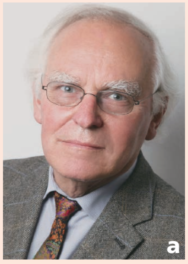
論説 Commentary

One-world chemistry and the quest for global sustainability



Henning HOPF[a], Goverdhan MEHTA[b], Alain KRIEF[c], Stephen A. MATLIN[d*]

a. Henning Hopf is a member of the Board of the International Organization for Chemical Sciences in Development (IOCD) and of its Chemistry Education Working Group. He is a Professor in the Institute of Organic Chemistry, Technische Universität Braunschweig, D-38106 Germany and is a former President of the German Chemical Society.

b. Goverdhan Mehta is a member of the Board of IOCD. He is University Distinguished Professor and Dr. Kallam Anji Reddy Chair, School of Chemistry, University of Hyderabad, 500046 (India).

c. Alain Krief is Executive Director of IOCD, Emeritus Professor in the Chemistry Department, Namur University, B-5000 Namur, Belgium and am Adjunct Professor, HEJ Research Institute, University of Karachi, Pakistan.

d. Stephen A. Matlin is Secretary and Head of Strategic Development for IOCD, Adjunct Professor in the Institute of Global Health Innovation, Imperial College London, SW7 2AZ, UK and Senior Fellow in the Global Health Centre, Graduate Institute of International and Development Studies, Geneva, Switzerland.

＊ Corresponding author: s.matlin@imperial.ac.uk

Introduction and Context

Chemistry has the potential to contribute solutions to many of the serious and pressing problems that the world faces in the 21st century. The challenges include those associated with a growing, rapidly urbanizing global population that makes ever-increasing demands for food, water, shelter, energy and materials for everyday living and that depletes the planet's natural resources and pollutes its environment with the by-products, waste products and discarded products from industrial production and rising global consumption. Furthermore, while improvements in medicine and public health over the last 1-2 centuries have resulted in dramatic increases in life expectancy, the development of multi-drug resistance in microorganisms and emergence of new and rare (orphan) diseases and periodic threats of pandemics are now regarded as a global crisis that could endanger healthcare systems globally and the practice of modern medicine.

To help meet these challenges with the greatest effect, chemistry needs to undergo major changes along three dimensions, involving there-conceptualization of its mission, the way that the field is taught, practiced and communicated, and the manner in which the professional bodies in the field organize themselves and promote the field.

The world has begun to recognize the magnitude of these problems and to try to galvanize efforts to address them—although these advances have not always been easy, rapid or without setbacks. It took almost two decades from the adoption of the Kyoto Protocol on climate change in 1997 to the adoption of the Paris Agreement[1] on climate change in 2015 and its entry into force the following year ; and a quarter of a century from the United Nations (UN) Conference on Environment and Development (the 'Earth Summit' in Rio de Janeiro) in 1992 to the agreement on the UN Sustainable Development Goals (SDGs)[2] in 2015. Global solutions are being sought to the growing problem of antibiotic resistance in microorganisms, but even the best way to frame the debate remains contested.[3]

Chemistry's capacity for innovation and ability to serve as the basis of a wide range of technologies mean that it can make a pivotal contribution to tackling climate change, meeting the SDGs and developing new approaches to combating diseases.[4,5]

Compounding these crises in the world at large, chemistry itself is experiencing deep-seated challenges. There is widespread lack of due appreciation of the field, which the public and the media often associate with pollution and toxicity ; while other, younger sciences are often depicted as more glamorous, exciting and forward-looking, leading to breakthroughs that capture worldwide attention.[6,7]

One-World Chemistry

How can chemistry respond in an optimal way to meet the current and oncoming challenges? We have proposed a re-orientation of the field which begins with the recognition that human and animal health and the biological and physical environments of the planet are all intimately connected—and then goes on to ask what the chemical sciences should look like if they are to give priority to this fact. Pondering the answer to this question led to the concept of '***one-world chemistry***'—to the belief that chemistry must extend its scope from 'being a science' and re-orientate its mission to 'being a science for the benefit of society'.[8] To achieve this, chemistry needs to go beyond simply looking for more 'useful applications'. It must try not only to meet the major challenges that the world faces in the 21st century, but in all areas it must strive to anticipate the possible adverse consequences, the possible harm that can be done, by chemistry applications and try to avoid this happening.

'One-world chemistry' embodies the concept that :

- Chemistry must go beyond '*being a science*' and embrace '*being a science for the benefit of society*'.
- Chemistry must play a leading role in developing responses to the challenge of sustainable development.
- Systems thinking is essential in the teaching, learning and practice of chemistry. This must recognize that human and animal health and the biological and physical environments of the planet are all intimately connected systems and that the solutions that chemistry develops to contemporary challenges must be informed by an awareness of the interactions between these systems.

- Cross-disciplinary approaches are vital, both to the evolution of chemistry as a science and to developing practical and sustainable solutions to 21st century challenges.
- Chemistry must be an ethical science.

Systems thinking

Taking account of the inter-relationships between human and animal health and the biological and physical environments of the planet requires thinking beyond solving immediate, separate problems. It necessitates being aware of whole systems (e.g. chemical, biological, environmental systems) and appreciating both how the internal dynamics of each system work and how the systems interact with and affect one another. In other words, one-world chemistry requires chemists to engage in systems thinking.

Consider, for example, the life cycle of a chemical product:

- Chemical reactions, whether they are small-scale laboratory or large-scale manufacturing processes, generate waste materials that need to be managed—including containment, disposal and recycling—in a safe and sustainable manner.
- The raw materials used, whether they are natural resources or other manufactured intermediates, must be sourced efficiently, cleanly, safely and sustainably.
- The products of manufacture may find very diverse uses, including household, medical, industrial and agricultural applications in which they come into contact with people, animals and the environment—and they must therefore be tested to ensure their biological and environmental safety.
- After use, the products or their consequent waste must be disposed of or recycled efficiently, cleanly, safely and sustainably.
- At every stage, the 'chemistry system' in which the product is manufactured, used and disposed of is interacting with the 'human system'. Actions involving chemistry don't just 'happen': they occur because of decisions that people take, individually or collectively. These decisions may result from diverse human motivations, including curiosity and aspirations for success, wealth, power or pleasure ; and they are influenced by legal constraints, by societal pressures and by movements for the advance of collective local and global goals.
- The 'chemistry system' therefore interlinks with a host of other overlapping systems including the biosphere, the environment, human and animal health, economics, politics, psychology and the law.
- A useful starting point is the adoption of 'green chemistry' principles.[9]

Cross-disciplinarity

A key requirement of the necessary redesign in chemistry—including the nature of the connections and engagements that chemistry makes to a host of other disciplines—is that both the teaching and practice of chemistry are informed by ***systems thinking*** and consequently embrace ***approaches that cut across disciplines***. These cross-disciplinary approaches may be, as appropriate, multi-, inter-or transdisciplinary.

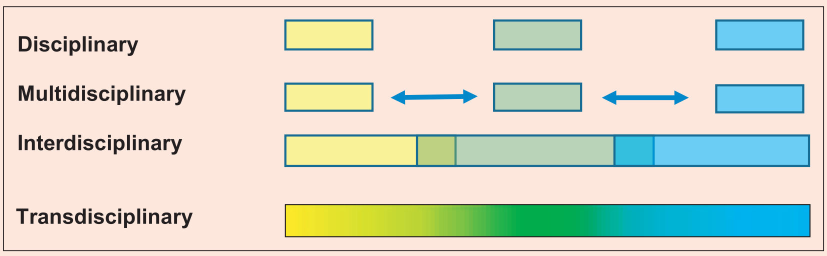
Chemistry's evolution as a well-defined and separate academic discipline has served the field well in the past. This has provided a secure base for research that has added to fundamental knowledge and contributed to technological applications in chemical, biotechnology and materials industries. From this base, chemistry has interfaced with a host of other scientific disciplines, contributing to theoretical, conceptual and practical advances in diverse biological and physical fields. But the nature of science—where, how and by whom it is performed and funded ; how disciplines interact and how complex problems are tackled ; how knowledge is created, stored, shared and valued—is changing fundamentally in the globalized world of the 21st century. The traditional separateness of the chemistry discipline does not appear to be aligned with these changes and fundamental revision is now required in how chemistry is situated and how it engages beyond its own boundaries.

Traditionally, chemists have been trained largely, if not entirely in their own discipline and have then been drawn into engagement with scientists from other disciplines. However, there are disadvantages to this compartmentalization of sciences:

- Within a complex and mature discipline like chemistry, both the inspiration for research (whether 'blue skies' or 'applied') and the capacity to tackle problems often originates from knowledge or challenges coming from outside ; and is increasingly dependent on the use of sophisticated techniques-such as advanced computing ; analytical instrumentation, bioanalytical and biotechnology processes, methods of observation, measurement and manipulation-that often originate in another field.
- Each stand-alone discipline has acquired a set of distinctive processes and methodologies. There are advantages in learning from an early stage how other branches of science think, what kinds of processes, techniques and measures they employ, how they think about constructing and testing hypotheses, what standards they apply to concepts such as purity and proof and what are considered to be the important fundamental and applied challenges in the field.
- Working effectively across disciplines does not come automatically—it requires the development not only of knowledge of other fields but also of skills (including communication, thinking outside the box, being able to synthesise information of diverse kinds, working in teams) that should be inculcated from an early stage of science education.

Chemistry has increasingly been drawn into cross-disciplinary engagements, the nature of which can take a number of different forms as illustrated below.[10] (Note : while they can be categorised separately in principle as below, there are often overlaps in practice with elements of the different forms being used in combination or tandem.)

- **Multidisciplinary**—bringing togeth-



Transition of modes of working: disciplinary, multidisciplinary, interdisciplinary and transdisciplinary

er knowledge and problem-solving approaches from a host of fields that can each contribute, 'side-by-side', to different stages or aspects of problem-solving; and **interdisciplinary**—developing expertise in working across the boundaries between chemistry and other disciplines and transferring methods from one discipline to another.

- **Transdisciplinary**—beyond interdisciplinary, creating a new discipline holistically: recognizing that valuable knowledge can be found in the spaces between defined disciplines, addressing the complexity of problems and the diversity of perceptions of them. It has been argued[11] that the shift from disciplinary to transdisciplinary research corresponds to a transition from compartmentalised, corrective, problem solving approaches to systemic, preventive ones.

Approaches that are cross-disciplinary in nature need to be fostered for chemistry to most effectively contribute. It is also notable that the adoption of cross-disciplinary approaches can make the field of chemistry much more attractive to potential students.[12]

Ethical science

One-world chemistry is concerned with benefitting all people and avoiding harm to people, animals and the environment. It must therefore be practiced as an **ethical science**. A starting point can be the equivalent of the physicians' principle of 'do no harm', but one-world chemistry goes further—in effect, advocating 'try to do good as the principle objective of practicing and applying the science'. Ethical behaviour and research integrity have been emerging as major areas of concern, including in the chemical sciences. But their promotion and practice in chemistry is often poorly visible and needs stronger enforcement. In 2015 a group of chemists (including one of the authors, HH) convened by the Organization for the Prohibition of Chemical Weapons developed a consensus in the form of The Hague Ethical Guidelines[13] based on 'norms of the practice of chemistry'. The main elements of the guidelines align closely with the principles of one-world chemistry. Subsequently, the American Chemical Society has drafted of a global code of ethics for chemists,[14] based on The Hague Ethical Guidelines, as a step towards filling this void; while EuCheMS has established a working party[15] on 'Ethics in Chemistry'.

The role of chemistry organizations

Chemistry organizations, at both national and international levels, have a long tradition of helping to develop and promote the interests of the subject and its practitioners. In a rapidly changing world, they need to contribute to the substantive adjustments and re-alignments required, including the need to refresh chemistry's sense of its own mission and purpose; reduce internal fragmentation and barriers to working across disciplinary boundaries; embrace systems thinking within the education, research and practice of chemistry; ensure the promotion of ethical approaches and research integrity in academia and industry; strengthen the promotion, championing and steering of the chemical sciences; and strengthen diversity and inclusion. In this endeavour, it is important that all chemistry practitioners—especially educators, researchers, the chemical industry and chemistry organizations—join forces in contributing to the evolutionary changes required. To be able to do this with objectivity and credibility, some chemistry organizations may need reforms that will amplify their remit and reset their priorities.[16]

Conclusion

To secure its own future and the sustainable development of the planet, chemistry must reposition itself. The concept of one-world chemistry offers a framework within which chemistry can re-orient itself as a sustainability science that is taught and practiced ethically for the benefit of society, incorporating systems thinking, cross-disciplinary approaches and green chemistry principles. Chemistry organizations, including national chemistry societies, can play a major role in fostering this evolutionary change.

1) United Nations Framework Convention on Climate Change: Adoption of the Paris Agreement. Conference of the Parties, Twenty-first session. Paris, 30 November to 11 December 2015. https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf
2) Sustainable Development Goals. New York: UN 2015. www.un.org/sustainabledevelopment/summit/
3) P. S. Jørgensen, D. Wernli, S. P. Carroll et al., *Nature* **2016**, *357*, 159. www.nature.com/polopoly_fs/1.20534!/menu/main/topColumns/topLeftColumn/pdf/537159a.pdf
4) S. A. Matlin, G. Mehta, H. Hopf, A. Krief, *Nature Chemistry* **2015**, *7*, 941. www.nature.com/nchem/journal/v7/n12/full/nchem.2389.html?WT.feed_name=subjects_sustainability
5) *Working for Sustainable Development.* International Organization for Chemical Sciences in Development, **2015**. www.iocd.org/v2_index.shtml#SUSTAINABLE
6) S. A. Matlin, G. Mehta, H. Hopf, A. Krief, Atlas of Science, 27 January **2016**. http://atlasofscience.org/repositioning-chemistry-for-the-21st-century/
7) S. A. Matlin, G. Mehta, H. Hopf, *Science* **2015**, *347*, 1179. www.sciencemag.org/content/347/6227/1179.full.pdf
8) S. A. Matlin, G. Mehta, H. Hopf, A. Krief, *Nature Chemistry* **2016**, *8*, 393. www.nature.com/nchem/journal/v8/n5/full/nchem.2498.html?WT.feed_name=subjects_policy
9) P. Anastas, J. Warner, 12 principles of green chemistry. American Chemical Society, **2017**. www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/12-principles-of-green-chemistry.html
10) W. Colón, P. Chitnis, J. P. Collins et al., *Nature Chemical Biology* **2008**, *4*, 511, doi:10.1038/nchembio0908-511. www.nature.com/nchembio/journal/v4/n9/fig_tab/nchembio0908-511_F1.html
11) U. Zoller, *Envir. Sci and Pollution Res.* **2000**, *7*, 63. www.ildesal.org.il/pdf/Professors/Uri_Zoller/5.pdf
12) D. Blankenhorn, RenewableEnergyWorld.com 16 May **2011**. http://blog.renewableenergyworld.com/ugc/blogs/2011/05/new-tools-let-chemistry-solve-the-energy-crisis.html
13) *The Hague Ethical Guidelines*. Organization for the Prohibition of Chemical Weapons **2015**. www.opcw.org/special-sections/science-technology/the-hague-ethical-guidelines/
14) *Global Chemists' Code of Ethics*. American Chemical Society, **2016**. www.acs.org/content/acs/en/global/international/science-and-human-rights.html
15) EuCheMS Working Party on 'Ethics in Chemistry', www.euchems.eu/divisions/ethics-in-chemistry/
16) G. Mehta, A. Krief, H. Hopf, S. A. Matlin, *Chemistry World* **2016**, *13*, online. www.chemistryworld.com/opinion/chemical-societies-must-adapt--heres-how-to-do-it/1017387.article

The commentary shown here is written by commentators invited by the Commentary Committee of the Society, and the authors are basically responsible for the contents. The Society acknowledges that this is important and worth publishing. Opinions and comments of the readers are highly appreciated.
E-mail: ronsetsu@chemistry.or.jp