Chief Guest's Address by Dr. Venkatraman Ramakrishnan
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I would like to begin by congratulating the winners on their wonderful achievements in such diverse areas that show the remarkable breadth of science. Now, prizes are not the goals of scientists, or at least they should not be, although sometimes human emotions get in the way. Rather, they are milestones in a long journey. If you were to ask any of these prize winners how they decided to embark on their journey - which is unfinished I should add - none of them would say, 'Oh well I thought there would be a big prize at the end of it.' It's much more that they found a question they were fascinated by, they saw an important problem and they went on to work on that. But having said that, prizes do serve a useful purpose, which is to give science publicity and also to produce good role models for young people. I mean, all sorts of people get publicity. We give sports people a lot of publicity. We give actors lots of publicity. But scientists are usually quietly working away – away from the glare of publicity. It is nice, once in a while, to recognize them for what they do because what they do actually has a much bigger impact on us than virtually any other profession. And the Indian science community should therefore be grateful for a major award for scientists, especially those who are working in India.

Why is science important and why should we pay attention to it. In the broadest sense, science is really a term for knowledge. Paul Nurse has pointed out that it comes from the Latin word 'scientia'. And, he has also said you can think of it as broadly divided into three kinds of science. You can have basic research – simply the acquisition of new knowledge about the natural world. You can have applied research, which can be basic but aimed at specific objectives and outcomes. And you can have translational research which is a bridge between basic and applied research or goal oriented basic research. So, you know, for example cancer biology falls into that sort of intermediate area. And technology is the skilled production of goods and services which relies on knowledge about the world in order to apply it. But, it is not a linear relationship. Many people say that basic science leads to applied science which leads to technology – as if it was sort of a one-way traffic. But it is a very complex intertwined web. A simple example is quantum theory, which was fundamental science that eventually led to transistors and lasers. Those, in turn, led to computers and new devices which in turn are driving new fundamental discoveries. So, sometimes things come full circle, sometimes they go hand in hand. There is no particular paradigm except to say that it is a complicated interlinked web.

One thing I should say about basic science is that it can lead to entirely new technologies that you could not even have imagined. And sometimes this happens decades or centuries later. A favourite example I like to give is Michael Faraday who was investigating the laws of electromagnetic induction and apparently some leading light visited him and said, 'well what good is it'. And he said, 'well, one day you may tax it.' And of course if you were to estimate tax on electricity today (and the way we generate electricity is based on Faraday's laws of induction), it is probably trillions of dollars. That's quite a lot of tax.

But it took a long time between Faraday's laws of induction, to electricity being a general feature of life. Even in this room, electricity makes it possible to actually listen to me through the speaker system. Another example is Newton's laws and satellites. Newton's laws of motion governed for example the satellites and the rockets that were launched to Mars depend very much on Newton's laws of motion. But to go from Newton's laws to satellites took about 300 years!

I will give you an even stranger example. When Einstein discovered the laws of special and general relativity, one could not have imagined that these extremely small changes in time – as a result of relative motion – would have any practical application. But I can assure you that without special and general relativistic corrections, none of your GPSs would work. So, today, relativity is present in every smartphone that you use to figure out where you are going. And that took about 100 years.

It can also happen in entirely unexpected ways and even faster. For example the internet was really designed to have a computer system that was resilient to failure - you could have a network of computers - and it was funded by the defense department, DARPA (Defense Advanced Research Projects Agency). That led to the internet. But even after the internet, high energy physicists wanted to figure out easy ways to exchange information that could be both visual and quantitative. That led to the World Wide Web. And no one imagined that out of high energy physics would emerge an application you would use to do your shopping or order services or even food. Science has not only transformed our world, but it has also brought enormous benefits to health. Life expectancy, for example, has doubled in the last century. A lot of that, not all of it, is due to common sense in public health measures. But a lot of it is due to scientific and medical advances, medical advances that depended on science. Even if we ignore all the benefits that science brings, it is a great triumph of human understanding. Imagine if we were to go back two or three hundred years and we were to talk to the smartest people of that time and tell them that we understand the molecular basis of inheritance – something that puzzled people for centuries – how do we inherit traits, why does a child look like his/her parents, why do fish when they mate only produce fish and why don't they produce frogs. If we were to go back in time and tell them that we understand how this molecular transfer of information works from one generation to the next, how a single cell can grow into an organism, this is a triumph of human understanding. It is as much a part of our culture as art and music and literature.

Finally, virtually every product you think of has basic science that underpins it. I mentioned how the smartphone and electricity is based on science. You can just imagine almost any gadget or tool that you use and you will find that there is some basic science involved at some point without which it would not have been possible. And many top companies today, if you look at the top ten by capitalization, did not even exist fifty years ago. More importantly many of their industries did not exist fifty years ago. And that shows you how transformative science and technology have been.

How to we achieve this sort of science and technology in a society? I am going to be accused here of practicing some economic history without a licence – you have heard that I am a physicist turned biologist, so I am no better at it than any of you. But I will just give you my thoughts. One of them is that natural resources don't seem to be as important as knowledge or technology. For example, Africa as a continent is extremely rich in natural resources. So is Russia. But countries like Switzerland and Singapore are much more advanced economically, certainly Switzerland is much more advanced in terms of science as well as technology. So I would argue that the wealth of a country depends on knowledge and innovation. Many of us like to think that Britain got rich as a result of colonization, and I would argue that this is not true. The converse may be true that colonies were hurt by colonization. But the reason I say that Britain's wealth came from innovation rather than colonization is that if you look at all of Europe, Britain was one of the most innovative countries in Europe. And if you look at other innovative countries in Europe, some of the richest countries in Europe – in the 19th and early 20th century – were Sweden, Switzerland, and Germany which had either no colonies or very few colonies. On the other hand, countries like Spain and Portugal which were not knowledge-based economies, which were not technologically advanced, but

which had huge colonies, were not very well off. In fact Portugal was a tiny country with very large colonies and probably had the highest colonization per capita. Yet, they were amongst the poorest countries in Europe. This shows you that really what makes countries wealthy is not resources, not colonization, but rather knowledge and innovation.

Poorer countries can initially spur growth by exploiting discoveries made elsewhere. I can give you two examples. For example in the US, we think of the light bulb as Edison's invention but it was really invented by a fellow called Swan in the UK. Edison was a genius at marketing and was able to scale it up. And a more recent example is about turbines. Danish companies set up manufacturing in China but then this resulted in know-how being transferred to the Chinese themselves and Chinese companies then set up their own factories in competition. Now they dominate the wind turbine market. This is a sort of general phenomenon, that is, that economic growth often precedes scientific growth. For example in 1908, the US became the world's largest economy but it wasn't a major scientific power until the 1940s or 1950s. Most of the basic fundamental discoveries in science were still being done in Europe. Similarly Japan had become a first grade economy by the 1960s but you would not think of it as a world leading scientific power until much later. But now for the last two decades or so, Japan is really a world leading scientific power that regularly wins Nobel Prizes.

Today you can think that perhaps Singapore – which is now a leading economy – is on its way to becoming a leading scientific power. And, possibly that is going to happen to China as well, a country which is heavily investing in science. But in order to make that transformation, from an economic power to a leading scientific power, you do need to have a certain level of high quality science. So, even by 1908, the US had world class scientists. It may not have been a leading scientific country but it had world class scientists. For example the Millikan oil drop experiment at Caltech showed that the charge on the electron was quantized. This was in the early 1900s. A very important experiment done in the late 19th century was the Michelson-Morley experiment which showed that velocity of light is the same regardless of motion. TH Morgan did brilliant work on the connection between the chromosomes and genes. So you need high level basic science in order to make that transition to a knowledge-based economy. And you need basic science even if you want to exploit new technologies. For example, if you did not have people who understood molecular biology, you would not be able to exploit biotechnology even if it was invented somewhere else. So, there is a need for broad-based support for science.

This leads to a question of why a country should invest in science. Why not simply use the discoveries made somewhere else, and apply them there. First of all, I pointed out that you need to have basic science within the country even to have enough understanding of new technologies in order to be able to apply them and that scientific understanding is the basis of applied fields like engineering or medicine. So without that, you would not be able to exploit new technologies. There is also the so-called first-mover effect. For example, if a new discovery is made, people nearby will hear of that discovery before anybody else has. So, they will have what is called the first mover advantage. This is one reason why places like the bay area in the US or Boston or the Cambridge cluster in the UK are such engines for new technology because there is a lot of basic science around them so they come to know about these discoveries first. Another phenomenon is the agglomeration effect. Once you have a large diverse group of industries, springing up around an area, all sorts of complementary expertise and skills are available locally. So if you are going to start up a company, you will want to do it where there is lots of know-how around, there is complementary expertise around, and there are other companies you can talk to. That is happening here in Bangalore and it is the same reason why we have many of these clusters in the west. This leads to a

question of how countries can become leading innovative countries and the US and Chinese history suggests that exploiting discoveries made elsewhere is a good starting point, but even that will require a basic level of science. And that means a strong indigenous research establishment. When it comes to the kind of research that could be done in India, there are a number of options. You could try to compete with the best in the world, or you could work on local problems that become globally interesting. For example, you could focus on problems that are particularly important to India but that does not mean sacrificing quality. We saw one of the winners of the Infosys Prize worked on rotavirus, a particularly important problem here that causes diarrhoea, but this work led to some really superb science. So, working on Indian problems does not mean that you have to sacrifice quality. In fact, you may end up being the innovator that everybody else becomes interested in. And, you can also work on areas where India has a unique advantage. One of the advantages of India is that, if you have diseases like TB or rotavirus which are prevalent in India, you can think of that as an opportunity to do excellent work. India has a large biodiversity, in fact it has large human diversity. The genomic diversity in India is greater than many parts of the world. So, it is a great opportunity to do interesting work. India also has trained a lot of people in physics, chemistry, engineering, and mathematics, and these people can be encouraged to go into other disciplines like biology, epidemiology, medicine, etc.

I heard recently that the government has announced an ambition to be a top science country, one of the top three countries by 2030. This is a rather ambitious goal considering where Indian science is today. There are lots of very good scientists in India but the overall level of science in India – for a country of its size – is certainly not where it should be. And it is certainly not anywhere near the top three. And, so, how could this be even achieved? I would say that it is very difficult but if you want to do it, it will require a sustained and substantial commitment for science. It cannot be 'ok I will try for some time and if it does not work out, I will move on to do something else'. You have to realize that it is a long term goal. Science takes decades before you can have an impact. It also has to be coupled with good practices of nurturing and supporting good science. India currently underinvests in science by quite a lot. And I am talking not just about the government of India. What is even worse than the government's underinvestment in science is the abysmal investment in R&D by the private sector in India.

For most countries in the west, the ratio is about 2:1. For every unit that the government invests in science, the private sector invests about twice that amount. So Indian industries have to ask why they are not investing more into R&D. If they want India to become an innovative country, they need to invest much more.

It also needs good governance. One of the Jury Chairs of the Infosys Prize, Inder Verma and I spent the last three days reviewing an organization called the India Alliance which funds biomedical sciences in India and is jointly funded by the Wellcome Trust in the UK and the Department of Biotechnology, Government of India. Although partly funded by the government, it is a completely autonomous organization. The organization is an example of very good governance and administration of science in India. When we asked fellows "what do you like about India alliance?", of course they liked the fact that they were generously funded but there were other things that they liked even more. For example, one of them said that if you applied for an India Alliance fellowship, and the fellowship is awarded, you can be sure that the money shows up in two months. That is not true in other agencies. There is no reason why it should not be true. The other good thing about the India Alliance is that the money granted can be used flexibly. So if you realize suddenly that you need more supplies, you can use money that was earmarked for equipment to buy more supplies. You have to be able to decide these things on the fly depending on how

your science is going. For example, if you haven't spent your money because you did not hire somebody right away, or the research went a little slower, you might be able to spend it next year when you need it more. You would be able to carry it over. This sort of freedom and flexibility is what scientists need. They also need freedom from politicization. Politics has no real role in science. Government absolutely has the right to set broad priorities. It is the job of elected politicians to set priorities for the country. Nobody elected scientists so they do not have the right to decide how to spend taxpayers' money. But after having set overall goals, government should leave scientists alone to carry out implementation of those policies. They should be free from intrusion and politicization.

In science, evidence matters, not authority. That is both its beauty and its strength, not caring what is someone saying but rather just looking at the evidence. So, you should not care whether someone who is a biophysicist dabbling in economic history is a Nobel laureate. But rather you should look at the evidence behind what the person is saying. Which means that you should take everything that I have said with a grain of salt, and look at the evidence behind it. The reason that it is important is that we are living in a world where all sorts of claims are propagated often with no basis in fact. Misinformation spreads through social media and often people take these to be indisputable facts. In fact, following the Brexit referendum and the recent election of Donald Trump in the US, the Oxford English dictionary announced that 'post-truth' was the word of the year for 2016. In the complex world we live in, science is more important than ever. So I want to conclude by thanking the Foundation not just for supporting the Prize but for supporting so many aspects like science education and many other areas of science. And, thank you all for listening.