

Chemistry and Humanity

Challenges our Profession Faces as we Advance Towards the
Third Millennium

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Abstract: This essay evaluates chemistry and its practitioners in four areas: whether chemists make informed decisions about the future direction of their discipline, whether chemists pre-analyze the impact of their research on the environment and society in general, whether chemists feel the need to reach out to society in general and educate them about their discipline, whether chemistry has a potential to still significantly contribute to humanity's intellectual and technological evolution. Chemistry is distinguished from other fundamental sciences by the specific issues it deals with. It is proposed that chemists could play a pivotal role in restructuring the priorities in basic research and defining a clear future path for fundamental science.

Keywords: *future direction of chemistry, basic research, environment, society in general, weapons research.*

London, Science Museum

As I walked among the real-life size wax depictions of scenes from the medical practice throughout history starting with 1880's on the 5th floor of one of London's most stimulating museums, I rediscovered how far humanity had advanced over the last century. As I read the black metal plaque in front of one of the glass cases housing a wax doctor in brown pants and a wax patient with a broken leg in what would be called a regular bedroom by today's standards, I realized with astonishment that the link between germs and wounds getting infected during operations had not even been firmly established until the late 19th century. The black plaque declared that there was a significant reduction in the number of unsuccessful operations due to

wounds getting infected when doctors took up the practice of washing their hands before a surgery. From this perspective the hundred twenty years that mark the interim between the adoption of basic sanitary practices to the integration of robotic surgeries into routine medical procedures, are definitely characterized by an exponential growth in humanity's scientific and technological capacity. I thought I was lucky to have been born during the 'enlightened' times. I also decided that mine is a special generation that is strategically posed in time: We are equipped with an extensive knowledge of the past and the wisdom that comes through a critical evaluation of the past. My generation is in a position to make an informed decision about what future route to take instead of tumbling down the alley where the outcome of the actions of independent units (different industries, governments...) will take us. I wondered if my generation would make the choice to be pro-active about its future.

London, Duchess Theater

The audience, which was comprised mostly of young people in their twenties, abruptly ceased all their murmuring when the stage lights came on and two of the players of the production *Copenhagen* appeared on the stage. It was a really well done play. With its modest décor (a chair) and three-person cast, the play was mostly relying on its script to capture its audience. Those people in the audience who possessed a certain level of familiarity with the development of the atomic bomb and the scientific considerations that went into its conceptualization were definitely at an advantage following the play and the drama it was trying to convey. As I sat there and watched Heisenberg try to convince Bohr to form a secret alliance to prevent the Americans and Germans from building the atomic bomb, I realized yet again what an incredible power scientific knowledge is.

Having continued my career always in academic settings where scientific knowledge is exchanged freely among scientists from different nations, it was interesting for me to watch how science can sometimes clash with international interests. I did not know how to feel about that. I have always perceived science and its practitioners as being above international borders and politics. I have been to international conferences a few times and in each case I had the distinct feeling of being surrounded by a merry community who derived great satisfaction out of sharing their work with each other. However, specific areas of science are far from being practiced on an international platform. Is this justified? Is it justified under any circumstances for people to sit in highly classified areas scheming against other nations, against their

own kind, when so many problems are facing our environment and our society right now? The large defense budgets governments set aside to fuel such research apparently reflect the opinion that indeed it is. There is a dark mentality out there which does not seem to recognize that the large amount of money and brain power drained into such projects will end up resulting in the production of weapons which may be unnecessary/detrimental to the future structure of the world. Do we have any right to burden the next generations with the major challenge of having to dispose of those weapons? Our generation is already the 'lucky' recipient of a large number of chemical and nuclear weapons whose destruction is a big-scale project right now estimated to cost millions of dollars not to mention the environmental damage that is bound to occur in the process. How can we get ourselves into such a vicious circle – make and destroy at a big financial and environmental cost to humanity?

Washington, D.C., Museum of American History

After a minute's hesitation in front of the entrances of two different exhibits, I decided to walk into the section labeled 'The Industrial Revolution' and save the 'The Mysteries of Clocks' for some other day. As I walked through the fascinating simple experimental set-ups that the inventors of the early 19th century built at their homes to discover the principles governing electricity and figure out how they can manipulate it, I could not help think what an exciting time it must have been to be an experimentalist then. It seemed like all one needed was some ingenuity and a 'well-equipped' attic or basement to be able to discover phenomena that could have significant impact on human life. Then I thought about the research efforts of today. The prospects of stumbling on something that can be considered as a significant contribution to science without access to some incredibly complicated and expensive experimental set-up are pretty grim. Why? One obvious answer is we have discovered all that is 'easy' to discover, so what we are pursuing now is harder to capture. We need to venture into regimes that are unfamiliar to us (*i.e.* extreme pressures, temperatures, microgravity environments) to discover new phenomena, to extend our understanding of the physical world.

As the science we do becomes more complicated, it also gets harder to communicate it to the non-scientist people out there. We no longer have the luxury of resorting to everyday experiences when explaining the novel concepts science deals with today. How can we tell Carpenter Jimmy about quantum mechanics? It would be hard, but does that mean we should not even try? Is it justified for scientists to form their own exclusive club and expect everyone else to trust that they are pursuing noble scientific goals, but

not put any effort into sharing their dreams, plans, reservations with society in general? Does being 'mysterious' and being the practitioner of a profession, which will be opaque to anybody without a certain level of education or intelligence, give scientists a feeling of superiority that they enjoy? Is that why communicating their pursuit to society is in general a low-priority task on scientists' agenda? Or do scientists think the non-scientists out there will simply be incapable of appreciating what they are doing since the non-scientists will lack the foresight necessary to see what great revelation a certain line of research could lead to. I think requiring the scientists to be more open about their research with the society in general will encourage scientists to evaluate their pursuits within a larger framework of reality and can be beneficial to scientists as well. It will increase interaction among different disciplines of science and will probably attract young, intelligent minds into science. The statistics published regarding the professions that young people choose to go into show a clear trend of decreasing interest in science, especially fundamental science. I think this is a very dangerous trend the scientific community should be concerned about. We cannot afford to have interest in fundamental science melt away. It is time scientists asked themselves the question of why they are walking alone on the road to their big goals. It is time they got the non-scientists back on the ride with them.

Boston, Logan International Airport, Airbus Industrie Jet, Transatlantic Flight

The plane positioned itself at the start of the runway and waited for the 'go' signal from the tower before it started its speedy take-off into the gray sky. As I watched the yellow signs with runway designations pass by me faster and faster, I hoped all the o-rings on the aircraft were in place and all the screws were tightened. Then I dismissed these thoughts trusting that this aircraft I was sitting on was equipped with redundant systems and multiple alarms that would alert the pilots if anything were slightly amiss. As the plane rose up into the clouds, I had a nice bird's view of a brown, jagged coast along the Atlantic. I felt very special, many generations of my ancestors had never had the privilege of rising above the clouds. I could only imagine what the first crew who went to the moon felt when they saw the Earth from a small window of their spaceship. Our scientific quest and our technological development have indeed taken us far. I sometimes wonder how close we are to the peak of our intellectual and technological evolution...

The preceding four personal anecdotes are intended to introduce within a context the four major points this essay addresses: scientists' (specifically chemists') role in sculpting the future of humanity; considerations that should factor into scientists' (especially chemists') choosing what line of research to pursue; the obligation to communicate and justify the current scientific endeavors effectively to society in general; and the role played by science (specifically chemistry) in humanity's intellectual and technological evolution. The science which gave us drugs, paints, plastics, cosmetics, adhesives, detergents; the science which manipulates molecules; the science which continually shuffles the material balance of the environment; that is the science that is on trial throughout this essay.

Just like in any other fundamental science, progress in chemistry is characterized by sudden bursts of revelation followed by an extended and highly concentrated period of intense research in the area of the new discovery. The compilation of the periodic table, discovery of radioactivity, understanding of the chemical bond, understanding of the structure and dynamics of molecules in a degree of detail that was made possible by the emergence of tools such as lasers, all mark cornerstones in the history of chemical research. A giant chemical industry has materialized which thrives on products whose conceptualization was made possible by the findings of basic research in the field. Chemists now have the tools and knowledge to manipulate molecules and reactions with unprecedented precision. They can look at a single molecule and see it in action. They can design drugs with specific therapeutic effects and synthesize them turning computer models into reality. Chemistry has expanded to overlap with other sciences. For instance physical chemists and physicists employ similar tools, approaches, and analytical techniques to pursue similar quests. Biochemists work closely with biologists as they try to understand what governs the interactions of bio-molecules in complicated systems. Science is moving towards a more and more interdisciplinary structure as scientists realize there is a lot to be gained from attacking the increasingly more difficult scientific problems of today with the whole arsenal of knowledge and experience we have at our disposal. This is a unique phase in the history of science where the whole community is moving in unity and synchrony towards solving the more elusive mysteries of the universe. Chemists provide a significant portion of this momentum forward. However, one question that has not been addressed is where exactly is the scientific community going to. It is important to have a sense of direction when there is so much momentum, as it may be very hard to change directions when committed to a certain path.

The motivation behind current research in chemistry has to coincide with the goals outlined by funding agencies. This suggests that funding agencies play a crucial role in defining the path science takes into the future. This is

indeed true because the interests of funding agencies have promoted 'information technology' and 'biotechnology' to the status of 'holy' research topics. These are definitely two very important areas that would benefit humanity in unimaginable ways; however, these lines of research are being pursued at the expense of other subjects that may need more urgent attention. Environmental research has not been receiving the emphasis it deserves. Everybody has been exposed to the environmental problems facing our world right now – the thinning ozone layer, the disappearing rain forests, the rising temperatures, the irreversible chemical contamination – to such a degree that they have been almost desensitized to them. The danger posed by these threats is not going to affect us tomorrow, the next month, or the next year. It is a gradual destruction, which unfortunately does not stir in people the feeling of panic awakened by more abrupt consequences.

Chemists should be genuinely concerned about the environment and structure their future research towards this end. Chemists are in a unique position to evaluate atmospheric phenomena, develop waste management strategies, discover new sources of cleaner energy, and devise effective recycling policies. Important progress can be made towards salvaging what is left of our environment if more chemists put their talents to tackling these problems. Unfortunately, what is missing from the equation is a genuine interest and concern in these environmental issues. A significant number of chemists still insist on pursuing subjects that are of personal interest to them, that they find mentally stimulating without giving much thought to what such quests would contribute towards solving the problems our society faces right now. Making a connection between a proposed research agenda and its relevance to environmental issues is done only at a very superficial level on grant proposals to attract the attention of funding agencies. However, if one does not make it one's true mission, one cannot hope to contribute to a cause in any appreciable way. Declaring that more chemists should devote their attention to environmental research may sound like a somewhat 'dictatorial' approach to how research should be done. Besides, a lot of revolutionary discoveries were stumbled on while investigating random phenomena. If we do not let the scientists run wild with their imagination, we cannot hope to advance in science. I think this is an opinion that we need to reevaluate under today's circumstances. It should be our fundamental obligation to make sure that our immediate environment, the planet we inhabit, will be able to sustain our activities. It would be sad if the style of life we strive to attain with our new technologies slips away from our grasp because of lack of a medium (*i.e.* environment) to sustain it. Chemists and the chemical industry are in a powerful, pivotal position to change current trends to put more emphasis on environmental issues. It is time chemists played their hand at this, any further delays may put us beyond the point of no return.

One cannot talk about environmental issues without a word or two about weapons research. It is true that defense-oriented research has propelled the development of high-energy lasers and harvesting of nuclear energy; reinforcing the belief that sometimes good comes out of bad. However, when one reads about the amount of money that will be spent in destroying the surplus of nuclear/chemical/biological weapons from the cold-war era, when one thinks about the raw materials and resources that were wasted in the production of these weapons in the first place, when one hears about the environmental threat posed by sunken submarines loaded with plutonium missiles, when one feels the media fear regarding nuclear weapons tests of developing countries; one wonders 'why?', one loses 'faith' in the 'system', and one concludes things are just not being done the right way. I think it is time we learned something from the patterns in the past and grew very skeptical of weapons research. It is time global concern rose above one's patriotic feelings or ambitious goals of doing 'high-profile' research in a well-funded area. Again, with their expertise in explosives, radioactive reactions, and combustion, chemists play a key role on this platform and have the power to redefine the rules of the game. Scientists are also citizens of the world and should exercise their right to oppose what is detrimental to their 'habitat' and its future (and present) occupants.

The present occupants of the world (*i.e.* society in general) are as innocently being affected by the scientific community's collective decisions as the future generations. Issues such as large-scale oil spills and 101 tons of missing mercury immediately impact the life of society in general despite the fact that society in general had no involvement with the cascade of events that culminated in these outcomes. The public needs to be educated and brought up to date about how the scientific community operates and what the issues this community deals with are, so that they can have intelligent input into decisions that may ultimately affect everybody. Chemistry is a special discipline because it interfaces so closely with people's everyday lives: the tooth paste one brushes their teeth with, the bag of potato chips one munches on, the mosquito repellent one sprays oneself so generously with in the heat of the summer days are all products of chemical research. It could be especially easy for chemists to make a connection with the public and educate them about the scientific enterprise.

Most manufacturers make sure that all the scientific details and complexity of a product are completely disguised before presenting it to the public. A simple example is the phones we use. I was just given a 'transparent phone' as a present and using it is literally an eye-opening experience. I can see the whole circuitry inside the phone. I can see how the LEDs start flashing when a call comes in and activate the ringing. I think people should be exposed to the details and the complexity of what they routinely use. It would be nice if

people had some vague idea about how televisions or the ever-so-popular cellular phones worked. It would be nice if people's interest went beyond the color of the case a certain electronic device is entombed in. I think 'transparent' computers and phones are a step in the right direction. Seeing the complexity of the miniature electronics world could pique people's curiosity in the subject of microelectronics. A little ball-and-stick diagram of how a detergent works added to the detergent labels that are usually dominated by pictures of colorful flowers could enlighten people about the basic principle behind the detergent chemistry. The public is systematically being 'protected' from exposure to the details of the technologies they use on an everyday basis and I find that very destructive to the public's awareness and understanding of their world.

Most scientists regard it a futile effort to try to convey to the public what their goals are. However, it is important for the scientific community to reach out and invest the time in getting the public interested and excited about scientific research. A society capable of critically evaluating its scientific community is the best defense mechanism against any ills an unchecked scientific enterprise may bring. Sharing their research and their reasons for pursuing a particular line of research with an informed public could give scientists a new perspective to evaluate their work in, and it could prompt them to do more productive and relevant research. Chemists could do the pioneering work in bridging the gap between scientists and society in general. Chemistry is already integrated into everybody's life on a very intimate basis, how challenging can it be to get people curious about finding out the inside story about their tooth paste or laundry detergent? The challenging part is to have chemists who believe in the necessity of reaching out to the society in general.

Most of the major research universities in the U.S. and the rest of the world are suffering from a dwindling number of incoming students interested in pursuing advanced degrees in fundamental sciences. This is a serious problem that needs to be addressed immediately. Why is it very difficult to get young minds excited about fundamental research? Is it because it is hard to see the relevance of basic research to everyday life? Why do young people fail to appreciate that basic research lies at the heart of every technology we have right now? Have we left the public so behind that it is hard to attract anybody into this 'mysterious, esoteric' enterprise anymore? If so, we are in a very sad situation. Even if some scientists may be skeptical about the benefits of having public input into their professional decisions, the trend in the career decisions of young people alone should be alarming enough for chemists and other scientists to take action on the issue of establishing a close relationship with Carpenter Jimmy.

Is fundamental research today really being perceived as a ‘mysterious and esoteric’ enterprise? According to John Horgan, the author of the controversial book *End of Science*, science has reached its limits and anything further contributed by current research would be mere details. Horgan claims quantum mechanics explains the physical world, the Big Bang theory answers the major questions of cosmology, Darwin’s theory is pretty much all there is to evolution, and the discovery of DNA and genes demystifies all riddles of biology and genetics. He claims that today’s efforts to try to understand how molecules interact, how proteins assume their three-dimensional structure, how the immune system works, or how the mass is distributed in the universe are all efforts aimed at clarifying the details of a gross picture that is already well established. By his analysis, today’s research efforts are, therefore, esoteric and possibly uninteresting.

Horgan does make strong arguments and outlines the opinions of famous scientists who agree more or less with the main theme of the book. However, when one thinks back to the 18th and 19th centuries, one remembers how scientists thought the whole universe could be explained by Newton’s classical physics. This changed when classical physics failed to account for black-body radiation. In order for theory to predict the observed profile of black-body radiation, Max Planck had to propose the quantization of energy. This small disagreement between theory and experiment, which could have been considered as a detail, led to the uncovering of a superior theory that explains the world accurately even at the scale of individual atoms. This was a major breakthrough stumbled upon only because some detail did not quite fit the accepted picture. It is hard not to think back to this revolutionary period in the history of science and wonder who is to say it is not going to happen again.

Quantum mechanics is indeed the most successful theory science has at its disposal, it has survived unscathed the numerous tests it has been put to. However, there are still mysteries to be solved, enigmas to be delved into, and hence, it is difficult to believe that the scientific enterprise could be nearing its limits. In chemistry alone, it is unjustified to classify research aimed at control of chemical reactions, or design of molecules with specific functions, ‘esoteric’ and devoid of a potential to enhance our understanding of fundamental phenomena. Chemistry, along with the other fundamental sciences, will continue to guide humanity to the peak of its intellectual and technological evolution; we may be close, but the last stretch of the journey may still have astonishing, yet-to-be-discovered realities for us.

On a more cautionary note, it is also naïve to claim there are no projects currently being pursued, which would fall under the category of ‘esoteric’ research. The decreasing resources and the increasing number of ‘macro’ problems (environment, human health, agriculture...) that need to be addressed

urgently make it a luxury to pursue ‘esoteric’ research which we cannot afford anymore. That is precisely why it is suggested that chemists and scientists in general should be required to evaluate their work and their reasons for committing to a certain line of research in the public spotlight so as to be able to make wiser decisions about the future direction of research.

Chemistry is still an evolving field. It is, however, no longer in its infancy. Its practitioners need to keep the mistakes of the past in perspective when firmly pushing ahead in their journey to the future. There needs to be more emphasis on environmental research and de-emphasis on defense-oriented endeavors. Chemists have the reins in hand in these areas, they can and should define the rules so as not to fall into the pitfalls illuminated by the mistakes of the past. It is a privilege to be a chemist and to have such a unique understanding of the world around us and appreciate its complexity. The chemistry community should do its part in trying to communicate their perspective to the general public and infect them with their enthusiasm about uncovering the truths of the world. Only a concerted effort towards this end will save chemistry and other fundamental science disciplines from a sad demise due to lack of interest and newcomers into these fields. I believe chemistry has still so much to offer, but is now ‘mature’ enough to adopt a more responsible, ‘strategic’ approach towards its goals.

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