Interview: "Quarks and Quantum Chromodynamics"

Friedman, Jerome

1. *What is the essence of the contribution for which you received the Nobel Prize?*

We discovered that protons and neutrons, which make up the nuclei of atoms, consist of even smaller particles called quarks. The existence of quarks had been independently proposed a few years earlier by Gell-man and Zweig, but physicists were very dubious about quarks because they were assigned fractional charges and no fractionally charged particles had ever been observed in nature. Also, many searches for quarks had been conducted but none were found, so the physics community in general had discarded the quark model.
Quarks were finally discovered in a series of high energy inelasic electron scattering measurements at the Stanford Linear Accelerator Center by MIT and SLAC physicists.
In these measurements, the electron beam and the detecting equipment were the equivalent of a very powerful electron microscope that probed into the interiors of the proton and neutron.
Point-like constituents were observed inside. These point-like constituents were later unequivocally identified as quarks after a comparison of electron scattering results with neutrino scattering measurements from CERN demonstrated that these constituents have the fractional charges assigned to quarks.

2. *What are the impacts of this contribution?*

The discovery of quarks changed our view of the basic structure of protons, neutrons and mesons. This discovery also led to the development of Quantum Chromodynamics, the theory of the strong force, which is one of four fundamental forces of nature. The strong force is the force that holds quarks together to form protons and neutrons, and holds neutrons and protons together to form atomic nuclei.
Both quarks and Quantum Chromodynamics were essential components for the development of the Standard Model of particle physics, which successfully represents the sub-atomic world when compared with observations made at existing accelerators. The Large Hadron Collider, the new accelerator at CERN that is expected to start operation in the latter part of 2009, is likely to find extensions beyond the Standard Model but all indications suggest that the framework of quarks and Quantum Chromodynamics will remain intact.

3. *What are the applications of your contribution that may change the everyday life?*

Perhaps it will have applications in the future; but in terms of our current understanding, this research has no applications to everyday life at the present time. However, it informs us about what matter is is made of and how the universe works. It also gives us a better understanding of the evolution of the cosmos, since quarks are some of the earliest particles that emerged in the very early universe. One of the great goals of human intelligence is to understand what we see around us and understand the laws of nature.
But there is another way, that the kind of research I do has contributed to society. Existing instrumentation often has not been adequate to address the challenging problems in particle physics and new types of technology have had to be developed. These new technologies have led to spin-offs, which have broader applications in society. For example, accelerators were invented to study the interactions of sub-atomic particles, and now various types of accelerators are used for such diverse applications as cancer therapy and the fabrication of semiconductors and microchips. Synchrotron light sources developed from electron accelerators are being used to design new drugs, study the structure of viruses and study new types of materials. Nuclear medicine and diagnostic tools such as magnetic resonance imaging, positron emission tomography, and computerized axial tomography also were developed from instruments used in basic research in nuclear and particle physics. The world wide web is an especially interesting example. This technology,

based on the internet, is reshaping the way that we communicate, learn, and engage in commerce. The World Wide Web is a spin-off that was developed at CERN to enable high energy physicists at laboratories across the world to exchange data and programs and work more effectively together. The rapidly developing world wide web is promoting vigorous economic growth in many parts of the world.

4. *Can you shed more light on the last answer?*

5. *We learned a lot from your lectures in Belgrade. Can you tell us, what are the issues that we have to teach our kids, so they become creative when they finish studies?*

We must make sure that children do not lose their natural curiosity. Children are scientists in the way they view the world, because they are continually trying to understand how the world around them works. The educational system should encourage and nurture this curiosity. At all stages of education, students should be given independent projects to do, and questions should be encouraged. Teachers should emphasize ideas and concepts in the classroom rather than the memorization of facts.

6. *What are the major things to keep in mind, when you form a team for a scientific experiment, or similar*

The people in a scientific team should be very capable, compatible with one another and good team players. They also should be open to new ideas, but have a strong sense of skepticism, and be willing to take risks in research.

7. *What are the people to avoid, when trying to generate a break-through achievement?*

People who don't have the above properties should be avoided.

8. What is your opinion about the impact of math?

Math is extremely important. It is the language of physics and engineering and plays an important role a number of other sciences. Students who want to pursue these areas should develop great competence in mathematics.

9. *When targeting a major breakthrough, how sensitive one has to be about the direct interests of tax-payers?*

Since basic research is primarily supported by the taxpayer, the scientist has a great responsibility to the taxpayer. The scientist must do what he/she has been supported to carry out and do the best job possible. The scientist must always keep the public informed about the research being conducted. The scientist also has a responsibility to provide scientific information to the public and political leaders regarding policy issues involving technical - scientific issues. This should be done in a politically neutral manner. Science should never be the captive of politics.

10. *What is the major driving force that motivates a Nobel Laureate to continue to create and generate results after he-she receives the Nobel Prize?*

The major driving force that motivates a Nobel Laureate to continue to create and generate results after he/she receives the Nobel Prize is the same one that operated before the Prize, curiosity and a desire to understand how nature works.

11. *For small nations like Serbian, what is your advice, which road to take, when it comes to science?*

Small nations, like Serbia, should invest in science education and research. If a nation, whether large or small, does not have natural resources, and wants to develop beyond an agricultural economy, it has to develop a knowledge based economy. And this requires developing an excellent educational and science-technology infrastructure. A good example is Singapore, which has a population of 4.6 million people. When it broke away from Malaysia in 1965, it had very little. By investing in education and building its technological base, it has become the 5th richest nation in the world in terms of GDP per capita. Finland is another example of a small nation (population 5.3 million) that has invested in education, science and technology and is doing well. A nation's most important asset is its people; and by providing first rate science education and

research opportunities for its people, it will be able to compete in the modern world.

12. *What road to take, when it comes to its general future development plans?*
Invest more in science education and research. Many Serbian students have gone overseas for their graduate education. I have had some outstanding Serbian students in my research group at MIT who have remained in the US. They have done so because they felt that they did not have adequate research opportunities in Serbia. It is important that Serbia provide good research opportunities so that such students are attracted to return home. Serbia should not lose such valuable human capital.