McKinsey Global Institute

Bio Revolution

Programming life: An interview with Jennifer Doudna

The co-discoverer of CRISPR-Cas9 speaks with partner Michael Chui about how genetics technology can expand coronavirus testing and what the future holds for the Bio Revolution.

by Michael Chui and Jennifer Doudna

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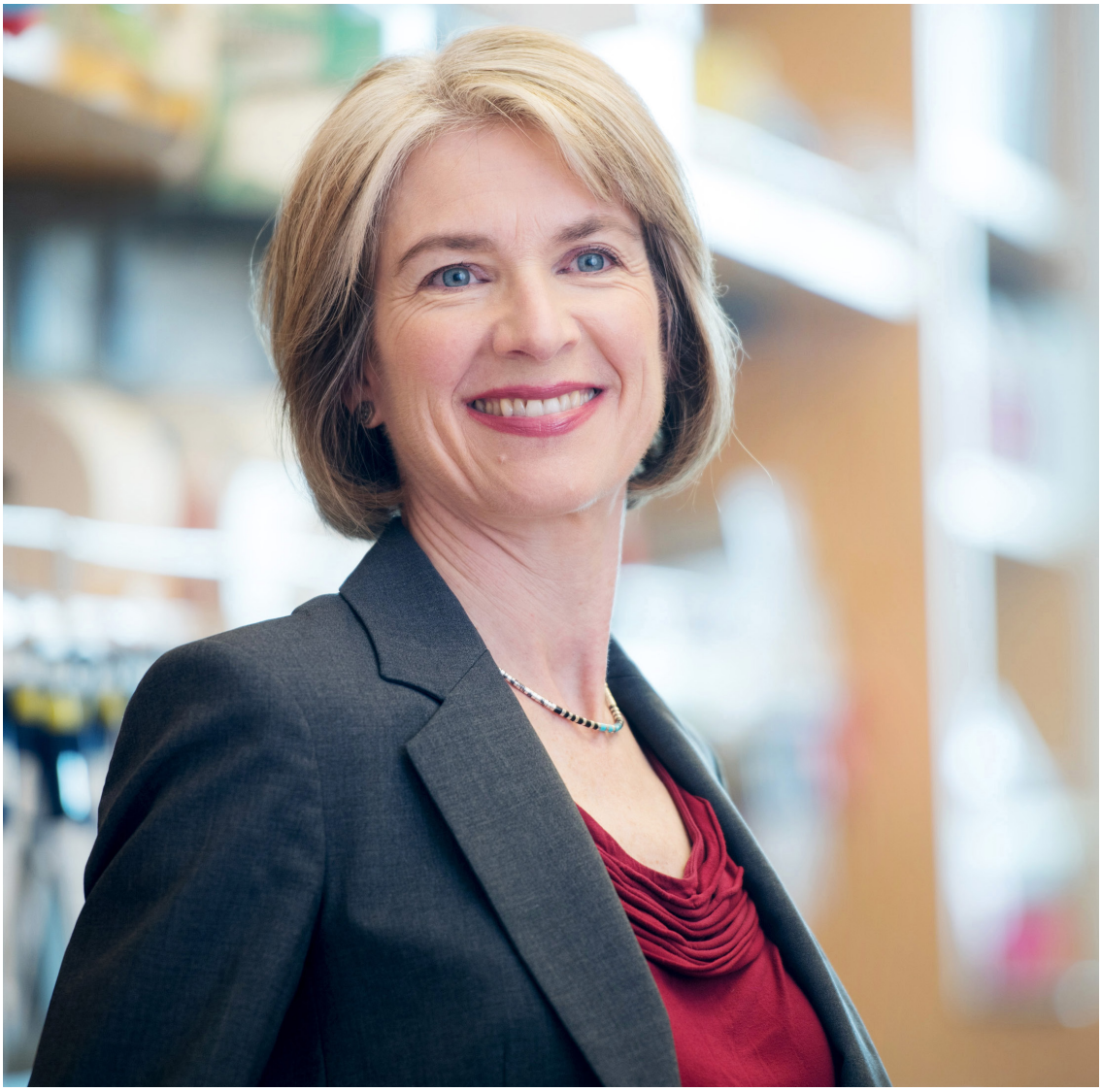
The Bio Revolution has the potential to transform our lives, and genome editing—the ability to change the DNA sequence in a targeted way using CRISPR-Cas9, is one of the key innovations that has sparked imaginations while also raising its fair share of controversy. What is the origin of this technique? How do we weigh the enormous benefits against the potential risks? And what is its role in solving the global coronavirus pandemic?

As part of the McKinsey Global Institute's research on the Bio Revolution, partner Michael Chui spoke with Jennifer Doudna, PhD, one of the scientists who discovered the genome-editing technique CRISPR-Cas9 and leading proponent of its responsible use. Jennifer is a professor of molecular and cell biology and chemistry at the University of California, Berkeley. The Doudna lab pursues a mechanistic understanding of fundamental biological processes involving RNA molecules.

Their conversation has been edited for clarity and legibility.



"Once we knew how the system worked, we could make a very simple way to reprogram the Cas9 protein." (Photo: Barbara Ries/UCSF)

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Transcript

Michael Chui: Jennifer Doudna, thanks for joining us today. We want to cover a lot of different things today. But why don’t we start with where we are today. We’re in a unique biological moment, you might say. We’re recording this in mid-April 2020, and we’re sheltering in place. This is an event that’s affecting everyone. And I’d love to ask you about this. What has the COVID-19 pandemic been like for you?

Jennifer Doudna: Like everyone, it’s a strange moment we’re in right now. It’s an odd experience to be sequestered at home doing what we can, both professionally and personally, to keep our sanity and possibly contribute to mitigating the effects of this disease. It’s a time when many of us are discovering things, or rediscovering things, about ourselves.

I’ll give you an example for myself. I’m an avid gardener but I haven’t had any time to work in my garden for, I don’t know, six or seven years with all the craziness going on with CRISPR and work that I’ve been doing at the university. This past month or so has been an opportunity to reconnect with my garden, my flowers, and rediscover what it means to have a more of a balanced life. That’s the silver lining, I suppose, to this current moment.

Professionally, it’s been an opportunity to pull together with colleagues and ask ourselves, “What can we do as scientists to address this current national and international emergency?” As you may know, we’ve been able to pull a team of scientists and computer specialists together at the Innovative Genomics Institute here in the Bay Area of California, to build a clinical testing lab that is now testing patient samples for the presence of the coronavirus. And in the future, we will also help some local teams to test new types of diagnostics that could eventually provide an at-home test for this and future viruses. It’s been a really extraordinary time in many ways.

What is CRISPR?

Michael Chui: Now, I think a lot of people who are listening probably have watched your TED Talk or, otherwise heard of CRISPR. But if you don’t mind can you explain what that technique is?

Jennifer Doudna: CRISPR is a nice segue from talking about a pandemic caused by a virus, because CRISPR is, in fact, a bacterial immune system. It’s an ancient system that evolved in microbes to allow prevention of viral infection. Our interest in this started with that fundamental biology, asking, “How does this work?” We did a collaborative research project with Emmanuelle Charpentier, a medical microbiologist, and our work with her laboratory revealed that one of the components of this CRISPR immune system is, in fact, a protein that’s called Cas9, that can be programmed to find and cut virus DNA.

Once we figured out how this protein Cas9 functions, the connection that we made was that this activity of the protein could, in fact, be harnessed for a different purpose in human, and plant, and basically any other kind of cell. It could introduce a break in DNA at a desired position in the DNA sequence that would trigger cells to repair the break and at the same time change the DNA sequence in a targeted way. We published this work back in the summer of 2012, and for me, life hasn’t been the same since.

It’s been a wild ride, with many labs quickly recognizing that this was a powerful way to control the genetic material in cells or even in whole organisms, in a way that was never possible previously, and it’s turning into a tool that will be used to solve real-world problems, whether it’s curing genetic diseases, or creating plants that have desired genetic traits. It’s been an extraordinary eight years.

Michael Chui: If I understand you correctly, this was a natural mechanism that existed already within bacteria; you're just repurposing it in order to—what we would say in computer science—"program" life, roughly speaking. Is that right?

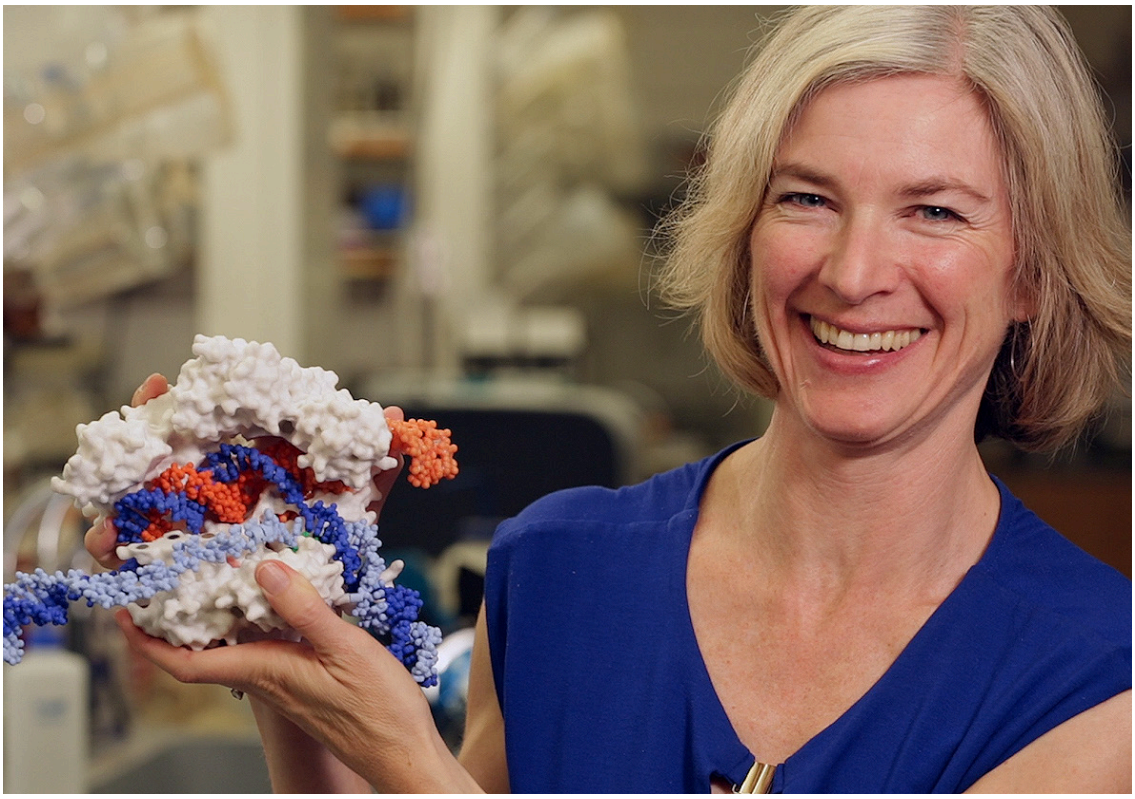
Jennifer Doudna: Definitely. I think that's a fair statement. It's taking a protein that can be targeted to a particular position in the genetic information in a cell and trigger a change. With all of the DNA sequencing that goes on now, we have increasing access to the whole genome sequence—in other words, the entire encyclopedia of genetic information that makes up an organism. If the information in a gene or a handful of genes needs to be changed, this tool, CRISPR, can do that. It's been an extraordinary opportunity for scientists to understand genetics at a much deeper level than was possible previously, and to rewrite the code of life, and rewrite genes in a way that gives us control over cells and organisms, with remarkable outcomes.

How was CRISPR discovered?

Michael Chui: I'd love to ask you about whether there was a eureka moment. I'm curious, how did you get to that point?

Jennifer Doudna: There were a couple of key experiments that were done in the lab. This was a project where there were really four key people involved in this work. It was myself, Emmanuelle Charpentier, a student in her lab, Krzystof Chylinski, and, in my lab, a postdoctoral scholar named Martin Jinek. One day, Martin had done an experiment in the lab that showed that he could program the protein Cas9 to recognize a specific DNA sequence and make a break in the DNA.

As quick reminder, DNA is a double helix. It's like two strands of a rope that wind around each other, and those two strands contain a sequence of letters that provide the code that is required to make a cell or make an entire organism. What Martin had shown was that you could cut that code of life at a particular position by giving a molecular signal to Cas9. You could program it to find a particular place in the DNA



Jennifer Doudna holds a model of CRISPR. "Every now and then there's this incredible joy of figuring something out." (Photo: Keegan Houser/UC Berkeley)

“That’s why we do science, because every now and then there’s this incredible joy of figuring something out...”

and make a break. That was an incredibly exciting observation, but as you can imagine it’s one of those nerdy things that you enjoy in the lab and you think, “Well, a few people on the planet might care about this someday.”

What changed everything was realizing that, once we knew how the system worked, we could make a very simple way to reprogram the Cas9 protein. And when Martin did that experiment, it was the “aha” moment and we looked at each other and said, “Wow, this could be a really great tool, because you can tell it where to go in the code of the cell and trigger a change.”

Michael Chui: Did you say, “Wow?” Did you call somebody? How did it feel when you figured that out? Were you on email with Martin?

Jennifer Doudna: We were in my office and he was sketching his data—a diagram of how we imagined this working, on my whiteboard. We looked at each other and said, “Boy, that’s cool. That could be amazing.”

I went home, and my son was probably about eight or nine years old at the time. And I was cooking dinner in the kitchen and I just suddenly just burst out laughing. My son said, “Why are you laughing, Mom?” And I said, “Because we’re working on this crazy protein and it can find viruses and cut them up.” He didn’t really understand what I was saying so I tried to kind of draw a little sketch of what I was picturing. It looked kind of like a racecar, zipping around the cell, and grabbing onto viruses, and cutting them up. Then pretty soon he was laughing too, and it was one of these joyful moments. I couldn’t help thinking of Richard Feynman. That’s why we do science, because every now and then there’s this incredible joy of figuring something out, and realizing that, I’m maybe the first person on the planet to know this little factoid, and it’s just incredibly fun.

Why CRISPR is a breakthrough

Michael Chui: Science can be truly joyful, right? People think of scientists as these automatons, but there’s great joy in finding things. You mention different applications. At the McKinsey Global Institute we’ve been researching the breadth of potential applications of some of these technologies, including ones that you’ve been instrumental in creating. I’d love to hear from you some exciting applications of CRISPR and other technologies around biology that you see coming down the pike.

Jennifer Doudna: Probably the largest global impact of genome editing, in the next few years, will likely be in agriculture. And the reason is that there’s so much need for engineering plants that will allow introduction of traits to deal with climate change, pests, reduced application of chemical fertilizers and things like that. Having a technology that allows targeted changes to be made to plant genomes is, in fact, very powerful. This is something that we’ve been working on at the Innovative Genomics Institute with our purpose being to identify some of the most urgent needs, where companies are not so likely putting their efforts for various reasons. And where, having a nonprofit focusing on these applications is a good idea. This is both interesting and highlights the ongoing challenges with the technology.

Even though CRISPR works very well for genome editing, and it works very well in plants, I would say there really are two things that hold us back right now. One of them is the technical aspect of getting genome editing molecules into plants efficiently, and figuring out which genes in plants need to be edited. But the other bucket really has much more to do with public acceptance and regulatory pipelines. How do you ensure that governments will allow plants that have been edited to be marketed? That’s being handled differently in different countries which sets up an awkward situation where the same

plant would be considered not genome-modified in one country, and in another country it would be considered genome-modified.

There's a lot of work to be done to educate regulators and the public about what is going on. What does this technology mean? Is it safe, and how do we deploy it in ways that will solve real-world problems?

Ensuring wide access to new biomedical applications

Michael Chui: You have touched on a few things that we looked at in our research as we were trying to understand taking something from the lab into the marketplace. You described how there were a number of scientific challenges in order to do that. Then there's a commercialization challenge that we discovered as well. Sometimes it's just making sure, as you suggested, the regulators will allow you to sell something. But sometimes the difference between creating something at laboratory scale, and as we were talking about in COVID testing, something that's more industrialized and you're really scaling up these challenges. What does it mean to succeed in the marketplace? You have to compete against products and services that already exist and as, you described it, ensure public acceptance and those sorts of things. Does that resonate with you? Do you see additional scientific challenges as you look across all of the applications where CRISPR and other biological technologies could be brought to bear? Have we "solved" all the scientific problems?

Jennifer Doudna: Certainly not. Those go hand-in-hand with the educational and societal challenges as well. Certainly in biomedical science, there's such an interesting opportunity right now with genome editing to think about ways that one could mitigate or even cure genetic diseases, and that's not a pipe dream anymore. I think it's just on the horizon, which is extraordinary. Imagine being able to cure everybody that is affected with sickle cell disease of that terrible disorder. This would be amazing. But when you look into the details beyond the immediate technical issues—which I, frankly, believe will be solved not long from now—then you get to questions around, how do you pay for that? How do you afford it? What would it cost for America, for example, to be able to offer that treatment to all folks in our country that are afflicted with this disease? Beyond that, what would it take to be able to offer that to people in Africa impacted by this? It's a big challenge.

One thing I've been thinking about is how we can ensure that this technology is widely available. How do you do that? It has to begin with the scientists and the science. From the very beginning, we have to ask ourselves, "How do we ensure that all of the steps for application of this technology are as affordable and accessible as possible?" In the case of sickle-cell disease and other blood disorders, one way that challenge could be met is to introduce the edited cells into patients without requiring a bone marrow transplant. That would save extraordinary amounts of money as well as reduce challenges for individuals having to go through that treatment. That's one example. There's a lot more that could be done and should be done, frankly, by scientists, to think from the very beginning, "How do I do my work and set up my research so that the outcome is going to be something that isn't just nice to publish in a journal, but is having real practical value?"

Michael Chui: The story you're telling is remarkable. In fact, my dad has worked on thalassemias for, basically his entire career as a hematologist. What you're saying is, in some cases, if we do things right, people can be cured of these diseases. Is that correct?

Jennifer Doudna: It's amazing, isn't it, to think about this? For thalassemias, again, these are diseases, blood disorders, that arise often from a single gene that has a faulty letter in it. In the past, that could be studied and it could be investigated in animal models. But the idea that you could actually do something in a person to correct that disease-causing mutation was completely science fiction. Now we're on the verge of being able to do exactly that, which is just remarkable. It really does open the door to a new era of medicine where in the future people's entire DNA sequence will be known, and perhaps all of us will have it carried around in a chip, or sitting in the cloud somewhere. When we have a medical condition, the genetic basis for that can be identified quickly, and perhaps rather than having to say, "Well, I'm sorry, you've got this genetic situation. You need to monitor it," there will be ways to correct

it at the at the source, and not have to worry about that disease ever again.

Michael Chui: You could imagine, taking some stem cells, using CRISPR in order to change that problematic "spelling" in the DNA sequence, and then bring it back to the patient, and they'd be cured. It's interesting, because that does create a commercial dilemma. There was an investment bank who said, "Curing disease is not necessarily good business model," because you can't sell somebody drugs or treatment for the rest of their lives. How do you see that playing out if we can, with one treatment, cure a disease? How would that work?

Jennifer Doudna: It does raise the question of coming up with a completely different model for how we think about therapeutics and how we pay for them. One idea that's been floated—and I don't know if this will catch on or not—is an installment plan, like how we have a mortgage on our house. Maybe we eventually have a similar thing on our health for a one-time therapy that is curative of a disease. It's expensive, but the way it gets paid out is just over time. It's effectively an investment that's made in someone's lifelong health. You could imagine insurance companies changing their model to accommodate that kind of system, where we could ensure that people who need a one-time but expensive treatment for a rare disease, so there wouldn't be any large number of people for any one of these rare diseases that would need this particular treatment. But if they do it's there, and the payment occurs over an extended period of time.

What are the ethical and regulatory challenges of gene editing?

Michael Chui: You've also talked about some of the potential ethical challenges. It's hard to argue against curing a disease which is going to cause someone to have a shorter life or a much-reduced quality of life, which is another way of saying a painful condition. But what about the ability to change who we are, or pick traits in our children—how do you think about those sorts of things? How do you address the broad topic of bioethics?

Jennifer Doudna: It has to be woven into everything that we do as we move forward with genome editing. This was one of my primary motivations for starting the Innovative Genomics Institute, which was to have a place where scientists not only advance their research and work towards real-world solutions to problems in medicine and agriculture, but also take on the challenge of the societal implications of this, and weave it into their work, not using it as an afterthought. Asking, "How do we integrate our thinking about the societal impacts of these applications from the beginning?"

In terms of the actual uses of CRISPR for the purposes you're saying here, for example, being able to choose traits that get passed on to future generations, this topic has received a lot of attention in the media. It sounds pretty "science fiction-y," and yet we are at a very interesting point where, technically, we're on the verge of being able to do exactly that.

This is a really profound use of a technology and really requires careful thought. There's a lot of danger to applying something like this. As many listeners will know, there already has been an application of CRISPR in human embryos that led to what are commonly referred to as CRISPR babies. Twin girls in China did receive genome editing during their development and we don't know what the future outcomes will be or the effects on their health. But certainly the announcement of this work caused an international outcry. For many of us it was really the moment where we said, "Look, this can't happen. This is not appropriate to be proceeding with." And it has triggered an international effort to ensure that there are appropriate guidelines for that type of use of CRISPR in the future.

"This is a really profound use of a technology and really requires careful thought."

Life finds a way

Michael Chui: There are ways to think about appropriate intended use and inappropriate intended use. How much do you worry about unintended consequences and opening Pandora's box? We intended to do this, and life finds a way.

Jennifer Doudna: It is a real concern. Because CRISPR has really pointed out how little we understand about our genome and the genomes of other organisms. Let's take humans. When the human genome was first sequenced back around the year 2000, there was incredible excitement. People were thinking, "Now we have the blueprint for a human and we need to make use of that information." I think it's proven to be a lot harder than was appreciated at the time. The genome is very complex. There's a lot of ways that genetic information is used that is still being figured out. And certainly the functions of genes in the context of an environment of the influences that an organism has that are external to the genome are still being sorted out. Just the knowledge of the genome, frankly, continues to be one of the limitations on using this technology.

Now, that being said, CRISPR is itself a wonderful tool for mining out the genome, figuring out what genes are doing, how sets of genes are working together. Increasingly, I see CRISPR being both the tool and the technology that allows changing the genome sequence, by understanding what it's doing in the first place, and then being able to make targeted changes. I think we'll see those two things going hand-in-hand both in medicine and agriculture going forward.

Michael Chui: I'd like to press this a little more. People describe it as the butterfly effect, where a butterfly flaps its wings and as a result many things happen down the road. The technology described as gene drives could be used out in the wild to reduce incidents of mosquito-borne illnesses, and yet could also influence the rest of an ecosystem. Are those the sorts of things that you think about? What should people think about the idea of organisms that might have had CRISPR or other techniques used being let out in the wild, and the consequences?

Jennifer Doudna: You bring up an interesting topic of gene drives. This is a subject that's received quite a bit of attention because of the ideas that it can trigger. I'll briefly explain what this is. A gene drive means a way to introduce a genetic trait into a population of organisms in a very rapid way that doesn't require Mendelian inheritance. You can imagine taking a population of mosquitos, which is where gene drives are one of the organisms where this is being applied, and introducing a trait very quickly using a tool like CRISPR. In principle, you could either sterilize those mosquitos or create mosquitos that were impervious to infection by parasites and avoid spreading viruses that would be normally mosquito-borne. These kinds of applications are actively being explored right now using CRISPR as a gene drive technology.

The flipside is that you could imagine a trait gets spread in such a fashion that it could get out of control. You've caused extinction in an insect population that provided essential food for bats, for example. How would that end up affecting the whole ecosystem? These things are still very much under experimental investigation. Here we have a very powerful tool, and it's essential that we take the appropriate time to assess it, analyze it, and work with it safely in the laboratory prior to ever releasing it into the environment and that would be difficult to pull back.

The business of biology

Michael Chui: I'd love to shift gears. In addition to the contributions you made in the academy and research, you've also founded companies. Using a commercial lens, what have you learned from your work as an investor, a founder, an operator of companies, which is unique to this area of biology that might inform other businesspeople? What have you learned in the business of biology?

Jennifer Doudna: It can be incredibly motivating to have a particular goal in mind, and build a team around that goal to solve a problem. For people in business this sounds like, "Well, yeah, we do that every day." But if you're in academic science, as I have been for my whole career, this is in some ways a foreign concept. But I have found that it's incredibly fun to identify a problem that a group of people can all agree to that, "Yep, that's something

we need to solve," and then build the team that's going to solve it.

Finally, for folks in business this is, again, no surprise. But every team and every company is different, no matter what, because it's about people. Every single company has a different culture, a different feel to it. I also find that fascinating because I really enjoy working with people. Working with these teams is interesting, and each one needs a different touch, a different set of inputs to be their best, and I find that to be rewarding.

Michael Chui: That's terrific. That'll resonate with a lot of our listeners who will be leaders in business. I'm curious, for someone who's seemingly far from biological sciences—a chairman of a bank, or the CEO of an industrial company, how should they think about what we're describing as a Bio Revolution? Is it something they should worry about in terms of their own health? Does it have more implications for industries that farther away from pharmaceuticals, for instance?

Jennifer Doudna: What we're going to see over the next decade or so is that the intersection of biology, information science, and computer science will affect us in ways that we couldn't have imagined previously, or maybe can't even imagine today. We're going to see biological solutions to problems that, in the past, seemingly had nothing to do with biology. Whether it's in industrial chemistry or solving problems that relate to climate change and pollution around the world, dealing with the issues of populations facing this current pandemic. How do we plan for the next one, and make sure that next time we don't have to shelter at home for many weeks to deal with it? Going forward, we'll see a combination of biologically based technologies, coupled with large data, and using machine learning to figure out trends, genetic susceptibilities to diseases, or how to engineer organisms so that they produce useful chemicals. These things are increasingly possible because of the advances in these technologies.

Why gender diversity matters in the sciences

Michael Chui: Could we talk about gender within science, business, and all the domains that you you've worked on? Female representation in bioscience is much better than my own discipline of computer science, and yet my understanding is there are still challenges. How do you see things currently, and how might they play out in the future?

Jennifer Doudna: Gender balance is, first of all, incredibly important in in any field. Good ideas come from everywhere. In my experience, you can't predict who who's going to come up with the next clever idea, invention, experiment, et cetera. I have found that to be true within my work at a public university that fortunately brings in students from every possible background, from every possible country. It's been an amazing experience to be working in a setting like that. And I think that gender diversity is the same. We need to be empowering all of us to feel supported and feel enabled to contribute whatever we can to our work, and to advancing science and technologies in particular because that's our field. I think traditionally women have been excluded from science and technology. Not completely, but certainly in many ways it's been hard for women. I just finished reading a wonderful advance copy of a book that's coming out by Rita Colwell, who ran the NSF for many years and very distinguished scientist. She writes about her own experience of being a woman in science and encountering some really harrowing examples of discrimination. It highlights the reasons we are working to ensure that future generations of scientists, no matter their gender, that they feel empowered and supported in their work. There's no easy answer to this, but I do think

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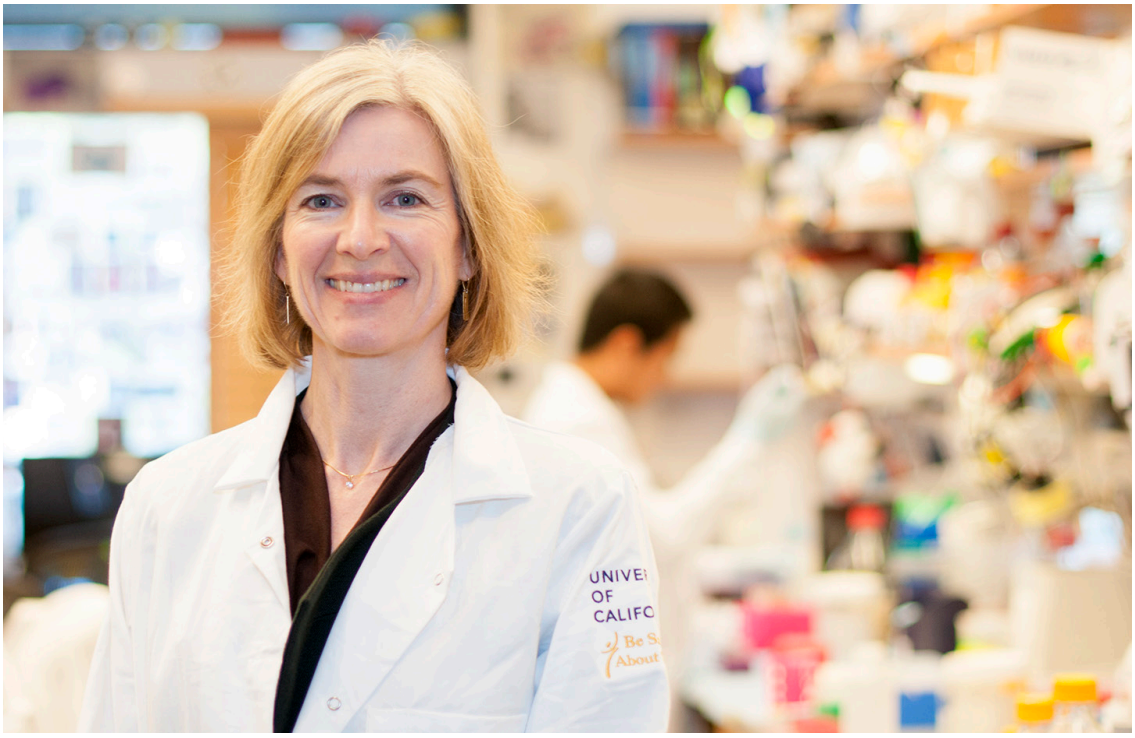
that it’s all about creating environments and cultures where people feel enabled. I certainly aim to do that in my own research groups and in the companies that I work with. We always try to make sure that we have good widespread representation of scientists from all walks of life so that it’s clear that we support diversity. We value that and we appreciate that it’s fundamental to doing creative work.

Michael Chui: Yeah there’s a history here too with Rosalind Franklin. My understanding is you’ve worked on X-ray crystallography as well. Why didn’t she get the same type of accolades that Watson and Crick did? Hopefully we can change the trajectory of things going forward. On that note, how do you think about your legacy?

Jennifer Doudna: When I think about my legacy, what I’m proudest of is the people I’ve had the honor to work with, and who have left my lab to do great things on their own. I feel so proud of the folks that that are now running academic labs, working at companies, or have other roles they’re playing whether it’s in the law, public policy science education, or communication. I’ve been running a lab 25 years, so you can imagine there’s quite a few folks that have gone off and done great things. I think that’s what I feel best about in my career. There’s always the next experiment you can do. There may or may not ever be another CRISPR moment for me. In the end it’s really about creating a future for science. And the future is the people that we train, and the people that they go on and train . That’s really what it’s all about for me.



“Gender balance is, first of all, incredibly important in in any field. Good ideas come from everywhere.” (Photo: Keegan Houser/UC Berkeley)

Lightning round: Quick questions and answers with Jennifer Doudna

Michael Chui: Yes, nurturing the next generation is an incredible privilege and a great joy. That totally resonates with me. Next, I'd love to do a quick lightning round of quick questions, quick answers. They're meant to be fun. If you don't like one you could just say, "Pass." Are you willing to do that with me?

Jennifer Doudna: Sure.

Michael Chui: Here we go. First, what's your favorite source of information about biological innovations?

Jennifer Doudna: Twitter.

Michael Chui: What's a thing you wish people understood about CRISPR?

Jennifer Doudna: Oh boy. I wish they understood that it's an ancient immune system in bugs.

Michael Chui: What's the number one thing that people get wrong about CRISPR?

Jennifer Doudna: I think what they get wrong is that it's not a cure-all. It's a powerful tool, but it can't do everything.

Michael Chui: What excites you most about the Bio Revolution?

Jennifer Doudna: Thinking about what's next and how we get there.

Michael Chui: What worries you most about the Biological Revolution?

Jennifer Doudna: Technology getting ahead of itself, and people proceeding to do things that can be done, but really should not be done.

Michael Chui: What application of biological technologies is most underhyped or underrecognized for its potential?

Jennifer Doudna: I think it's the work in plants and agriculture. It doesn't get a lot of attention, but it's going to be extremely impactful.

Michael Chui: What application of biological innovation is most overhyped?

Jennifer Doudna: CRISPR babies.

Michael Chui: What job would you be doing today if you weren't doing what you're doing now?

Jennifer Doudna: I think I'd be an architect. I like building things.

Michael Chui: Not tomato farmer?

Jennifer Doudna: Well, that too. That's very possible.

Michael Chui: Okay. In terms of tomatoes, do you think of yourself as a latter-day Mendel? Or is it just something you do for fun?

Jennifer Doudna: Mostly I do it for fun. I often tell my son, "If I had another life to live, I would probably be a plant geneticist." Plant genetics is really fascinating.

Michael Chui: Did your childhood in Hawaii have anything to do with that? Because they have crazy plants there.

Jennifer Doudna: They do have crazy plants there. Yes, I'm sure it has a lot to do with it.

Michael Chui: All right, I have two more lightning round questions. To a student who is entering college today, what would you recommend that they study?

Jennifer Doudna: Computer science or robotics.

Michael Chui: Wait, we just spoke about how amazing biology is, and you're saying computer science and robotics. What gives?

Jennifer Doudna: Well, I think those are going to intersect with biology. I really do. And when I say computer science and robotics, I increasingly think that those fields will include biology, because they have to.

Michael Chui: Finally, what one piece of advice do you have for listeners of this podcast?

“Pay attention to what’s happening in biology because it’s changing very quickly.”

Jennifer Doudna: Pay attention to what’s happening in in biology because it’s changing very quickly.

Michael Chui: Great. Jennifer, thank you so much for joining us today, for sharing some of your insights. I’m Michael Chui with the McKinsey Global Institute. My guest has been Jennifer Doudna, discoverer of the gene-editing technology known as CRISPR, and who also directs the Innovative Genomics Institute at UC Berkeley and UCSF. Thank you.

Jennifer Doudna: Thank you, Michael.

Michael Chui is a partner of the McKinsey Global Institute. **Jennifer Doudna**, PhD is a professor of molecular and cell biology and chemistry at the University of California, Berkeley. Jennifer is also the executive director of the Innovative Genomics Institute, the Li Ka Shing chancellor’s chair in Biomedical and Health Sciences, and a member of the Howard Hughes Medical Institute, Lawrence Berkeley National Lab, Gladstone Institutes, the National Academy of Sciences, and the American Academy of Arts and Sciences.

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