



Bruce Alberts

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Paul Nurse

Annual Review of Cell and Developmental Biology Science, Education, Leadership, and Politics: An Interview with Bruce Alberts and Paul Nurse

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Annu. Rev. Cell Dev. Biol. 2025. 41:1–14

First published as a Review in Advance on
June 10, 2025

The *Annual Review of Cell and Developmental Biology*
is online at cellbio.annualreviews.org

<https://doi.org/10.1146/annurev-cellbio-101323-034601>

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Keywords

interview, biography, molecular biology, COVID, climate change, National Academy of Sciences

Abstract

Science is often portrayed as the objective search for knowledge. However, science is also part of complex societies that shape science and in turn are shaped by scientific findings. In this interview, Bruce Alberts, former president of the US National Academy of Sciences, and Paul Nurse, former and future president of the Royal Society, discuss the roles of science and scientists in society. They share their passion to understand the natural world and the joy of discovery. They emphasize the importance of leadership in building institutions that support science and evidence-based decision-making. They share their frustration that current science education falls short in teaching the way science arrives at a better but incomplete understanding of the world. They urge scientists to organize and make their case to the public and fight misinformation and mistrusts.

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INTRODUCTION

Bruce Alberts is a renowned American biochemist and a leader in science education and policy. Born in 1938, he earned his PhD in biophysics from Harvard University in 1965. Alberts is best known for his pioneering work on DNA replication, particularly his research on the protein complexes responsible for this fundamental cellular process. Alberts spent most of his academic career at the University of California, San Francisco (UCSF), where he served as a professor and later as chair of the Department of Biochemistry and Biophysics. He served as the president of the US National Academy of Sciences from 1993 to 2005. During his tenure, he emphasized the importance of science education reform and global scientific cooperation. Alberts is also a coauthor of the widely used textbook *Molecular Biology of the Cell*, a fundamental resource in life sciences education (Alberts et al. 2022). He later served as the editor-in-chief of *Science* and as a US Science Envoy. Recognized with numerous honors, including the National Medal of Science, Alberts continues to advocate for evidence-based education and policy worldwide.

Paul Nurse is a distinguished British geneticist and cell biologist known for his groundbreaking discoveries in cell cycle regulation. Born in 1949, he earned his PhD from the University of East Anglia in 1973 and conducted postdoctoral research at the University of Edinburgh, where he identified key genes controlling cell division. His most influential work focused on the *cdc2* gene in fission yeast, which he demonstrated to be a master regulator of the cell cycle. In recognition of his contributions, Nurse was awarded the 2001 Nobel Prize in Physiology or Medicine alongside Leland Hartwell and Tim Hunt for their work on cell cycle regulation. He has held prestigious leadership positions, including president of Rockefeller University, president of the Royal Society (2010–2015), chief executive of Cancer Research UK, and founding director of the Francis Crick Institute. A passionate advocate for science policy and education, Nurse has been a vocal proponent of increased public engagement in science.

Alexander F. Schier is a developmental biologist known for his pioneering research on vertebrate embryogenesis. Born in 1964, he obtained his PhD from the Biozentrum at the University of Basel and conducted postdoctoral research at Harvard University/Massachusetts General Hospital. Schier established his laboratory in 1996 at the Skirball Institute of NYU School of Medicine before joining Harvard University in 2005 as the Leo Erikson Life Sciences Professor and later chair of the Department of Molecular and Cellular Biology. In 2018, he returned to Basel as professor and director of the Biozentrum. Schier's research has made fundamental contributions to the understanding of morphogen signaling and microRNA-mediated mRNA regulation. He has helped pioneer large-scale genetic screens and single-cell sequencing technologies to understand

development at global scales. Schier was elected to the European Molecular Biology Organization and US National Academy of Sciences.

This interview was edited for length and clarity.

BECOMING A SCIENTIST

Alex Schier: Why did you become scientists? What inspired you when you were in school?

Bruce Alberts: I think everybody in my generation I've talked to, in the United States at least, read two books that were really formative in getting us to think that science was something we wanted to do, although we didn't really know what science was. One was *Microbe Hunters* by Paul de Kruif (1926), a book about the history of microbiology—Pasteur, Koch, and so on. It's incredibly effective in capturing the spirit of science. We also had read *Arrowsmith* by Sinclair Lewis (1925). It is a novel about a really dedicated person who wants to do science. He is using bacteriophages to cure bacterial infections. After disillusioning experiences, he very idealistically moves to Vermont and pursues pure research. It's amazing how many people in my generation will say they read these books in high school. But in my high school, I never met a scientist. I didn't know you could actually be a scientist and get paid. We all knew that Einstein had to work in the patent office. On career night, the only person who talked about careers that used science was a guy who talked about how chemistry worked in the petroleum industry. I thought that was really boring. And then there was a doctor who talked about how science is used in medicine. So I became a premedical student at Harvard College, thinking that, like many of the heroes in those books, with a medical degree I could practice science.

Alex Schier: Paul, how does Bruce's story compare to your story?

Paul Nurse: It's a bit different for me. I came from a nonacademic family and there were few books at home. I was more motivated by natural history and astronomy. I got a little telescope and saw the rings of Saturn, craters on the Moon, and the moons of Jupiter at around age 11 or 12. Science seemed quite interesting as a consequence of that. I wanted to go to university to do ecology because of natural history, but I couldn't get into university because I failed a rather simple examination (O level) in a foreign language needed for entry into all universities at the time. I'm hopeless at foreign languages, and I managed to fail the basic French exam six times. (I suspect this is a world record in failures.) So as I couldn't get into university, I worked as a technician at the local Guinness brewery in London, where I was brought up. Surprisingly, I worked on infected eggs. My job was to make up the media in the lab, and every day I had to go around and ask the scientists what media they wanted. I soon realized they always asked me for the same thing, more or less. So after a couple of weeks, I just made it all up on Monday and then aliquoted it for Tuesday, Wednesday, Thursday, and Friday. I then went back to my boss and said, "Look, I can do this job one day a week. What do you want me to do after that?" So he put me on a research project where I used newly invented immunofluorescence and many other techniques. That exposed me to cellular molecular biology.

Alex Schier: What was your experience in college and graduate school?

Paul Nurse: I eventually went to Birmingham University for my undergraduate studies. They let me in without O level French at the request of the professor of genetics and I'm really grateful for that. When I went to university, I got fed up with ecology, as you had to go out in the rain and the cold to collect samples. It was just too unpleasant. So I switched over toward more molecular and cellular studies that led to a PhD at the University of East Anglia in Norwich. My project was not the most interesting one—investigating amino acid metabolism in fungi. What I mainly remember was using a Beckman amino acid analyzer prototype that didn't work properly. The

reason it didn't work is that it was full of safety devices, such that when the pressure built up in the chromatography columns, it switched itself off and dumped all the data that it had collected. The only way I got it to work was to inactivate all these devices with bits of plasticine and Sellotape. But that meant I had to sit in front of the machine and constantly watch the pressure gauge so that I could switch it off if it really went too high. But the advantage of this was that I read a lot of papers. I sat in front of this damn machine for so long reading papers, and that's where I discovered the work of Lee Hartwell working on the budding yeast cell cycle. It set me on my subsequent research career, which was to work on the same problem but with a different yeast that divides in the middle like most eukaryotes—fission yeast.

Bruce Alberts: When I was an undergraduate at Harvard, all the science degrees required that you had to take labs at least three afternoons a week. They were horrible! They weren't science at all. It was like cooking. You do something like distilling, and then you measure how many grams you get. And if you spill something, you try to cheat by looking at what your neighbor got—just the opposite of doing science! But then finally, in my third year in college, I couldn't take it anymore. I was in the physics basement, measuring refractive indices, trying to get the right answer, and cheating. And so I approached a tutor assigned to me, Jacques Fresco, and I asked, "Can I just drop the lab for this course?" He said, "No, you can't. You can only do that if you work in a research lab." Well, nobody had ever told me that was a possibility. And then the most important thing happened: I could spend all summer in the laboratory of Paul M. Doty, where Fresco was a senior postdoc. I worked 80 to 100 hours a week. And I really lucked out. We discovered and published that if you have a mispaired base as an insertion in a double helix, it could loop out. So I thought, well, this science is so easy. Why should I go to medical school? I learned I could do science, and people were going to get paid as scientists without having a medical degree. So I never applied to medical school. Doty wanted me to stay in his lab, so I stayed at Harvard, even though I had been accepted at Stanford University and my wife wanted to go to Stanford.

Alex Schier: And your PhD experience?

Bruce Alberts: It was completely different from my undergraduate experience! I was totally independent. Doty was always in Russia or on President Kennedy's Advisory Committee. So I thought science was so easy. I was going to solve the genetic code. I did this crazy thing: I didn't do the control before I did all the work to prepare my critical experiment. So that was a massive failure after two years. And then I had developed a theory on how DNA replication could be carried out with only one enzyme, DNA polymerase, even though DNA polymerase only worked on single-stranded templates. I spent another year trying to test that model, and it was wrong. And then to graduate, I started studying something I discovered in my second project that's still a mystery—naturally cross-linked DNA. After five years, Doty thought I had done enough to go to the oral thesis exam, which nobody ever failed. Matt Meselson and Wally Gilbert were there, and Doty was supposed to be there, but he had a sudden need to go to Russia or someplace else. So to my great surprise, they failed me. They didn't believe that I had found out anything about naturally cross-linked DNA. I had to stay another six months. My wife and I had already given up our apartment. I had a one-year-old child. We moved into the apartments of people who were on vacation, and eventually we ended up in a hotel. That was a huge learning lesson about strategy and science. I came to understand that doing good science is like painting a great painting. You have to have a very careful strategy ahead of time and think it out. And I hadn't done that. I hadn't done that either time. When I was an undergraduate, I didn't have to. It just fell in my lap. And throughout graduate school I had made the mistake of not having a good strategy.

BEING A SCIENTIST

Alex Schier: When you look back, what brought you the most joy as a scientist?

Paul Nurse: Although I've done a range of things, and they're all satisfying in different ways, it is discovering something new that brought me the most joy. It's such a privilege. Sometimes I meet colleagues who in my view feel too entitled about doing research. As scientists, we are paid to follow our curiosity and discover things. It's both a joy and a great privilege.

Bruce Alberts: I still remember the basement lab of Princeton University, when I was assistant professor. It was the worst space. No light, no windows. One night, I don't remember what the discovery was, I had this thrill that I was the only person in the universe who knew this.

Paul Nurse: It's strange, because science is a communal collaborative effort but also individualistic. You switch between these positions. The pleasure of knowing something that nobody else has ever known is the individualistic part. But of course, you always have to build on what everybody else has done.

Alex Schier: What was your greatest frustration as a scientist?

Paul Nurse: It used to be when experiments don't work, but now as I have gotten older, I have realized when they don't work, there's often a reason for it that may open up new understanding or experimental approaches. I think the main frustration for me now is just balancing the time that you have between research and other things like leading institutions. I've always tried to do a job that allowed me about 50% of my time to work on my own research, so I've never taken on a job that made that impossible. But sometimes I get frustrated when I am forced out of the lab.

Bruce Alberts: I was certainly frustrated by my PhD thesis because I was disproving my own theory, and nobody cared. And I did not do the controls and did not have a strategy. That was very frustrating. But I think we were very lucky in our era. We didn't have the frustration that scientists have now, needing to write 10 grants a year to get your lab funded. I wrote a grant every three years. Paul and I were so lucky to find science. My father wanted me to be a lawyer. That would have been a miserable life for me. So I think both of us were incredibly lucky, both in what we chose and in the time in which we did it. The job of Paul, me, and others is to try to restore some of the aspects of science that existed back then. Because it's just such a shame that young people don't feel liberated to just try to solve an important mystery that needs to be solved.

BECOMING A LEADER

Alex Schier: What was the impetus for you to move more into politics and leadership?

Paul Nurse: I felt guilty that I was just pursuing my own curiosity in what research I did. So I thought if I pursue my own curiosity for half my time, I will pay my debt back to society by running things in leadership positions. That has kept me balanced—half the time in research, doing whatever I want and paying back society with the other half, which is doing jobs running things, setting things up, doing politics, and so on.

Bruce Alberts: For me it was completely accidental. I never wanted to do this stuff. It all started in 1985 with the brief editorial I wrote in *Cell* about why small science is good science (Alberts 1985). One of my arguments about having a small lab was that you should be able to do experiments from time to time so you could really understand the methodology and give good advice to your post-docs and students. And so I argued for a lab size no bigger than 10. I became famous for defending small science. I had moved to UCSF and I was really happy there. All of a sudden I get this telephone call. It's funny how we remember things. I have a distinct memory of how my desk looked

when I was holding up the phone. They had called me from the National Academy of Sciences to say we've got this committee set up to discuss whether or not there should be a special project to map and sequence the human genome. They told me who was on the committee: Wally Gilbert, Jim Watson, people who had failed me on my thesis exam. Both had been strongly advocating for such a project. Then there were scientists who had been against the idea, like Shirley Tilghman and David Botstein. It was a wonderful committee—really balanced with outstanding people on both sides. And they said, "We decided you're the perfect person to chair the committee." I said, "What? I haven't been involved in this at all." And what they said was, "We need somebody who was never involved." But what they didn't say, and I only recognized subsequently, is that people like David Baltimore and many others were saying the Human Genome Project was a terrible idea, because it would make biology a big science, and biology needed to be a small science. So somebody at the National Academy of Science had the brilliant idea that if I were the chair of this committee and it decided to have a genome project, it would not be so heavily criticized by all the biologists who, on balance, were against the idea. That committee was really a wonderful experience in science policy. We worked out a strategy, agreeing that we would not discuss recommendations until we had held a series of information gathering sessions. We brought in young people, Maynard Olson and many others, who were actually doing this kind of work to bring us the hard truth about the challenges for completing a human genome sequence. We actually got embedded in the facts, which is the way science is done. We left the final recommendation chapter to the last meeting, where we all came to the agreement that there should be a genome project. But we had all these constraints that made sense. Start by sequencing yeast, because there's all this homology. Don't sequence the human genome until you get the cost below 50 cents a base pair, and so on.

Paul Nurse: My introduction to running things was when I was made the head of a department at Oxford University in my late thirties. It was microbiology, quite a small department, part of the Biochemistry empire there. I had to run a teaching and research department and found that I was okay at doing that, even in the complex politics of Oxford University! I was then hired to run the Imperial Cancer Research Fund laboratories in London. I was working on cell division in the yeast cell cycle. But when I first went there, the main interest of my colleagues was how to keep me out of their way so I didn't contaminate their tissue cultures! Things got better when my lab cloned the human gene and showed that cell cycle control in fission yeast and humans was similar. I found out there that if I'm in charge of an institution, I can give jobs to other people, and often they're as good, if not better, than I was at doing most things. So really the job is to lead. You have to deal with strategy and crises, but the actual running of it can be delegated as long as you're close enough to be paying attention. And that gave me a way of working that liberated time to do my own research.

Alex Schier: Bruce, how did you end up running the US National Academy of Sciences?

Bruce Alberts: The Human Genome report was so successful that the Academy decided I could do science policy, and they gave me other small committees to chair. But then they were looking for a new president, and I said I definitely did not want to do this, because it's a full time job. But then Harry Gray, who was the chair of the search committee, a very charismatic Caltech chemist, said, "We realized you didn't want to be considered, but we chose you anyway." Harry had the very skillful strategy of saying, Well, you know, you're very interested in science education. I had a big grant in San Francisco to redo elementary science. So Harry said, "If you don't take this job, the Academy is never going to do the kind of science education we should do, and you're going to feel very guilty." And so I went home, trying to avoid guilt, and said, "Well, I'll do it, but I'll only do it for four years, not for six years," so I could have a chance of going back to science. But of course, I never went back.

BEING A LEADER

Alex Schier: What do you think people saw in you? There are many people who might want to be leaders. What did people recognize in you?

Paul Nurse: If somebody really wants to be a leader, their motivation may not be right. It is better if you have to be dragged to leadership as Bruce just described. I wouldn't exactly say I was dragged, but I wasn't seeking it. In fact, I never applied to be the chair at Oxford microbiology. They wrote to me and said, "You have been appointed." Typical Oxford! What I think is important for leadership is that you have to have empathy for people. And if you have to make difficult decisions, it is important to be really straightforward about it, no backstabbing or gossiping behind people's backs.

Bruce Alberts: I think people trusted me because I had no motives other than to try to make the place the best I could make it. It wasn't that I was trying to make myself famous or do anything for myself. They knew that if I took the job, it was because I wanted to do something for the community. I didn't actually want to do it at all. And I often say that people who really want to be department chair probably want to be department chair for the wrong reasons. I had been acting department chair at Princeton at a very young age, and then I was chair at UCSF. But those were very small departments, and it wasn't a huge time sink. But the Academy has, like, 1,100 employees. The first year, I didn't know what I was doing. The critical thing to me, Paul hinted at this, about leading anything is getting the right people to work with you, and giving them the responsibility to make important decisions so you don't have to be in the middle of everything. When I was at the Academy, I often flew back and forth to San Francisco, and United Airlines once gave the passengers this newsletter to read about how to be a manager. It said that to be a good manager, make sure that no decision can be made without your approval. I found this horrible, because what I wanted was a team where I didn't need to be involved. The important thing was to get the right people to make decisions and to trust and not interfere with them, unless they were really screwing up, and then you had to fire them. I had to do that at the Academy, because I had inherited a bunch of staff from my predecessor who did not want to change. But once we had the right people, it all worked. The first year was horrible: The council and president would decide to do X, but then six months later nothing had happened because critical people wanted to keep on doing their job the way they did it before. So we fired them, and I had never fired anybody before. That was the tough part. The important thing about being a leader is having people feel that whatever decisions you make, they're made for the right reasons. Even when you make a mistake, it's an honest mistake. It's not a self-serving one.

Alex Schier: As a leader, you have to make some tough decisions and face challenges and resistance. How do you deal with that?

Paul Nurse: My first port of call if somebody isn't working out is to see if there's some other way in which they can be used. In other words, try to find the strengths they might have. So I tend to be more tolerant of things not working properly by trying to change the job that people do. Although if that doesn't work, you have to do something about it, but always treat people with respect and compassion.

Alex Schier: There was a lot of resistance to setting up the Francis Crick Institute.

Paul Nurse: Yes, there was a lot of opposition. We merged three institutes, and probably the majority there didn't want to be moved and merged. So there wasn't huge enthusiasm for it. I had a town hall meeting in every one of these locations once every three or four weeks. I went there and tried to make the discussions as good-natured as possible. If I didn't have an answer

to a question, I'd come back in three to four weeks with my best answer. I didn't always satisfy people, but they were decent and in the end recognized that I was trying to do my best. We've been operating together only since 2017 and it is now working well.

Alex Schier: Bruce, what was your kind of experience with difficult decisions and opposition at the Academy?

Bruce Alberts: I've been trying to improve science education since 1985. At the Academy, we produced the first-ever National Science Education Standards in 1996, and we published more than 100 studies on education when I was president for 12 years. But I had to deal with scientists, members of our academy, who wrote very aggressive letters stating that, "Science education was not the problem of scientists. It's a problem of textbook writers, unions, school boards. And we should have nothing to do with it. Bruce Alberts is misusing Academy resources." Quite strident letters from very successful scientists. That was just the start of my realization that scientists are not always rational. They're very sure of themselves in areas where they're not using any data or facts. In fact, what we know from research, and all my experience, is that how a college science course is taught sets the model for teaching science at every level, because you're teaching the future teachers. If Harvard teaches biology in a way that every damn thing needs to be memorized, then that goes back to high school, AP Biology, lower high school, first-year biology, middle school biology, et cetera. You get these hideous textbooks that I have written about many times. Middle school biology textbooks with 500 words to memorize are the hardest books to understand that I've ever seen, because there is only a paragraph about each word. And then you're supposed to spit it back. *What is the endoplasmic reticulum?* That's an exam question that they want 12-year-olds to answer. It doesn't mean anything if you know nothing and memorize sentences like "the endoplasmic stores and sorts materials." What the hell does that mean? So getting scientists to change how science is taught in college is critical to the whole science education system.

BEING AN EDUCATOR

Alex Schier: What should science education look like?

Bruce Alberts: The rate-limiting step to make the public understand science is to change the nature of science education in the introductory science classes in college. Because, as we found in the COVID pandemic, it was so terrifying to all of us scientists to realize that the American public, many of them, have no idea where scientific judgments come from. They think we're just like priests, right? "Scientists are a cabal. We make up what we want to believe." The former governor of Texas and then secretary of energy under President Trump [Rick Perry] stated, when he was governor, that climate change is a hoax made up by scientists to get grants. If the public understood how science works, they would know how outrageous that statement is, but they don't. And why don't they understand? We never try to convey how science actually works. In science class we think it is most important to get everybody to learn the "facts" that science has discovered. But there's too many of them, and now we actually have Google to find those facts. The critical thing about science education at all levels is to get students from an early age—and certainly in college—to understand how the scientific community works and why it is not a cabal. It can't invent climate change as a hoax because it would never fly. But science also can never be absolutely certain. It is so important for people to understand that if science is absolutely certain, then that science is dead. We have to leave room for change and improvement. For example, Tony Fauci changed his mind about masks when the data became different. This is now viewed as a reason to put him in prison. It's just a complete misunderstanding. This is actually the way science works. If you don't understand how science works, how are you supposed to distinguish between fake

information and real information? Through education, adults need to become empowered to find out what the consensus view of the scientific community is.

Paul Nurse: There are two important things about science education. One is the process, the approach to producing reliable knowledge. And the second is the inspiration and wonder of scientific discoveries. And both of those don't always get done well in schools and textbooks. The key goal of science is to generate reliable knowledge about the natural world, but it's important to emphasize that knowledge is always refutable. It's an evolutionary process. This is something that doesn't fit so comfortably with political opinion, because when we have to explain things we need to say there is some doubt. So when former Prime Minister Boris Johnson said, "We are following the science," the implication is that science is chiseled in stone, like Newton's laws of motion. But when you're faced, as we were during the pandemic, with a new pathogen about which we had only limited knowledge, at the beginning all you can do is to make your best guess at what is happening and what to do about it. Scientists always need to emphasize that things may change as knowledge gets better. This is more difficult if science is taught in school as infallible knowledge and if politicians want to claim they are acting on certainties. If scientists say the right thing to do is to shut the country down, a politician will find that difficult to say if they also have to add, Well, that's what we think at the moment.

BEING A POLITICIAN

Alex Schier: Bruce, how do you deal with the uncertainty in science and the questioning of consensus?

Bruce Alberts: If a scientist challenges a consensus and is proved to be correct in the end, they become famous. That's one of the best ways to become a famous scientist. So there's a strong motivation for people to question the consensus, which is good, but just because there are people who will say that climate change is not proven doesn't mean that you can ignore the consensus view. If somebody told you that there's a 99% chance your house is going to burn down if you don't change the curtains or the furnace, you change them. We're not saying it's 100%. We always say it's 99% or less, so we don't close science to progress. But none of that is really taught in American science classes, unless you have a very unusual science teacher. We don't leave enough room for teaching what I think is most important: How do scientists create reliable knowledge? When a statement you see on your social media challenges what scientists say, how do you figure out whether that's complete bunk or something you should think about? You're not going to be able to analyze it yourself, you have to look at sources. My latest passion is trying to get teachers to focus on teaching how the science community is not a cabal and cannot make up facts. And why scientific knowledge is, in general, quite reliable. You should rely on it, like you would if you knew your house is going to burn down with a 99% chance. You change the furnace.

Alex Schier: Paul, you were very involved in the COVID pandemic and the politics. How did you deal with the uncertainty that Bruce described? Even friends of mine would say, "Well, you guys constantly change your mind. Why should I wear a mask now? You told me two months ago that I shouldn't." So how do you deal with this?

Paul Nurse: How was it dealt with in the United Kingdom? I'm no expert in infection and COVID. My message was pretty much to actually describe where we were and what we were doing. I was critical particularly of how the testing was done at the beginning. But this wasn't a problem just with the politicians. It was also a problem with us scientists. The way you can deal with a pathogen before you know anything about it is to separate infected from uninfected people. So that means you have to test quickly. The advice given to our government by the scientists was

that it will be more efficient if we had big testing centers, which could get high-throughput assays done. That's true, but not if it takes a year to put it in place. It was the right scientific decision in the long run but the logistics weren't in place at the start. I went on the news to say, look, we have already places that can test, like here at the Crick. We've got PCR (polymerase chain reaction) machines; we've got trained scientists who we've all sent home. If we actually activated all that infrastructure and people, we could get testing going in a month. But the scientists wanted the big testing centers and as a consequence so did the politicians, and also the private companies that made a lot of money. What we did here at the Crick was to set up, within a month, voluntary labor to come in and do the testing. And at one stage we were doing over 10% of all testing in the United Kingdom. We were protecting around 10 hospitals, 150 care homes. The reason it worked was because we made use of the local logistics already in place. Of course, we lost samples and things went wrong, but when that happened, you lifted the telephone and you found the samples because it was local. We had the logistics in place already so we just expanded the front end testing. If that approach had been rolled out everywhere, it would have been in place much more rapidly. If ever we have a pandemic again, this is the way to deal with it. The big testing labs would come later. So sometimes these things are difficult, and it's not always just the politicians fault, sometimes it will be the scientists' fault by not thinking deeply enough about how to deliver it.

Alex Schier: But, Paul, you were critical of the politicians. One view of the scientist is to only state the facts, to be an honest broker. As Bruce put it, you say, "Your house has a 99% chance of burning down." That's all you say. You don't say, "Change the furnace, change the curtains." But Paul, you were more of an activist. I heard you say that talking to ministers is "like talking to a blancmange. You sort of poke it, and it wobbles for a while and then more or less goes back to the original shape it had."

Paul Nurse: What I said was talking both to politicians and to scientific leaders was like talking to blancmange (which, by the way, is a kind of jelly). If you talk to them, they wobble for a while like blancmange and then return to their original position. Big institutions have got stasis built into them. For a big university to do what we did here at the Crick was difficult because by the time they'd gone through legal advice, health and safety advice, trustee advice, nothing happened. And so the universities shut themselves down.

Alex Schier: But is it okay for a scientist to voice opinions?

Paul Nurse: I think the point you're making is that the role of the scientist is to give the facts and not give opinions. My view of that is, yes, in a pure world, but when knowledge is uncertain, the scientist may well be expressing only an opinion. You also have to have an impact on society. And using the media can require more expressive language, like "blancmange." When talking about COVID-19 testing, I used a metaphor of the boats at Dunkirk. There were small boats collecting the soldiers as well as large ships. For testing, there is room for the small labs as well as the large ones. So you do sometimes have to be not pure.

Alex Schier: But how far should we go? There are climate scientists who are so upset about what's happening, they would glue themselves to an airport.

Paul Nurse: I was president of the Royal Society from 2010 to 2015. I was attacked a great deal by the climate change denialists, including some fellows of the Royal Society, some physicists in particular, because some didn't realize that different areas of science operate in different sorts of ways. We are all reliant on good evidence. But if you're a particle physicist working to many decimal places, then you have a different view than a climatologist. So I got some criticism. I decided to deal with it as far as I could by talking to them. The climate change denialists were often funded

by quite rich people and got airtime, and sometimes misbehaved. I said, Look, I'll connect you to Royal Society fellows who know about this, so you can have a discussion. Then immediately their public relations department would say, "The Royal Society is considering climate change denialists seriously." So they play politics. My view is this: You work with denialists who are antiscience and when it doesn't work, when they behave badly, you have to kick back. If they continue peddling mistruths, we have to bury their ideas. You have to do this forcefully.

Alex Schier: Bruce, how much of an activist can a scientist be without losing their credibility?

Bruce Alberts: When I was president of the Academy, I was pretty conservative. We let other people talk. When George W. Bush was president, we couldn't talk about climate change. We could only talk about climate change research. But later on in his term, we suddenly got a letter from the White House asking 12 questions about climate change, which were reasonable questions. They had asked for it, so they had to pay attention to it—it was a report back to the president. The report said that there is a 95% chance that climate change is human induced. This request with 12 questions really changed what we could say.

Paul Nurse: The US National Academy of Sciences and the Royal Society are somewhat different. The Academy is a much bigger organization and it's more closely integrated with government. The Royal Society is independent of government, but it is not independent of its fellowship, so there is a restraint on the leadership. But there will be differences of view. As I just said, some of the physicists had a different view from the climate change researchers. You can't shift too far away from what the fellowship as a whole would say. But we don't have to deal directly with government. Bruce could be liberated because of communications from the White House, whereas the Royal Society doesn't need that.

DEFENDING SCIENCE

Alex Schier: But we do have a problem, don't we? In the United States, scientists are popular with one political party but not the other political party. Republicans don't trust scientists anymore. What do we do about this?

Bruce Alberts: Well, the United States is really disappointing. I view the whole situation as a massive failure in our education system to teach people how to avoid "alternative facts." This whole idea that magical thinking is okay. It's just so dangerous. If one doesn't pay attention to what science knows, we're all doomed. Education systems have a tremendous challenge. We have to change how we educate young people so they can think for themselves and use evidence. People believe in the craziest things. Really intelligent people, like Republican senators, are afraid to say what they really believe. So it's all based on fear of their supporters, who are completely misinformed and believe in one conspiracy or another. It is just very disturbing. The only really long-term answer is to try to think about how education can make a bigger difference in creating adults who can deal with uncertainty and deal with what's true and what's not true. It is very hard. I've been trying to change science education in the United States for 40 something years, and I have not been successful.

Paul Nurse: What's sad about this is that the United States has always been a beacon of scientific endeavor, particularly since the Second World War. That is now being undermined by this political divide. It is less severe in Europe. The United Kingdom has had a right-of-center government for 14 years, but they were never antiscience. I worked with them a lot. They knew my politics were different, but they still worked with me, and they are supportive of science. We've had the attacks on Fauci being repeated in the more right wing press in the United Kingdom. These ideas

contaminate the world. This problem has taken root in the United States, and I think that we have to be really aware of that in Europe.

Alex Schier: What can we do now? Bruce hopes that if we educate six-year-olds now, in 20 years they're going to be smart rationale adults. That's a long time. What can we do now?

Paul Nurse: I think we do probably have to get into the political fray, because we have to have influence in the now. What I try to do is to say, "This is the evidence I know as a scientist but I am also a common citizen and have political opinions as well, which are separate from the science." However, whether anybody ever listens to that distinction, I am not so sure.

Bruce Alberts: I have a passion for a program, the AAAS (American Association for the Advancement of Science) Science and Technology Policy Fellowship, which started about 50 years ago in the United States, that transitions young scientists into positions in the federal government. When I was in Washington, DC, for 12 years, I saw people who understood science all around the government, in congressional offices and committees, and in the executive branch. It all started with the idea that the AAAS would raise money to fund a one-year salary for a selected group of young PhD scientists and offer them to congressional offices and congressional committees. It turned out that half of those people went back to science after the year, and half stayed on to work in policy. Over the years, the number of these people in Washington, DC, grew, and they became the adapters between what the Academy and scientists think and what the politicians and government employees think. Fifteen years ago, we started the same thing in California. And just like in Washington, half of them have stayed on. And now in the California state government these people network with each other and bring evidence-based decision-making to California, which it really lacked. They often deal with legislation that pretends to have scientific evidence to back it, because everybody wants to say science supports them, but much of it is just fake. So they've helped to bring scientific thinking to legislation.

Paul Nurse: The Royal Society has been running a similar program for 30 years, where you go and shadow a member of Parliament for a period of time. My own daughter, who's a physicist, did this when she was a postdoc. Later, she became a particle physicist and full professor at UCL (University College London). But a year or so ago, she came to me and said, "I think I'm going to switch to something more useful, because the Large Hadron Collider (at CERN) isn't producing much new physics; it needs a bigger ring." She joined the Climate Change Committee, which is a civil service committee that doesn't report to a minister or a department, but reports to Parliament, so it is completely independent of politicians.

Alex Schier: Another political aspect is science diplomacy.

Paul Nurse: Yes, and science is a tool of diplomacy, because science speaks a common language across nations, even quite different sorts of nations. Scientists often can be the first to open diplomatic doors. We had Pugwash Conferences on Science and World Affairs in cold war times, but now it is the United States–China relationship that is in the deep freeze; keeping science contacts between them is important.

Bruce Alberts: I'm part of an academy committee that's trying to do that and create high-level trust between Chinese and American scientists. We scientists have a special role to play, and it's not been enough used in the world. It needs much more emphasis, as it provides an important connection between countries. In this context, I want to mention one other program that I've been passionate about. It was started by the Germans, the idea of a Young Academy, where young scientists become involved in science-informed decision-making. Now there are Young Academies in more than 50 countries. The Young Academy movement is really a very hopeful, important

development for science, because young people are more energetic and think differently than we do. I discovered quite recently that in the Netherlands, they have extended the Young Academy idea to all of their major universities. Now I'm trying to get our university to be the first US university to have a Young Academy. The basic idea is to get young volunteers to apply, 35–40 years old, and become future leaders. They have to promise to devote at least six hours a month to this. In Germany, it was brilliant because they empowered this young group with a small amount of resources to do whatever they wanted. They didn't tell them what to do. They had to come up with their own ideas. That's exactly what all universities need. All countries need it. The world needs it. If I were a billionaire, I would invest in this Young Academy movement everywhere, because many of them exist on no resources at all. There's a Young Academy in Indonesia that has been really effective in a very difficult situation. They're not effective enough, because the government often doesn't listen, and they have zero money to do anything.

Alex Schier: How can we defend the sciences and scientists when a government tries to undermine, discredit, or even destroy them?

Bruce Alberts: This is a very pressing problem for us now in the United States. There are many successful politicians who want to suppress the truth whenever it interferes with their supporters' prejudices or priorities. This has long been obvious with respect to climate change, but now it extends very broadly, for example, to immigration and critical medical issues. Because most scientists are addicted to truth-telling and reality, we can be viewed as an enemy to be destroyed by such people. How to defend against that? Even though the public derives enormous benefits from science, including a doubling of average life span, too many are completely unaware of that fact. For that reason, our Academy produced 18 small pamphlets in the 1990s, titled "Beyond Discovery: The Path from Research to Human Benefit" (National Academy of Sciences 1996). Each explained how one important innovation arose, and included a graphic timeline—tracing the eventual development of GPS systems all the way back to physicists' discovery of atomic clocks, for example. We all need to do that again, and much more broadly, taking advantage of social media and YouTube. In addition, the strength of the United States in science and technology has been a major driver of America's economic prosperity and the world leadership that results from that. This needs huge emphasis, inasmuch as even our most antiscience politicians are concerned about us being overtaken by China.

Paul Nurse: Indeed, this is unfortunately happening in the United States right now. Scientists have to organize, they have to protest, they have to make their case to the public, and they must speak constantly to the politicians with evidence and courtesy. They must never give in.

Alex Schier: Let me end by asking, What do you think were your biggest frustration and biggest success as a scientist-politician?

Paul Nurse: My biggest frustration? I wanted the Royal Society and the Royal Institution (which is a more public engagement education body) to merge so there would be one single public-facing part. I even raised money from the government to do it, but it didn't happen.

Bruce Alberts: My biggest failure was not fixing science education.

Alex Schier: Biggest success?

Bruce Alberts: I got the Academy deeply involved in education, scientific views of education—not just science education, but the science of education. We did a major report when I was there titled *How People Learn* (National Research Council 2000). That report has had a dramatic effect on how people think about pedagogy. But I think my greatest legacy was this textbook [*Molecular Biology of the Cell*]. It was first published in 1983. Now it's become 14 different editions of two

books. As I go around the world, I think that it has had a substantial effect on young people who read it and realized that they had a scientific mindset and wanted to become scientists. All of these people who have become scientists because of the textbook, that has been very rewarding to me.

Paul Nurse: I think probably putting the Crick together was quite a success. In the Royal Society, another success was making it more open to society, to get out there more in the media and explain science, whereas traditionally it was thought that all the influence had to be behind closed doors. A third one would be the climate change debate, which was quite important at the time, because it influenced decisions in the United Kingdom. Science is part of society. And I think thinking of how science can impinge more generally on society, and education is a major aspect of it, is what I think we should strive for. There are two objectives. One is putting science at the center of government. And the second is to put science into society as a whole. Scientists are part of society, not a high priesthood separate from society. I'm not quite answering your question, but that outcome would give me pleasure. Science cannot be properly pursued unless it has the society's support, and it can benefit society in all sorts of ways. There is joy in seeing rationalism exported from science into society.

Alex Schier: Last question. What advice do you have for young scientists who have doubts about their future?

Paul Nurse: If you have the passion to understand the natural world better, then stick with it if you can. It will deliver a very worthwhile life.

Bruce Alberts: Hang in there! The world badly needs you in whatever way you chose to use your scientific expertise in the future—research, teaching, policy, communications, administration, advocacy, or just spreading rational thinking in a world threatened by magical thinking.

Alex Schier: Thank you so much, Bruce and Paul!

DISCLOSURE STATEMENT

A.F.S. is an advisor to Novartis. The authors are not aware of any other affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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