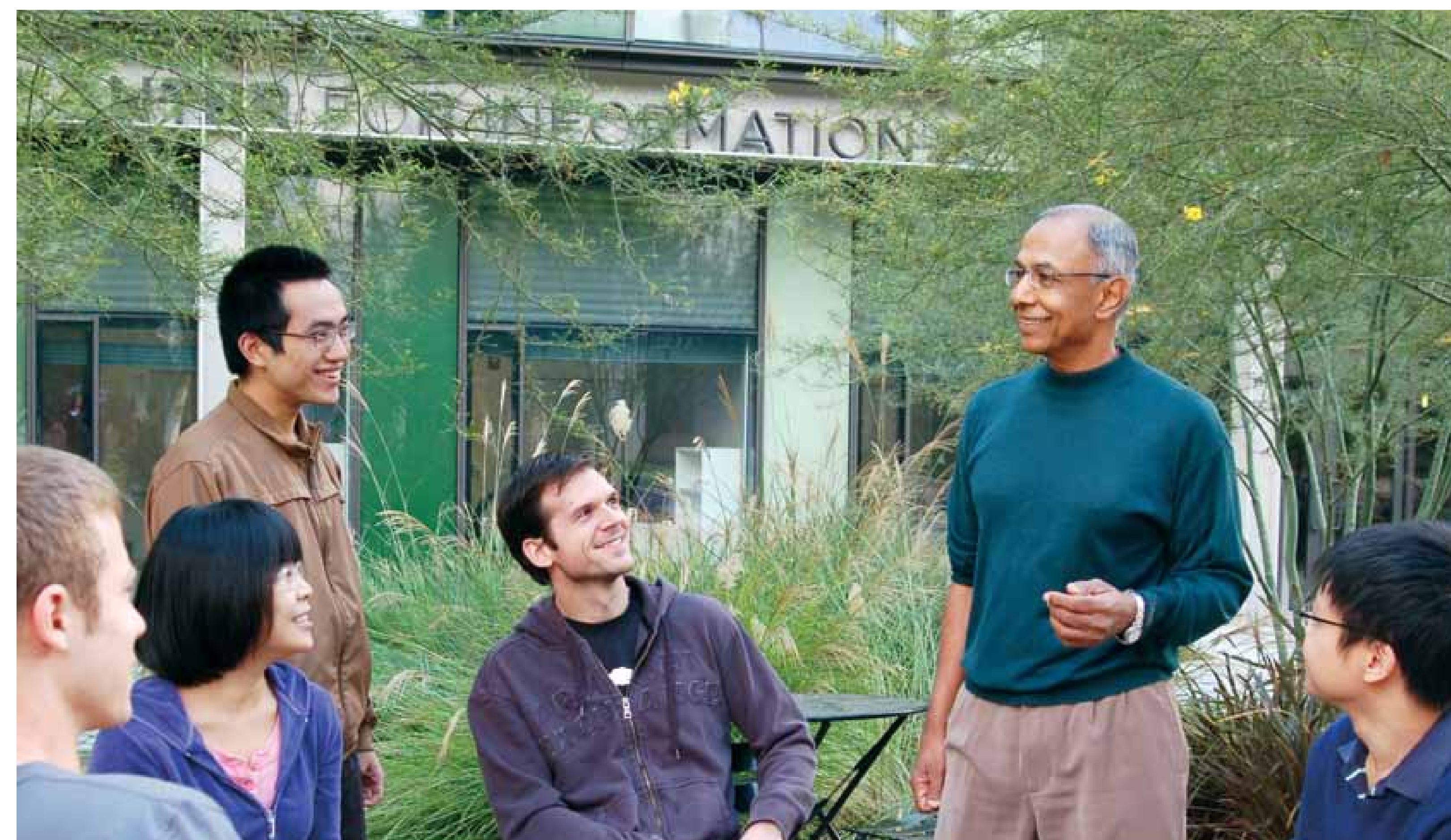
Collaboration is central to the EAS approach of transforming basic sciences into societal impact. At the most macro level, this collaboration occurs through cross-divisional centers focusing on a variety of areas, including natural hazards, quantum entanglement, energy, bioinspired engineering, and information technology. In the next level of collaboration, Departments within EAS join forces. For example, the Departments of Computing and Mathematical Sciences (CMS) and Electrical Engineering (EE) have come together to support the efforts of Information Science and Technology (IST) to benefit science, medicine, and society. In particular, notes Professor Mathieu Desbrun, Director of CMS and IST, "researchers from the core IST constituents of EE and CMS are together tackling a range of societal problems, from the design of prostheses and cornea implants all the way to green IT."

The CMS Department, Professor Desbrun notes, has brought together researchers from three different disciplines. "Scientifically speaking," he says, "the fact that we are mixing dynamical systems, computer science, and applied mathematics gives us a huge playground to play in. For instance, we have collaborations with NASA for coordination of satellites, and we have projects in biomedicine for treatment of diseases, so the mix has extreme leverage. Research-wise, we have plenty to do for the next few years."

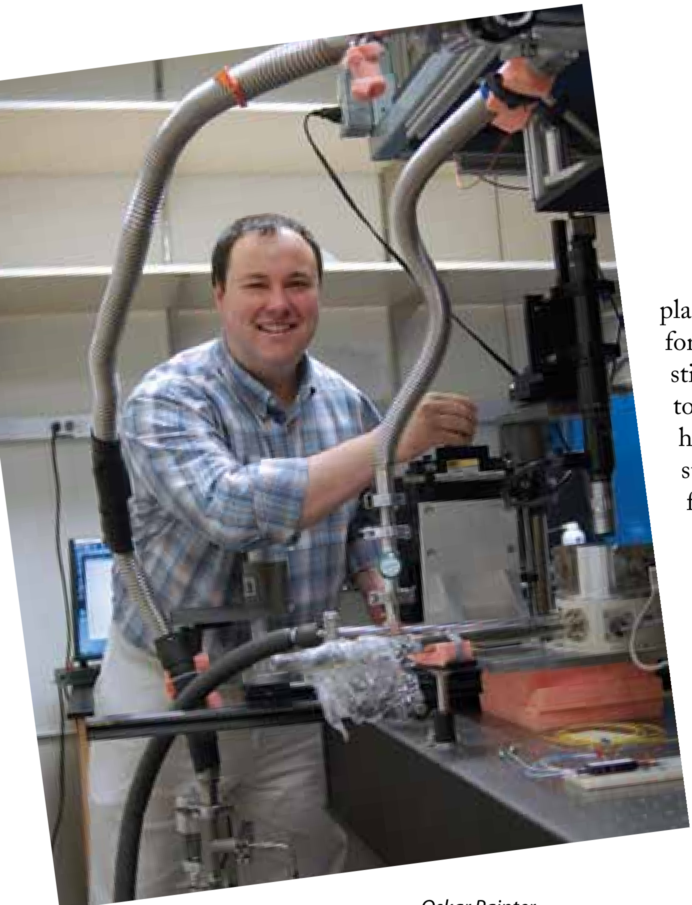
The recent re-engineering of the EAS Division has also had a positive impact on the Applied Physics and Materials Science Department, explains Professor Oskar Painter (MS, '95), who is Executive Officer. "Some of the restructuring we've done has allowed us to speak in a more coherent, more unified voice to our Division and in turn to the greater Institute and community," he says. "Combining Applied Physics and Materials Science into a Department has broadened us intellectually and has broadened our perspective of research and teaching, which has great benefit for the faculty and students."

Professor Babak Hassibi, Executive Officer for Electrical Engineering and Associate Director of IST, echoes this take on the benefits of collaboration as they relate to teaching and learning. "I see the 21st century as an opportunity for the disciplines that have become highly specialized to begin to talk with one another. A lot of exciting research happens on the boundaries," Hassibi says. "For example, the areas of intercellular signaling, signal processing, and communication have been something that EE researchers have worked on for a long time. They can bring a lot to the table when collaborating with biologists. The EE students are open to this mode of thinking, and every year we have more undergraduates who double-major in areas that would not have been associated in the past, such as EE and biology or EE and economics. The potential societal impacts of these new ways of thinking are boundless."

The Aerospace Department has a long history of redefining boundaries through collaboration. For example, Professor Guruswami Ravichandran, who leads the Department, is working with Professor David A. Tirrell in Chemistry and Chemical Engineering to understand how cells interact with extracellular matrix in a 3-D environment. In another project, his group is exploring the mechanics of cell scattering that leads to metastasis, one of the most dangerous phases of cancer. "We are using a model cell cluster, which is our substrate, and a technique called digital volume correlation, which is a mechanics technique, to measure the displacements that are caused by cells when they are scattering," he explains. From the dis-



Mani Chandy with EAS students



Oskar Painter

We are the people who live on the border between engineering and fundamental science, and we are the people who are able to transition the new science into technologies that really impact us, so you're investing in your own future!

Oskar Painter, *Professor of Applied Physics; Executive Officer for Applied Physics and Materials Science*

placements, we can understand the forces and how the increase in the stiffness of the surroundings leads to cell scattering. Such studies are helping in advancing our understanding of the role of mechanical forces in cellular processes."

This blossoming marriage of engineering and biology is further described by Niles Pierce, Professor of Applied and Computational Mathematics and Bioengineering, and Executive Officer of the Bioengineering (BE) Department: "The field of bioengineering will revolutionize medicine, renewable energy, global health, and manufacturing over the coming decades. The potential is so vast that it's a very enjoyable time to dream about what might be achieved. By taking a principles-based approach, we are positioned to play a profound role as biological principles enter the engineering arena."

From Fundamental Science to Impact

The importance of fundamental science to address the greatest challenges faced by society is described by Tapio Schneider, the Executive Officer of the Environmental Science and Engineering Department: "With a background in physics and math, I was looking for a field in which there are unresolved fundamental science questions whose resolution is important for our day-to-day lives. The climate sciences are such a field; resolving its fundamental questions is clearly relevant for understanding our past and planning our future." Professor Ravichandran further explains that "we are not here only to educate engineers and scientists to work on today's systems, but to create the systems of tomorrow. We believe that in order to achieve that, students need to have very strong fundamentals and truly understand the principles underlying the operations of engines, rockets, fluids, structures, and materials."

In the area of mechanical and civil engineering, fundamental science is seen as a key to developing technologies that enable and improve society. "I see a range of technologies being developed in our Department that have the potential to improve society," Professor Kaushik Bhattacharya says. "One of the more important issues is energy. Thus the research of all three of our recent faculty hires has an energy side. We are also working on a variety of biomechanical and biological engineering issues. Finally, we have a huge opportunity and a huge challenge in bringing rather fundamental principles of multiscale models into larger scale engineering—such as on the scale of earthquakes and geotechnical engineering and predicting these behaviors from small scales and fundamental principles."

Professor Schneider goes on to make a key point about how science can impact societal decisions: "What we can deliver for society at large is solid scientific understanding of how our Earth environment works and how it responds as humans interfere with it. Solid and unbiased science is what we can deliver and should deliver. We are not interested in becoming embroiled in political controversy, and none of us are. Our focus is on gaining clear insights into natural processes and human effects on them, to provide a basis for making decisions, for example, about which policies are effective and efficient to improve air quality."

To gain this clear knowledge needed to impact the future, Professor Painter appeals to the alumni to "invest dollars, invest time, invest thought. We are the people who live on the border between engineering and fundamental science, and we are the people who are able to transition the new science into technologies that really impact us, so you're investing in your own future!"

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Babak Hassibi, *Professor of Electrical Engineering and Executive Officer for Electrical Engineering, and Associate Director of Information Science and Technology*

Lifelong Education and Impact

As illustrated by the work of the seven academic Departments of the EAS Division, societal impact starts with an emphasis on education. "We want to ensure that anyone who touches the EAS Division accentuates and enhances his or her skills in lifelong education," says Professor Chandy. "We are looking at lifelong education because it is not just about what happens while they are at Caltech, but what happens after they leave. Students are only here for four years as undergraduates, maybe

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Mathieu Desbrun

five years for graduates, two years for postdocs. These are short periods of time. They've got a thirty- to forty-year career ahead of them. We need to help ensure that they perform superbly at every stage in their life!" He adds, "The Division's commitment to lifelong learning is evident in the increasing importance of the Center for Technology Management and Education."

Professor Ravichandran describes how this approach to education is implemented in the Aerospace Department: "Our students are trained in the broad disciplines of fluid mechanics, solid and structural mechanics, and materials and propulsion in aerospace systems and in space engineering, so that they are well prepared to work not only on problems that are of interest today but also the unknown problems of the future. To continue the preeminence of the United States in aerospace," he adds, "I think it's a good idea to invest in the young people who represent the future of this field. We need to have graduates who are well equipped and trained not only to solve problems but also to develop more efficient systems

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> G. Ravichandran, *John E. Goode, Jr., Professor of Aerospace and Professor of Mechanical Engineering; Director, Graduate Aerospace Laboratories*

G. Ravichandran

EAS FEATURE

and spacecraft to explore the unknown. There are many opportunities in space, not only in space exploration, but also in areas such as energy harvesting."

Professor Painter tells his graduate students that it is his job to make sure a PhD degree is more than a graduate school accomplishment for them—it's a mark of a quality scientist. "I think that if you have a dual nature in that you really enjoy tinkering with things like electronics or radios and you also enjoy the mathematics and physics behind such devices, then you should consider Applied Physics and Materials Science. It allows you to live in both worlds. You get to do theoretical work as well as continue to tinker and build new things. You're going to get an education that allows you to be a serious physicist, but also allows you to be an engineer, entrepreneur, and a technologist."

Professor Chandy summarizes the EAS approach to education as a holistic one: "It's not merely about science as an end to itself, but rather success is measured by how the research makes a difference in somebody's life. We tend not to distinguish between theory and application. We don't distinguish between education and research; we expect the best teachers to be excellent researchers and vice versa." Speaking directly to alumni and friends of the Division, he says, "If you care about people individually or you care about society, then you have to be concerned about sustainability, you have to be concerned about disease, you have to be concerned about hazards. If you want to help people in the long term, then invest in science that impacts society. How do you invest in science? By investing in the lifelong learners—today's students who will impact our society for the next 50 years."

Tapio Schneider

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> Tapio Schneider, *Frank J. Gilloon Professor of Environmental Science and Engineering; Director, Ronald and Maxine Linde Center for Global Environmental Science; Executive Officer for Environmental Science and Engineering*

A Long History of Greatness and Impact

The EAS Division has a rich and long history, with several Departments more than a century old. When planning for the future, many of the leaders reflected on the great researchers and educators that came before them and how they are standing on their shoulders. "In many ways, I missed the heyday of Applied Physics," Professor Painter says. "Applied Physics at Caltech was started in the late '70s, so it's not that old, but a lot of important things were done prior to my time and I think it's important for me to learn from the alumni about how things were done back then and figure out ways of maintaining that strength." Professor Ravichandran says, "The Aerospace Department is headed in many ways back to its roots. The Department started in

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Kaushik Bhattacharya, *Howell N. Tyson, Sr., Professor of Mechanics and Professor of Materials Science; Executive Officer for Mechanical and Civil Engineering*

1928 as part of bringing scientific understanding of phenomena which were of interest to the aeronautics industry. At the time, the aeronautics industry in Southern California and in the United States was in its nascent stage. Today we have similar new opportunities in space: the next stage of space exploration, such as a mission to an asteroid or to Mars. To remain a leader in these areas," he says, "we need to develop expertise in flight, materials, propulsion, and systems. To this end, we are also strengthening our connections with the Jet Propulsion Laboratory."

Almost a year after celebrating the centennial of Electrical Engineering at Caltech, the students are still very energized, Professor Hassibi reports. Speaking on behalf of the EE undergraduate students, he shares a need: "At the moment, all the equipment that undergraduate students can use is attributed to either a particular course or a particular research group. If there's an undergraduate that has an idea and wants to build something on their own, they're really on their own. We've tried through the student organization to get some money to fund an undergraduate lab, but to do so they will have to accrue the money over several years. If any of the Caltech alums were interested in funding such a thing, I know the students would greatly appreciate it!"

Kaushik Bhattacharya

The roots of the ESE Department are also quite deep and interdisciplinary, Professor Schneider notes. "The modern study of ice sheets, their mechanical properties and stability to perturbations, started here at Caltech in the 1960s, and for many glaciologists, Caltech is the holy grail. Also, Caltech scientists were the first to discover that lead was accumulating in the environment and in humans, and first figured out how smog forms from tailpipe and industrial emissions. This led to the banning of lead additives in gasoline and to the Clean Air Act and the re-engineering of internal combustion engines. We and our children are breathing much cleaner air because of pioneering environmental research at Caltech."

Taking Risks

The research with the greatest societal impact very often also poses the greatest risk, to both researchers and investors. Professor Schneider explains, "At Caltech, we are in a unique position to deliver a broad, big-picture understanding of environmental systems. Of course there are many people working on similar questions, but many are focused on shorter-term results, such as producing next year's climate projection. We at Caltech can take a step back and ask, 'If we want a much better climate model in ten years, what can we be doing now?'" At Caltech, Schneider notes, "we have the luxury of thinking about approaches that are substantially different from the current mainstream, rather than being merely incremental advances over it. These approaches may have a higher risk of failure, but they also have a much higher potential payoff in the longer run. It helps," he adds, "that we have access to private funds at Caltech, because they help us start radically new projects. Once we can prove the viability of new approaches, it's not so difficult to get other funding. But the initial 'intellectual venture capital' is crucial, and Caltech is uniquely good at providing it."

Such seed grants, Professor Bhattacharya says, have transformational power. "When you do research, you often have a new idea, but it's very new and unconventional. It is at that point that you need a little bit of support. Faculty members will tell you that some of the best work they've done is from these seed projects. The first thing you want to know is: Will that work? And if it works, how good will it be? In that situation, you don't need a very large effort; you need to break the conventional wisdom, and those are the kinds of projects that are the hardest to obtain support for from traditional funding agencies—and those are the kinds of projects that private philanthropy helps us the most with. They also have the highest failure rate because that is the nature of it," he says, "but the ones that succeed have an incredible impact! You are really enabling things that would not have happened otherwise."

"We are not after one-off success," Professor Pierce says. "We are after principles that can underlie a sustained technological revolution over the next three decades. Caltech and EAS are an oasis for research. Tiny and excellent! Because of our small size, we know each other, we talk, we think up ideas together, and we collaborate. Because we are small, we cannot afford to take small risks. We must take big risks. We must identify and tackle the challenges in our fields with the potential for the highest possible impact. It's an exhilarating experience to think and work in this environment." ENG

Learn more about the faculty at eas.caltech.edu/people, and visit eas.caltech.edu/research_centers to learn more about the research centers.

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