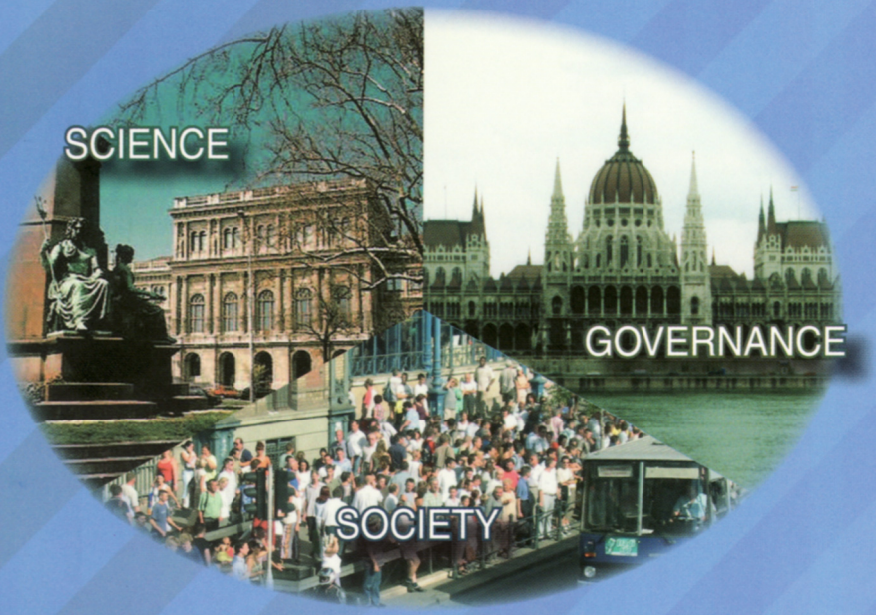
WORLD SCIENCE FORUM

12 Scientists on the 21st Century



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12 SCIENTISTS ON THE 21ST CENTURY

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AHMED H. ZEWAIL

PERSPECTIVES ON KNOWLEDGE AND HUMANITY

by Ernő Keszei

Ahmed H. Zewail is the Linus Pauling Chair Professor of Chemistry, Professor of Physics, and Director of the Physical Biology Center for Ultrafast Science and Technology at the California Institute of Technology (Caltech). He received his M.Sc. from Alexandria University (Egypt) and a Ph.D. in chemical physics from the University of Pennsylvania (U.S.). Following an IBM postdoctoral fellowship at UC Berkeley, he joined the faculty at Caltech. In 1999, he was awarded the Nobel Prize in Chemistry for his pioneering developments in femtoscience that made it possible to observe atoms in motion – the transition states of molecular transformations – founding the discipline of femtochemistry, a field concerned with molecular reactivity on the femtosecond (10^{-15} s) time scale.

His research group recently developed *4D Electron Microscopy* for the direct visualization of matter in the four dimensions of space and time, a new field aimed at understanding the complexity of materials and biological function. He has published 13 books and over 500 papers on science and world affairs. His biography, *Voyage through Time–Walks of Life to the Nobel Prize*, was published in seventeen editions and different languages, including Hungarian. Dr. Zewail has given public lectures around the globe on science, education, and world peace. He is widely recognized for his leadership role in the U.S. and for his tireless efforts to help the developing world. On April 27, 2009, President Barack Obama appointed him to the President's Council of Advisors on Science and Technology. Besides the Nobel Prize he has garnered many recognitions for his contributions to science and society, including commemoration on postage stamps, 40 Honorary Degrees, Orders of State, and election to many international academies and learned societies. In his name, four international prizes have been established in the Netherlands, Italy, and the U.S. The Cairo-based AZ Foundation was inaugurated in 2004 for the purpose of disseminating useful knowledge, and merit awards have been bestowed on gifted students in the sciences and the arts.

– Professor Zewail, I would like to thank you on behalf of the Hungarian Academy of Sciences for accepting our invitation to give this interview for the "12 Scientists on the 21st Century" volume. As the editors suggested we should follow a standard format for the interviews, let me ask the proposed questions. To begin with, what are the most challenging problems facing the world, generally speaking, and in science at large, including your particular field?

As far as the 21st century is concerned, the major issues facing the world are many, but I would rather focus on the ones that threaten our peaceful coexistence. The first is **education**. It is disturbing that in the knowledge-based 21st century there are countries with populations approaching 50% illiteracy. And women are not given the appropriate status for education and career opportunities in many countries, so the workforce is reduced in value. The impact on children's development and contribution to the pursuit of happiness becomes minimal in a world that is increasingly dependent on advanced knowledge and high technology. Education in the 21st century will rely increasingly on information technology and we should use such technology to eradicate illiteracy, which is the real enemy of human society. Both economic prosperity and democratic governance are dependent on the level of societal education. The second issue is **poverty**. The number of poor in the world is increasing at an alarming rate within some developed countries and certainly in the developing world. I believe the disparity in wealth will cause imbalance and disturbance in the world unless we find some reasonable solutions. We have to think of how to assist the have-nots, not only by increasing material aid but also by helping to provide the know-how for increased productivity. The third is **energy**. There are insufficient resources for the six, soon to be seven, billion people in the world. We have depended for too long on natural, carbon-based fuels, but very soon we will need alternatives such as solar energy, fuel cells, bio fuels, and other sources. The fourth is **immigration**. The migration of the poor in large numbers into wealthy countries is creating problems, both for the receiving nations and for the immigrants themselves. The developing countries lose skilled people and developed countries cannot assimilate them, and so friction over resources, culture, and religion develops. This mass movement of labor is not to be compared with traditional immigration for particular professions. Developing countries, with the aid of developed ones, should invest in capacity-building. The last issue is **our planet.** Resources are limited, we are consuming them at a tremendous rate, and globalization is not without problems. Climate change, food shortage, water resources, the threat of pandemics and nuclear

weapons are issues that must be addressed seriously by means of dialogue between nations. I do believe in human creativity and the power of science to alleviate these threatening problems.

In science and technology, the opportunities are truly exciting in this century. Just as scientists of the 20th century revealed the nature of the atom and its language, quantum mechanics (which led to major discoveries such as lasers, transistors, and the molecular structure of our genetic material), in the 21st century we will witness revolutionary advances in life sciences and in medicine. Similarly, there are unlimited opportunities for discoveries in outer space – the solar system and beyond. It is possible that we will discover new planets, and we may find new forms of life on nearby planets. But just as importantly, we will learn more about our cosmos, including the now unclear nature of dark matter and dark energy, and the forces that determine its laws. In the world of the very small, the manipulation of matter at atomic and nano scale will open up new frontiers in miniaturization and in building and controlling new structures made of atoms and molecules. We have already been able to visualize atoms and molecules in space and time, and the door is now open to myriad applications, hopefully to understand how biological machines really function and how complex systems acquire their unique emergent behavior.

– You seem to be quite certain that science can play a great role in meeting, or at least reducing, those challenges and threats.

Clearly, science is essential to our economic progress, and, as importantly, to an education that is based on reason and the search for facts. However, there are areas in which science will play a critical role. For example, the development of simple technologies to help developing countries will solve major problems, from water purification to epidemic diseases. Developments in IT will clearly bring access to global advances, especially to the developing world, but at some expense regarding social life. Personal privacy and an over-zealous media are problems to be dealt with. Science will also play a major role in improving food production, especially for the needy. However, what I fear most about developments in science and technology is their misuse, or the political consequences of using those advances. What we can hope is that scientists will be conscious of the issues as they develop and will be involved in promoting the peaceful application of science to all nations. Good education and good governance are the basics that must guide rational decisions about the complex issues facing humanity in this century.

– In your opinion, what are the most outstanding results of the last decade in your scientific field, and how can they influence the course of the 21st century?

– In my own field, I believe that one of the big problems is understanding complex systems, their assembly, and behavior. Visualization is therefore critical for developing new concepts and theories that describe such behavior. The development of microscopy to image in the four dimensions of matter's space and time has, therefore, become the focus of our research at Caltech. Since the days of Robert Hooke's Micrographia in the 1600s, the advances that have been made are remarkable. We can now time events in microscopes 13 orders of magnitude faster than the still pictures that used to be taken in seconds. For the world of the very large, advances are opening up new vistas. The 30-meter telescope will allow us to go "back in time" by some ten billion years. And the new techniques for sequencing the genome, understanding the behavior of the brain at the cellular and molecular level, and the remarkable advances in molecular medicine are but a few of the many frontiers of research for this century.

– What are the major differences in "doing science" between the 20th and the 21st centuries?

The structure of science and the scientific community has changed. In the 20th century, science was defined by towering leaders of research schools. The number was relatively small around the world and basically, each school had a well-defined objective. In the 21st century, the number of scientists who are involved has increased significantly – maybe exponentially—and the boundaries are dissolving. As a result, the meaning of schools per se is no longer what it used to be. Science is becoming multi-disciplinary and inter-disciplinary. In a way, we are going back to Aristotelian thinking in the sense that knowledge is diffuse and is gathered from different disciplines in order to tackle multidisciplinary problems. Yet, scientists, in many ways, are becoming highly specialized in narrow areas, and the providers of funding focus more on short-term benefits. My hope is that in this process we do not sacrifice the cornerstones of scientific progress, which are the understanding of fundamentals and the quest for new knowledge driven by curiosity, in favor of short-term objectives and the need to attract funding.

– What are the major (breakthrough-type) questions in your scientific field, what social impacts will they have, and what social responses will they evoke?

– Perhaps some examples will illustrate the answer to this question. In spite of all the advances in understanding atomic and molecular structures, we still do not know why a protein molecule of thousands of atoms collectively at work sometimes misfolds into undesirable structures, and in so doing causes diseases such as Alzheimer's. What directs the misfolding of such macromolecules, why does it sometimes go wrong, and can we arrest the process and control it? Another is molecular recognition. How can we design a molecule that selectively recognizes a given part of the gene to prevent it from functioning, or deliver a drug to a diseased cell, such as cancer, and not to a healthy one? A final example is that of behavior on the nanoscale. Does this length scale bring to our understanding a "new" description of matter, and can we control the processes involved? In other words, in such a world of complexity, do we need "new physics" and would revolutionary technologies emerge? Obviously, the fruits of such investigations could have huge consequences for society. That is why the fundamental understanding of such functions through visualization during the event is of critical importance.

– *You are well-known as a scientist who is active in societal issues, including the promotion of science in society. What measures, initiatives, and actions do you suggest in order to enrich and reinforce the interrelationship between science and society?*

– I believe that society appreciates the value of science when considering its myriad daily applications, from the soap we use in the morning, to the pills we take during the day, to the many technological tools that are essential to modern life. People are also in awe of tangible scientific triumphs such as the landing of a robot on Mars or the cloning of Dolly. However, there is a gulf in the understanding of how science works. Scientists do not go to the lab knowing what they will discover. Notwithstanding the vision and brilliance of some, in general the process is long-term and in most cases it requires hard work and perseverance. As Thomas Edison said, "Success is 10 percent inspiration and 90 percent perspiration." My concern is that government and society at large may think that scientists can find quick answers to the technical questions of the day, while in fact many of the discoveries that ultimately lead to problem-solving technologies come as a result of creative research, and in some cases, by serendipity. Scientists should articulate the process and benefits of science and leaders should support the quest for knowledge in the long, not the short, term. There is another serious problem; that is, a misconception about the conflict

between science and religion, which seems to be on the rise. Just because science searches for the truth and utilizes reason in its approach, we should not assume that scientists as human beings are without faith. I see no need for any conflict between reason and faith and I believe people on both sides should not be dogmatic, as we truly do not understand so many of the questions pertinent to this elegant universe. Therefore, more dialogue is needed to explain what science is about and what faith is for. I also think that scientists should make more efforts to inform society about the beauty of science, the fundamental discoveries that uncover mysteries and define what we are – human beings thirsting for knowledge in a vast universe.

– *This interview will be published in a special volume of the World Science Forum 2009. How would you formulate one of the main messages of this Forum?*

– My message would be: "Our world is in need of education; not only an academic one, but also one that brings about world perspectives."

– *You yourself had a long and presumably excellent education. What were the major experiences, and important individuals who had a determining influence on your professional career?*

– Throughout my voyage, I have been fortunate to be "in the right place at the right time." In Egypt, I received an excellent primary education and grew up in a family and society that taught me principles and values that later proved vital both to my career, and, perhaps as importantly, to my human interactions. Coming to the U.S., I was given such opportunities and encouragement that I really felt I could reach out with "the sky as the limit." I learned in the U.S. the significance of individual liberty and the role played by human creativity. Caltech, my scientific home, was ideal in providing me with the best environment possible, and with high-quality colleagues, exceptional students and staff. Naturally, through that evolution, many have contributed to the outcome, and it would require a few pages to list them.

– *Your scientific career is exceptionally rich in original results. What are you most proud of among your professional achievements?*

– Although scientists in general are proud of most of the contributions they make to the advancement of knowledge, there are a few jewels in the pile. One is our contribution to changing a dogma in molecular dynamics on the femtosecond time scale and the birth of the field of *Femtochemistry*. Another is the development of *4D Electron Microscopy*,

despite the challenges and the initial belief that it would not be possible. These are the scientific contributions, but also of significance to me is the school of scientists that emerged from this research, with more than 300 young researchers, many of whom now occupy leading positions worldwide. Finally, a personal note is worth mentioning. It is a great pleasure and thrill to communicate concepts of science and public affairs issues in lectures, especially when the aim is to help the have-nots. I am fortunate to have a profession that is my passion – both for learning and for making a better world.

– *You have mentioned changing a dogma in molecular dynamics. Could you explain in a few words for non-experts what this dogma was and how it has been eliminated?*

– When you enter the microscopic world of atoms and molecules, you encounter uncertainties that are of no relevance in our classical world, which is governed by Newtonian mechanics and the like. One of these two uncertainties is between "time and energy" – if you shorten time it will be at the expense of losing the energy resolution. For nearly a century, energy resolution has been fundamental in studies of the quantum states of molecules, and one can resolve such states when the measurement is made at long times, preferably "infinite time." But if we measure systems at "infinite time," we cannot see the motions of atoms in them. Many believed that the femtosecond time scale would be of no value as the energy resolution would be poor and quantum states would be blurred. What was missing in this picture was the fundamental role of "coherence." The states of the system can be prepared with in-phase synchrony and the result is a symphonic group of states, what is known in physics as a wave packet; a localized density in space and time. Thus, by using femtosecond strobes (or "cameras") we were able to follow the motion of atoms in molecules in real time. The fog surrounding the uncertainty principle had abated. Going back to our science and religion discussion, we can say that such uncertainties cannot in fact be explained easily in terms of the physical world. It is like saying one cannot be wealthy and spiritual at the same time – why? Another concept that I feel belongs to the same category is that of "duality" – what does it physically mean that light (or electrons) sometimes behaves as waves, and at other times as particles? Our universe is indeed vast and elegant!

– *You are still an active scientist full of ambition. What else would you like to achieve in your professional career?*

– I do not know what comes next, but what I know for sure is that whatever I do, I hope to maintain my passion and enthusiasm, which I believe are the two essential qualities for achieving one's goals – in a word, success.

– *Thank you very much for the interview.*