Ken Ono

Ken Ono is a number theorist specializing, among other things, in integer partitions, modular forms, Umbral moonshine and the Riemann hypothesis. He is the Thomas Jefferson Professor of Mathematics at the University of Virginia and is a Vice President of the American Mathematical Society. Ono received his Ph D in 1993 at UCLA and has received many awards including the Prose Award (Best Scholarly Mathematics Book), Association of American Publishers in 2018, NSF Director's Distinguished Teaching Scholar Award in 2005, the Presidential Career Award (PECASE) in 2000 and National Science Foundation CAREER Award in 1998. He has also won a Sloan Fellowship a Packard Fellowship, and a Guggenheim Fellowship. In 2012 he became a fellow of the American Mathematical Society. He was an associate producer and the mathematical consultant for the movie *The Man Who Knew Infinity* based on Ramanujan's biography.

During his visit to India during December 2019 as the Jubilee Chair Professor 2019 of the Indian Academy of Sciences, Ken Ono was interviewed by Tirthankar Bhattacharyya. Transcription of the interview is by S. Priya.

We would like to know a bit about your journey. What motivated you to take up mathematics and not something else? Did you ever consider taking up something else? Often one finds oneself in the situation that one is able to do many things somewhat well. Was that the case for you or were you always, as far as you can remember, focused only on math?

My father was a mathematics professor at the Johns Hopkins University at Baltimore, Maryland. When my parents discovered that I had talent for mathematics, they decided to raise me in the image of my father, and for as long as I can remember their plan for me was to become a mathematician. In fact, I have very clear memories of the time when I was in primary school. In summer breaks, I would sit at my little table doing my geometry while my father would sit at his large desk next to me doing his research. I grew up with the parental expectation that I would be a mathematician. However, by the time I was in middle school and certainly by high school, I came to think of mathematics as nothing more than a collection of problems that one was supposed to solve very quickly and with near perfection. Just tests and exams. As a result, there was a fairly long period in my life when the last thing I wanted to be was a mathematician. It took me a long time to come around. The story of Ramanujan was told to me in my tenth grade, and it marked a turning point in my life. I learnt for the first time that mathematics could be something beautiful (which came as a big surprise to me), as opposed to a just a set of skills meant to be mastered to perfection. That is when I started perceiving mathematics as an art form in its full beauty, like music, for example. To answer your question as to whether I was good at many things, I would say absolutely not. If you ask me to compose a poem or draw a landscape, I wouldn't be able to do it as I don't have those gifts. In my case, I am somewhat lucky as my talent for mathematics is like the apple that did not fall very far from the tree. Owing to my father being a mathematician, and also thanks to the nurturing I received early on, I ended up building some skills in mathematics.

Often the talent for mathematics and physics are seen together. And of late, your work has been connected to physics. We would like to know whether this was coincidental or something that you have worked towards consciously?

During my elementary school years, I wanted to be an astronaut. As other scientifically inclined kids, I was infatuated by Carl Sagan's book and television series *Cosmos*. At that time, I wanted to understand this great, vast universe in which we live. However, by the time I was in graduate school and for well over half my professional career, my science has been directly related to pure mathematics. Fortunately, the functions that I studied as a mathematician often happened to be functions with roles beyond pure mathematics. By the time I was a full professor, I began to learn that some physicists, string theorists in particular, were interested in some of the functions that I was studying. I was invited by physicists to give lectures about my mathematics at conferences. Though I was petrified, it was quite reassuring that the string theorists really wanted to understand the mathematics. I also wanted to learn some string theory and this is how best of collaborations are born. Thus, to answer your question, in a way it was quite accidental. If one is lucky enough to work in rich areas of science, which certainly applies to pure mathematics, the time might come when one's ideas are needed. It is possible that such a time won't materialize in one's lifetime. In my case, I am lucky that some of these subjects have become important. There is also a debate as to whether string theory is genuinely part of physics as opposed to being part of mathematics. Some physicists even say that string theory is mathematics; in which case maybe I have not strayed very far.

This debate is well known and is perhaps fuelled by the fact that in string theory, you cannot do an experiment by going to space.

Quite honestly, I think it is definitely true that the string theorists and mathematical physicists have the benefit of underlying 'agreed upon' physical principles. This has been a rich source of mathematics. There have been definite instances where applying physical principles to mathematics has resulted in precise questions in mathematics that the mathematicians did not come up with themselves, only to later discover that this thinking resulted in brand new fields of mathematics. Mirror symmetry and umbral moonshine offer two prominent examples. This collaboration has been a very profitable symbiotic relationship.

We shall now come to a topic which is very relevant to India. I have read multiple times in your interviews that Ramanujan has affected your life at crucial junctures. Could you tell our readers about Ramanujan's influence on your life?

I can talk for hours on this. I am going to surgically address your question as many questions. I would first need to answer the question – Why do role models in science matter? Students need role models that they can look up to. It can be difficult times for a student completing his/her Ph D. There are many periods in one's life where one could be discouraged by difficulties. However, as we all know, the sweetest rewards are the ones that are obtained by overcoming difficulties. So, for a young student, Ramanujan is the ultimate role model. He overcame racism, distance and the absence of formal training to ultimately earn a fellowship in the Royal Society. This indeed is quite inspirational. In Ramanujan, you have the story of a man who overcame many obstacles in his life. He was born in the late 19th century India at a time when India was a colony of the British Empire, when circumstances were difficult for anyone. From such difficult circumstances emerged a young man whose ideas, expressions and formulas were so creative that mathematicians of the world at that time struggled to make any sense of them. Ramanujan found a saviour in Hardy, even though Hardy was well known to have very few friends, to be arrogant, and to have had personal feud with God. In spite of all these colourful aspects of Hardy's personality, the fact remains that in Hardy, Ramanujan found an incredible mentor who made it possible for Ramanujan to have access to the library at Cambridge and the larger scientific community in general. Hardy ultimately saw to it that Ramanujan's ideas saw the light of day. So, for students Ramanujan matters because he offers hope as a real life human being to overcome obstacles. Being a student is difficult, I have never met anyone who said that it was easy doing a Ph D. The true story of Ramanujan gives hope to students, and it illustrates the important role of mentors, as imperfect as they might be.

Ramanujan was a school dropout and worked at the Madras Port Trust to make ends meet. Despite his circumstances, he continued to do his mathematics. What if he had given up on mathematics? What if he found it too difficult to continue? Well, some of the string theory questions would remain unsolved, for example. Is that not a great story of hope?

Why else does Ramanujan matter? He matters for his mathematics. The famous part of Ramanujan's story in terms of his legacy can actually be classified into two parts. First of all, there is the work that Ramanujan left behind in his notebooks and the papers that he wrote while he was in England. There were many great formulas there. That body of work alone was so substantial that he was the first Indian scientist to be elected a fellow of the Royal Society. And he achieved this at the young age of 30. In England, Ramanujan and Hardy invented a method called the circle method – it is a fundamental tool in analytic number theory, which people to this day are still perfecting. People working on harmonic analysis and those working on famous open problems in mathematics such as Waring's problem need it. In two deeply influencing papers, Ramanujan and Hardy developed a method for the simple problem of counting how many partitions are there for an integer. It is one of the first questions you can ask in number theory. As is typical in mathematics, some of the simple problems turn out to be difficult.

The second part of Ramanujan's legacy is far more important. In mathematics, there is an award called the Fields medal. It is awarded every four years to mathematicians who are not older than 40, and the mathematicians of the world, particularly the International Mathematics Union recognizes the very best in mathematics among young scientists. I work in number theory, and number theory is one of the oldest, most traditional subjects in mathematics. It turns out that many Fields medals have been awarded in number theory. Now that we are coming up to Ramanujan's 100th death anniversary, I have encouraged people to think about writing a story or a book in which all the living Fields medallists who have worked in number theory are interviewed and asked one simple question – 'What does Ramanujan mean to you?' It would be startling to see how the answers vary from each Fields medallist who has worked in the field. Atle Selberg, who was a long time professor in the Institute of Advanced Study, ended up pursuing mathematics because he learnt about Ramanujan in high school. His first paper was about Ramanujan and his most important contributions in the theory of automorphic forms are largely born out of and related to papers of Ramanujan. Jean-Pierre Serre is a French Fields medallist. He made conjectures that Pierre Deligne, another Field's medallist would later prove, proving what are called the Ramanujan conjectures, which Ramanujan formulated quite innocently in one line in a paper that could have easily been lost. Wiles' proof of Fermat's last theorem is written in the language of Galois representations. It is a very specific type of mathematical construction that combines algebra, topology, algebraic geometry and group theory. It is a beautiful subject whose existence was conjectured by Serre, who in studying Ramanujan's notes noticed that some of Ramanujan's formulas were actually proven in a very awkward way, i.e. in Ramanujan's own magical way. Trying to understand these formulas, Serre developed the Galois representations which thirty years later would become the 'language' in the proof of Fermat's last theorem.

I could go on and on. I started by saying he is a role model, a perfect role model for students because of the difficulties he overcame. The second answer was that the mathematics he produced in his lifetime was breath-taking. But his true legacy lies in the gifts that he gave to the best mathematicians of the world who saw glimpses of his theory from bizarre-looking formulas that Ramanujan wrote down. It encompasses a breathtaking cross section of modern mathematics and is now touching string theory, signal processing and many other different fields.

There is a third answer. You could ask – Why would Ramanujan matter to anyone who doesn't care about science? I regret to say that presently we are struggling worldwide with this rise in the dumbing down of the world. Science has somehow been belittled in my country and the world over. This is something that we have to fight because mankind is facing many obstacles, be it climate change, need for green energy, loss of resources, etc. This is why entities like the Indian Academy of Sciences matter. Ramanujan did not work on climate change or green energy. But even to the naysayers Ramanujan matters because we have this incredibly beautiful collaboration between a British and an Indian scientist in early twentieth century that changed analytic number theory. Science usually proceeds by the work of thousands in small increments, either in a laboratory adding in the form of an experiment, or carrying out an analogous computation. But at what point in time does science really take some major steps forward? When people like Newton or Einstein come along. And it is absolutely clear that in Ramanujan we have someone whose ideas have propelled science forward. My point is that collaboration between two different people from two different countries and cultures was required for this advancement to happen, and that is a lesson we can all learn today. Scientific and political collaborations are the exact opposite of classifying people into little convenient groups. It is utterly important and in Ramanujan, we had that.

I cannot think of a single example in mathematics from North America that begins to approach the aura of his true story.

What about the world?

I think you could argue that in algebraic geometry, Alexander Grothendieck had this property, quite singular. People are still perfecting his ideas. But in terms of the whole scope of why Ramanujan matters, I cannot think of anyone who has all of those features.

You have been involved in the film – '*The Man Who Knew Infinity*'. *You travelled to Pinewood Studios. I have seen a photo of yours explaining mathematics to Dev Patel on a blackboard. As a professional mathematician, how did you feel spending time on the film? I suppose you enjoyed the work in the film or would you have rather spent the time on mathematics?*

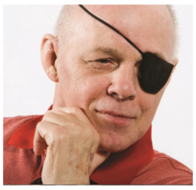
I explain Cauchy's integral formula to Dev (laughs) in that picture. In our profession, nobody trains you how to portray your field for a Hollywood film. There are no courses that teach you how to do it. If I give a lecture and two hundred people turn up [Interviewer's note: Ken Ono has given Ted talks], I am ecstatic. But a multi-million dollar film wants hundreds of thousands of people to see it. Working on the film was very exciting. As you can probably tell, I am passionate about this story and I think that the reason that it was so much fun is that I had an audience of professional film makers who really wanted to understand something that I was passionate about. The actors genuinely cared about telling the true story. Since this was a Hollywood film, some artistic licenses were exercised. I think most mathematicians will agree that the actors did a great job of playing the roles of mathematicians. In Dev Patel and Jeremy Irons, you have two famous actors who took their roles very seriously. The photo that you are talking about originated because Dev and Jeremy Irons told me that I had to teach them some mathematics – not so that we understand the mathematics, but so that we understand how mathematicians talk. We did hours of that. Both Dev and Jeremy care about their own craft. We filmed in the summer of 2014. That is the same time the film *Batman vs Superman* was going into production. And Jeremy Irons was playing Alfred Pennyworth, Batman's butler. We were nearly unable to get Jeremy because of this conflict. But Jeremy made it a point to play a distinguished Cambridge mathematician. Irons likes to choose sophisticated characters. In G. H. Hardy, he found one of the most interesting and intriguing people – a man with no friends and who could barely tolerate his own image in the mirror. Irons read *A Mathematician's Apology*. Irons asked me to help him get into this man's mind. That is when I knew that Irons liked artistic challenges. Jeremy did a wonderful job. His facial expressions reveal many of the qualities that we generally associate with Hardy. The film occupied a lot of my time from preproduction to filming to the rehearsals and then finally the promotion of the film. But one cannot do math all eight hours a day. If I can work productively for an hour or two a day without interruption, if I can get two hours a day every day without interruption, that is pretty good. And sometimes those hours come at a time when I am on an airplane or when I am driving to work. On the sets, with several retakes there was so much downtime that I could actually find the peace and solitude to prove a couple of theorems on the set.

I think the readers would like to know about your favourite piece of work and why that is favourite.

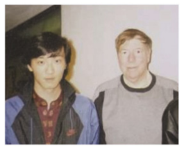
Partition functions are one of my favourites. The partition function p counts the number of ways of adding up positive integers to get a given number n. The point though is that we don't allow for reorderings. The famous example is $p(4)$ where there are 5 partitions of 4, i.e. 4, 3+1, 2+2, 2+1+1 and 1+1+1+1. I have proved a number of theorems about this function $p(n)$ and what I like about them is that they were inspired by Ramanujan. Ramanujan proved that every fifth partition number starting from 4 and thereafter, like $p(4)$, $p(9)$, $p(14)$, $p(19)$ and few other special sequences remarkably are all multiples of 5 and/or are multiples of other designated numbers, depending on the sequences. Ramanujan found these rules in terms of factoring by 5, 7 and 11. So $p(5n + 4)$ is always a multiple of 5. About 20 years ago, I came upon an idea where I could fit these identities of Ramanujan into a much larger framework and I ultimately proved that there were patterns for every prime number, except for 2 and 3. They are ubiquitous, but the rules tended to be much more complicated than what you could spot and easily describe as I just did to you. I was very proud of that. Similarly there is a famous formula for $p(n)$, an asymptotic close approximation that Hardy and Ramanujan developed that was later perfected into an exact formula by the German mathematician Rademacher. However this exact formula has a curious property. To exactly calculate the number of partitions of a number, Rademacher's exact formula required adding up infinitely many numbers that slowly converge to the exact answer. So Rademacher's exact formula has the property that if you add up enough terms, at some point you can prove that you are close enough to the actual values and rounding to the nearest integer gives you the right answer. It's a procedure that gives the right answer and gets longer and more complicated as the numbers you are trying to compute grow. Jan Bruinier and I found a finite formula for $p(n)$ as a finite sum of algebraic numbers that could be computed very quickly using the theory of congruence for elliptic curves and it is a finite number.

Probably my favourite paper in the last six years is a joint work with my friend Don Zagier and two of my former students Larry Rolen and Michael Griffin. We wrote a paper about the Riemann hypothesis. It is one of the most difficult open problems in mathematics and we don't expect to prove the Riemann hypothesis. What we want to do is understand the Riemann hypothesis. It is a problem that Riemann posed in the 19th century because he wanted to understand the distribution of prime numbers. We really want to know where the prime numbers live in the number line. They eventually become very rare, but not so rare that there aren't infinitely many of them, and because they become infinitely very rare, the problem of estimating locations remains quite difficult. So, if you prove the Riemann hypothesis, this would be the gold standard for locating primes as we walk among integers to infinity. So, although we don't prove the Riemann hypothesis, we revisited some old work of mathematicians by the name Jensen and Pólya. In the 1920s, they had developed a criterion equivalent to the Riemann hypothesis. If you could check this criterion, it implies the Riemann hypothesis and if this criterion is false, it proves that the Riemann hypothesis is false. We were able to make some great inroads into this criterion and just loosely speaking we proved that this criterion is actually true almost all of the time. Almost all of the time doesn't forbid the possibility that it is false occasionally. This criterion has infinitely many cases and we show that virtually all of it is true. We are quite pleased because, by proving that, the four of us feel that we have a better understanding of what the Riemann hypothesis is all about, because of which we find it even more terrifying. It turns out that the theorem we prove illustrates that the Taylor coefficients of the function called the Riemann zeta function have very little wriggle room. If you perturb some of those Taylor coefficients a little, the Riemann hypothesis would be false. If you study our proof, you realize that there is basically only one path that could possibly be compatible with the truth of Riemann hypothesis and this is why it is very hard. Being stuck between a rock and a hard place is where you don't want to be. However, in case of the Riemann hypothesis that is where we want to be because there is no wriggle room and we can't find a way to squeeze in between the rock and the hard place. Usually, you are proud of a theorem because you developed tools or solved a conjecture. But in this case, it was a great satisfaction to come face to face with a difficult problem to understand for yourself why the problem is difficult. That a problem is not solved is not convincing enough for me that it is hard. To properly understand why a problem is difficult is also a great satisfaction. No one will prove Riemann hypothesis by extending our method unless something new is discovered. We know that we are missing some idea. I believe that the Riemann hypothesis is true.

We would like to know about the people, other than Ramanujan, who have influenced you. You have not met Ramanujan. So, tell us about some real life people who shaped your life.



There have been many. For the purposes of this interview, I would like to identify a few very important people. When I was in college at the University of Chicago, which was academically rigorous, I was not the best student. I was a poor student. It would have been very easy for the faculty in the math department to write me off [with a smile]. When I go back now, no one remembers that they could have written me off. They are proud of me. But that was not the reality when I was there. But there was a professor by the name Paul Sally, who worked in representation theory and was a legend among the undergraduates at Chicago. He was a towering figure with a booming voice. He was genuine and in his straight forward manner, could see through the students. If someone was struggling, he could see through it and offer help. For me, he could see that I was struggling internally as I wasn't yet ready to accept the idea that I could be good at mathematics and enjoy it. I was hoping to be something else at that point. I ended up meeting with him once a week and he transformed me largely because he turned out to be very much like me. He never intended to be a mathematician, he wanted to play basketball and he ended up working as a cab driver in Boston. One of his fares, in his early twenties was Ray Kunze, a professor at Brandeis. They started chatting and somehow Ray Kunze convinced Paul Sally to apply to the graduate school at Brandeis and ten years later, Paul Sally was a professor at Chicago. You have to give yourself permission to fall in love with the subject and Paul Sally taught me that.



My Ph D advisor at UCLA, Basil Gordon was an amazing man. He was a descendant of the British royalty. Ironically, they immigrated to the United States and settled in Virginia. The Gordon family was one of the first families to settle in Virginia and the name of one of the early Rectors of the University of Virginia, where I work now, was Basil Gordon and my Ph D adviser was named after him decades later, which was ironic. Basil was a gifted man in music, arts, literature, mathematics and so on; he was a renaissance man. He was good at everything. He got two Ph D degrees – one of them with Richard Feynman. One of his first jobs was with NASA. Because he was independently wealthy, he did not have to work. He offered to teach at UCLA. There is something very special about the relationship I had with him because here was man who did not have to work. He worked because he loved intellectual things. He was a surreal man. When you are a graduate student who is just starting out, the thought of taking all of the classes and qualifying exams and memorizing all proofs, can be really daunting. In particular, the level at which you have to master these subjects always goes far beyond what the expectations are in college and it is frightening what you have to step up to. The meetings that I had with Gordon were never about those requirements or about those courses. Rather, they involved discussions about the beauty of the subject. We often met at his home at Santa Monica in the comfortable confines of what might be called a museum. I was a protégé or an apprentice – someone of whom he would take great care. His point was when you set out to do mathematics, it would be difficult, but if you do it right, then something beautiful will emerge. So, why start with equations unless one sees the beauty first? I was worried that in four years I had to finish a thesis, start looking for jobs etc. And he was so right. All of that automatically happens if one sees the beauty.

The third person I want to mention is Andrew Granville, who happens to be one of the most influential analytic number theorists of modern day. He was brass. The first thing you realize when you meet him is that here is a confident man who is not afraid of tackling difficult problems. Usually when you attack a problem in science, you want to master all the literature related to the problem, so that you can maybe find the glimpse of an opening, an entry way into what might become a solution. When I was Andrew's post-doctoral fellow that was the last thing he wanted me to do. He wanted to craft or understand for himself why people struggled with an open problem. I thought that was crazy. What I learnt from Andrew is that you can be reading all day long and leave no time to do your own work. You have to give yourself permission to try to solve a problem, be willing to fail, fall face first in the dirt, get up, brush yourself off and try again. If all you do is read, then you become a librarian of mathematics. By no means, I am suggesting that one should not read. Make no mistake. Reading is necessary. But if you go into a problem mastering all the literature that fell short of solving the problem, you might brainwash yourself to be the next person to fall short of the goal as well. What I learnt from Granville is being part of the majority is not a good thing. By definition, there are already many people in the majority. If we want our work to be important, we need to think that way, but be willing to accept defeat when progress can't be made, but then wake up to fight another day. I thought that was amazing. It is interesting that I am in India at this time for the Jubilee lecture tour. I chose this time period because Ramanujan's birthday is coming up on 22 December and every year, a very prestigious prize is given out to a young mathematician not older than the age of 32. It is called the SASTRA–Ramanujan prize. This year, I am going to travel to Kumbakonam to help award the prize to Adam Harper [Interviewer's note: Adam Harper is a mathematics faculty member at Warwick University. He has, among other things, improved earlier results obtained by Kannan Soundararajan and Andrew Granville.] Andrew Granville is a distinguished mathematician. But, there is one more reason why he should be world famous. SASTRA prize winners are shooting stars, many of who have gone on to win Fields medals later. The ability to identify world class talent at a young age is something that the SASTRA prize committee is very good at doing. Granville has mentored an incredible number of SASTRA–Ramanujan prize winners. Granville mentored James Maynard, Adam Harper, Kannan Soundararajan, Ben Green, me and many more. By the way, one of the experiences I share with him is a few years ago we went to the Trinity College library and looked up Ramanujan's old notes and found some formulas which no one had noticed before.

Thus, mentors like Hardy exist today, sometimes in the form of people like Paul Sally, Basil Gordon and Andrew Granville.

That brings us to your own mentorship. You are a very successful supervisor with 31 students. How do you do this and what is your advice to other Ph D supervisors who want to ensure their students become mathematicians who enjoy what they do?

Building on the previous discussion, I think I have learnt a lot from my own mentors. Genuine enthusiasm goes a long way. I develop a relationship with all of my students, which is very open, communication channels are very honest and that helps. If a student does some great work, or makes a great observation that could be of potential use, I celebrate that. If someone isn't making good progress, I don't sugarcoat it. I tell that may be we need to revisit our progress; we are not being very productive. I don't generally meet with my students weekly for an hour. I rarely meet with students for as long as an hour at a time. I run into them at the mail room or they come into my office and spend a quick 10–15 minutes discussing a particular problem. I do not generally use the language of Ph D supervisor or Ph D student. I am officially their Ph D advisor, but I would hope to be something a bit better than that. By the time that they are ready to defend their thesis, I want it to be absolutely clear so that it goes without saying that we are colleagues. I make it a point actually, towards the end of a student's career at graduate school, after a seminar or after acceptance of their paper, to have a conversation at a very high level where nothing is written on the board and we are talking about mathematics. I emphasize to them that their ability to engage and converse at a high level is what qualifies them to be a professor. They may not have their Ph D yet, but the ability to engage and converse at a high level is a quality of professors. So maybe how I train my students helps somehow to achieve this.

Although scientists from different disciplines have different approaches, it seems to me that the common thing that binds us together is the inquisitiveness. What are your thoughts on mathematics as a profession vis-à-vis other sciences?

If you work in pure mathematics or for that matter also applied mathematics, ideas are often very hard to quantify to people outside the field. In fact, even among fields within mathematics, often it can be very difficult for people who are experts in one subject to communicate with people who are experts in other subjects, almost to the point where they cannot even read the first sentences of each other's papers. This is part of the nature of mathematics because it is embedded so much in terms of terminology, language and the framework which we require to be able to do our work. So, it is incumbent on us in our field, in particular this is a responsibility of all scientists in all fields, to take great steps. Some critical mass of experts in each field really need to champion the cause of promoting one's field to others in such a way that the sciences can uniformly get together and present a very clear message that science is important for mankind. Presently, there is a situation in many countries of dwindling resources towards science. So, one starts counting which field gets what amount of grants. This is terrible. So, the differences in different kinds of scientists, though true to a certain extent, shouldn't be viewed as a negative. They should really be viewed as a positive, as there could be opportunities to bring together people with different types of expertise so that our body of knowledge grows. So, I am not asking every scientist to do it. So, what I am asking is that the senior leadership in the mathematical societies, physical societies, chemical societies, need to take this on as an important challenge, without which science begins to start losing its way. Then the questions tie together. I am sure entities like the Indian Academy of Sciences recognize this need and organize events where from time to time, leaders of different fields get together and share their ideas so that we realize that what one does is a small part in what is called science. It is happening and one has to pay attention to the examples which highlight this. My friend P. P. Vaidyanathan is a distinguished electrical engineer at CalTech who works in signal processing which is about as applied as mathematics could be. He won the Kirchoff prize. He recognized a need for some mathematical functions. He approached some mathematicians and the mathematicians told him that, by the way, we have been using these functions, called Ramanujan sums, in relation to Waring's problem. Number theorists have known about these functions for a long time. It was wonderful to bring mathematics to this very engineering problem. The stuff of string theory and quantum computing is also this. So, this interaction between mathematics and engineering is all around us. I heard a lecture recently by Peter Sarnak, one of the most important analytic number theorists. He was talking about quantum gate design and the role of lattices and modular forms. I knew nothing about these, but when he explained the framework, it became clear that mathematics could play a role. So, I am not saying that everyone has to do this, but the leaders should recognize this because we are all part of the same enterprise.

What is your key message for the younger generation?

We now live at a time where we over test our kids. Kids from an early age are trained to believe that a certain small number of tests taken at critical points in their lives will define their lives. Some of this was true when I was growing up, but it is definitely truer today. We live at a time when we have to rank and quantify things. We rank universities and people spend a tremendous effort trying to tabulate these rankings and move up these rankings, as if anyone believes these rankings are accurate. We have forgotten what's important, and this is confusing for students as to what they should be really doing. The point of college is that you grow and mature into someone whose ideas can matter, and then ultimately become an adult who can make the world better in one's own way. But everywhere I have taught in the last couple of years, even 21–22 year olds think that it's important to get the right test score on their graduate admission score. When did we lose sight of the fact that the quality of one's achievements and character is what actually matters most?

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