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Are the Current Changes Good or Bad for Chemistry?

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We live in challenging times, with daily reminders of various threats such as climate change, wars, and other violence that arise from resource-motivated military adventurism or religious fanaticism, and political and corporate corruption. Nevertheless, thanks to scientific advances, the prospects for solving many of the world's problems in the areas of health, energy, food, and water supply have, in principle, never been more promising. Scientific knowledge, one of the greatest testaments to the intelligence, dedication, and creativity of humanity, has continuously provided opportunities for improved living standards (although in the wrong hands, or as a result of political directives, it also has an enormous potential for damage and destruction).

For over two thousand years, scientists, just like artists, often performed their creative work on relatively small budgets, in many cases supported by wealthy benefactors. However, performing cutting-edge science today requires a substantial amount of financial investment in equipment, personnel, and supplies. Governments, realizing the benefits of supporting scientific discovery, set up funding bodies to dispense research grants, mainly on a competitive basis. Similarly, corporations, as well as having their own research and development activities, also provided support to projects, usually of direct commercial interest. In recent decades, in the face of intense global economic competition, economic crises, moves to cut rates of taxation, and an increasing number of other valid claims on public funds, resources for science have been placed under extreme pressure in most countries.

After around 25 years working as an academic scientist both within, and at the interface of, the fields of inorganic chemistry and macromolecular science, much has changed. In addition, as I have resided in the UK, Germany, the US, and Canada during my career, I have observed first-hand how national approaches to performing science can differ. After 10 years at my current location in the UK, I offer my opinion on the changes that have been occurring here, which also appear to be surfacing worldwide.

It is hard to imagine a more exciting time to be involved in chemical research. The range of remarkable techniques and (often expensive) associated instrumentation available to interrogate and characterize matter in all its forms is unprecedented. Atoms can be routinely imaged, and fluorescent nanostructures with dimensions down to around 30 nm can be resolved by using superresolution methods. Over the last few decades, the gradual removal of the straightjackets and tunnel vision provided by the more overbearing aspects of an organizational framework consisting of disciplines and subdisciplines has led to flourishing scientific research at the boundaries of traditional subjects.

Developments in molecular biology and pathology, and as a consequence of mapping the human genome, have provided astounding opportunities for important advances. The origin of Huntington's disease can now be understood, whereas the causes of schizophrenia appear to be highly complex. Expanded knowledge relevant to the design and delivery of therapeutic agents offers unprecedented opportunities in cancer therapy and hope in tackling dementia. The creation and exploitation of chemical systems that exhibit artificial "lifelike behavior" represents a fascinating, immense, but increasingly realistic current challenge. This requires an understanding of self-assembly processes that are dynamic rather than static, and of energy-dissipative systems that exist far from thermodynamic equilibrium. However, the design of complex chemical networks with feedback loops that offer the possibility of emergent properties is still at a primitive stage.

Although the erosion of the artificial barriers between disciplines and subdisciplines and the enthusiasm for multidisciplinary activities have clearly led to many exceptionally positive developments, there are also some unfortunate negative side-effects. More and more, the many exciting and important scientific challenges that still reside nearer the centers of disciplines are being ignored. The development of carbenes as stable everyday synthetic reagents, main-group-element compounds that can activate small molecules such as dihydrogen and ethylene under mild conditions, and useful catalysts based on earth-abundant metals such as calcium and iron, as well as noble metals such as gold, provide a timely reminder that the potential for key scientific advances can also reside within single disciplines as well as at the periphery.

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The translation of scientific discoveries into practice requires a combination of research and engineering, together with the skills associated with commercial development. The key discoveries on which many commercial products are ultimately based are often the result of fundamental, exploratory research performed with no (commercial) end-use even contemplated. The discovery of NMR spectroscopy in the US after the 2nd World War, and the subsequent development in the 1970s of the now ubiquitous MRI machines for medical diagnostics in hospitals, provides an illustrative case.

It is remarkable that the idea of supporting truly fundamental research (where no direct application can be perceived or targeted) is under assault to varying degrees worldwide. Funding decisions and policy are being increasingly made with political oversight in mind. Even in Canada, where the country's national funding agency NSERC operates a highly original and often envied program to support fundamental research that involves funding scientists at levels mainly determined by their track record of scientific originality, recent funding cuts and directives have significantly eroded the system.

The current situation in the UK is of particular concern. Out of the G8 industrialized nations, the UK has the lowest percentage of national income devoted to science, and this figure is declining in real terms. Thus, the current prospects are not encouraging (see M. Burke, *Chemistry World* **2015**, *12* (November issue), 10–11). The lack of investment relative to other countries is compounded by an out-of-touch system of control that generates an ever-higher workload without respite. Often with exasperation, highly dedicated and talented scientists with little or no effective administrative support try to keep up with an ever-increasing bureaucratic burden that includes time-allocation surveys, timesheets, reporting of "outputs", rapidly expanding commitments to micromanage student's PhDs (progress monitoring/reports/documentation and ensuring "transferable-skills" training), instructions to adhere to open-access and data-storage requirements, and the constantly changing procedures arising from the latest visa rules for hiring new personnel from overseas. For exploratory science proposals submitted to the UK's national funding agency, EPSRC, a very large percentage of the pages are now dedicated to trying to pressurize the applicant to conform to the latest areas deemed to be of "national importance", to demonstrate "impact", together with elaborate calculations of estimated future research costs. Enormous sums of public money that could be invested in improving what are, in most cases, appallingly low funding success rates for exploratory science proposals are instead periodically diverted to massively time-consuming national reviews of departmental performance (currently called the Research Excellence Framework). These exercises produce results that are almost entirely predictable and are reported in such a manner that virtually every unit under review is able to successfully create some sort of "good news" story of demonstrated excellence by using one carefully selected statistic or another.

The selective use of statistics in order to trumpet self-serving but misleadingly positive conclusions is particularly prevalent among the politicians and bureaucrats who run the system. For example, it is regularly espoused that UK science is characterized by a higher impact in terms of citations relative to that of other countries, despite the relatively lower level of national investment. This leads to the regular assertion (based on an analogy with the sport of boxing) that chemistry in the UK is "punching above its weight". But this conclusion requires critical consideration. Citations are likely to be highest in established areas in which large numbers of scientists are working as there are more papers (along with their references) published. Therefore if funding directives focus resources on areas of high international activity that are deemed to be "nationally important" to the UK, it is scarcely surprising that citation data gives a superficial appearance of efficient funding investment (and therefore impressive political policy).

Examples of relevant questions for any funding body that is serious about supporting scientific discovery should surely be: What new areas of science that were previously unknown elsewhere have we enabled? What truly innovative new ideas to profoundly change scientific thinking have we helped cultivate? Another useful question to address should surely be: Which of our current programs would have supported the exploratory research on flipping spin states of the hydrogen nucleus in 1945–1946 that ultimately led to the development of MRI as a routine diagnostic tool in healthcare?

Increased investment in innovative exploratory research may lead to a relatively lower number of citations per unit investment as such projects tend to be more risky. A fair proportion of projects will never reach the point where they attract the attention of a large number of investigators worldwide. Nevertheless, science, and ultimately humankind, will benefit from an environment where the emergence of completely new areas and ideas is encouraged. This assertion is evidenced by the history of science and its impact on humanity. Given increased resources for nurturing fundamental research, together with the equally important support for applied research and commercialization, I am certain that the scientific community in both the UK and internationally will continue to deliver outstanding value to global society.

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