One-world chemistry and systems thinking

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The practice and overarching mission of chemistry need a major overhaul in order to be fit for purpose in the twenty-first century and beyond. The concept of 'one-world' chemistry takes a systems approach that brings together many factors, including ethics and sustainability, that are critical to the future role of chemistry.

Chemistry has achieved outstanding success over the past two centuries in terms of advancing fundamental knowledge as well as its impact on applications relating to human health, wealth and well-being[1]. However, a number of observations suggest that chemistry is facing an existential crisis of sorts, including reflections from the fields of education[2], industry[3], the environment[4] and the public arena[5]. If this is the case, there are a number of likely contributory factors, including (1) the discipline has not been effective in reinventing itself or projecting its contemporary advances on prominent external platforms, (2) it is intrinsically an incremental science and has acquired the image of being a jaded and slow-paced discipline in an era of 'big bang' or 'instant' science, (3) it has witnessed encroachment on its own core space by other disciplines (for example, nanoscience, molecular biology and Earth sciences) and (4) there has been a lack of communication and public engagement, lack of sensitivity to societal issues, and an absence of credible and influential voices to articulate chemistry's importance and contributions.

A challenge for a 'mature' and omnipresent science is that it can enter a phase where it is often taken for granted and can seem stale[6]. Such perceptions have an adverse impact on its standing as well as the extent to which it is able to attract resources, talented students and practitioners and, ultimately, achieve its potential for adding to the stock of human knowledge and enriching life and lifestyles. Modern-day chemistry largely progresses through step-by-step advances rather than game-changing events and so it tends to be regarded as plodding along by doing more of the same and fails to excite the public and media in the way that other sciences hailing major breakthroughs can. There is a risk that chemistry might be thought to have reached a plateau where there is a lack of fundamental challenges and the focus is instead on incremental progress and on new applications of what is already known[7].

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This state of affairs is compounded by the fact that other fields have been much quicker than chemistry to mobilize efforts to address 'grand challenges' — large-scale and fundamental science problems that demand collective global effort and that seize the imagination of the media, the public, policy-makers and funders of science as well as the scientists themselves. Examples include the physics challenges that have united the quests for understanding the fundamental structures of atoms and the origins of the universe, and the molecular biological challenges of understanding the genetic processes of life. Although chemistry played a vital role in developing the Human Genome Project, this is broadly seen by the world as a success for biology, genetics or medicine. No project requiring such global effort and clearly identified as a 'chemistry grand challenge' has yet been implemented, although a number have been proposed and some adopted on a smaller, national scale[8]. The idea of chemistry as an exciting scientific pursuit generating groundbreaking new discoveries in its own right is giving way to its portrayal as a 'service science' for other fields.

Attitudes of the general public, media and policy-makers towards chemistry and its practitioners are complex. They sometimes recognize chemistry's pivotal utilitarian role that impinges on every facet of life[9] while at other times they focus on negative aspects, such as its ability to cause harm to people and the environment through deliberate (for example, chemical warfare) or accidental or unintended (chemical spillages, disasters in chemical plants, toxic side effects of drugs and food additives, build-up of environmental contaminants) actions. This unsettled view can result in the subject periodically losing popularity among potential learners in many countries[10]. Chemists themselves sometimes contribute to the negative image — it is striking that a recent survey in the United Kingdom has shown that chemists lack confidence, suspecting a much more negative perception of how they are regarded than is actually the case[11]. A discipline projecting even a semblance of self-doubt can undermine its own creativity and inspirational horizon and it must assiduously endeavour to present a positive and realistic image to the public.

Chemists and their professional bodies often seem reluctant to engage wider audiences — to project and explain their discoveries in everyday language, display an authoritative stance on a broader canvas transcending beyond their own research interests, or dialogue on topical and controversial issues of the day. There is also currently an absence of champions of the field who excel in communicating the excitement, achievements and potential of chemistry to the general public as, for example, Justus von Liebig did in the early days of chemistry, Richard Feynman did for physics, and James Watson and Jacques Monod did for modern biology in recent times. Chemistry educators could also do more to 'humanize' the subject and increase its appeal by the inclusion of examples depicting the history of key chemistry events, personalities and ideas.

We[12] and others[13–17] have drawn attention to the nature and extent of these challenges and the need for chemistry to develop a fresh idea of itself that will motivate its redesign to ensure that it becomes aligned with twenty-first century conditions, needs and expectations while remaining a productive and creative science.

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Essential roles for chemistry

The re-imagining and redesign need to encompass the internal content, practice and teaching of chemistry in addition to its external orientation, connections and engagements with a host of other disciplines and the world at large. These internal and external aspects are both essential if chemistry is to pursue the delivery of its potential while being valued and esteemed by society — which ultimately pays for and promotes that pursuit.

In our view, the re-imagined chemistry must go beyond 'being a science' and embrace the concept of 'being a science for the benefit of society'. This implies that chemistry must pursue a triple role, involving (1) creating new scientific knowledge, (2) translating knowledge into useful applications and (3) helping to meet the emergent challenges of multiple unfolding global crises. Chemists have traditionally engaged more in the first two elements, but adding a strong emphasis to the third is now an imperative.

Creating new scientific knowledge. At the core of chemistry is the search for new knowledge and understanding about the properties and transformations of atoms and molecules — creating a global public good on which all can draw. The discipline has been outstandingly successful during the past two centuries in providing fundamental knowledge, but chemists have largely failed to communicate the subject's quintessentially and distinctively creative character. As a science of substances and their transformations, chemistry's unique position among the natural sciences is defined by its creativity, a notion that has a dual aspect in chemistry. All sciences must be creative to arrive at solutions to their problems but, as Marcellin Berthelot observed in the nineteenth century[18], chemistry creativity also means the actual making of its object of study. This object now extends from small molecules to large supramolecular assemblies and beyond to synthetic biology; from the compounds found in nature to the 'unnatural products' deliberately designed by chemists for a particular purpose. In this respect, the canvas and creative element of chemistry are more akin to the arts[19] than, for example, other branches of the natural sciences. Developing chemists as material creators has been the goal of chemistry training in the past: it is the unique characteristic that must not be relinquished in any future developments in the chemical sciences and needs to be communicated within and beyond the domain of science.

Chemistry has also functioned as an enabling or central science[20,21]. It has underpinned the development of fundamental aspects of a range of emerging physical and biological sciences that depend on an understanding of molecular properties and interactions, including biochemistry, molecular biology and nanoscience. It will undoubtedly continue to do so — but must seek better and more proactive ways to foster productive engagements while ensuring that its own contributions are recognized and valued.

Translating knowledge into useful applications. Chemistry's innumerable applications have transformed life in the past two centuries, with major practical advances seen in such fields as agriculture, biotechnology, energy, the environment, genetics, information technology, materials and medicine[22]. A key enabling factor for this knowledge translation is the existence of productive interfaces between academia and industry and between chemistry and other disciplines. Both interfaces currently present challenges — that with industry because of major changes in the structure and orientation of the global chemical and pharmaceutical industries in the past couple of decades, and that with other fields of study because the necessary engagements across disciplines are increasingly complex in character, but the structures and systems of academia have not always evolved in a way that creates an enabling environment.

Gearing up to meet the challenges of multiple unfolding world crises. The world is facing a number of severe crises in the twenty-first century, many of which have their origins in the progress that has been achieved by human beings in the past two centuries. As a result of the improvements in agriculture, health, energy production and manufacturing capabilities that scientific and technological knowledge and applications have provided, there have been dramatic increases in population, average life expectancy and the consumption of material goods. But these very successes have brought with them their own problems: the increasing population of the planet — which was 1 billion in 1800 in the early days of successive agricultural and industrial revolutions and is set to exceed 9 billion by 2050 — faces the prospects of shortages of food and drinking water, severe depletion of key resources from 'endangered elements' to biological species and products, pollution of the planetary environment that risks damage to climate systems and ecosystems, and emerging and re-emerging diseases that pose severe threats to global health security.

Chemistry must play a central role in tackling these global challenges[23], including through addressing the Sustainable Development Goals[24] that the world's governments collectively adopted at the United Nations in September 2015. To do so effectively, a radical repositioning of the field of chemistry will be required[25].

Re-imagining as one-world chemistry

As a dynamic science, chemistry must constantly find new ways to refresh itself and be productive and creative. To fulfil its triple role, it needs to find new fundamental challenges and to engage across interfaces with a host of other disciplines and with industry, without losing its own identity but with a clear and visible presence in developing joint solutions. We propose that the concept of one-world chemistry provides a unifying vision that can orient chemistry's redesign to fulfil these ambitions. Over time, the complexity of structures and problems addressed by chemistry has increased and so has the complexity of our thinking: one-world chemistry is the next phase of this evolution.

The one-world concept embodies the idea that chemistry is a creative science that is practiced in both fundamental and applied arenas in a sustainable and ethical manner for the benefit of society.

A central characteristic must be that it enables those who learn and practice chemistry to be aware of and respond to the interconnectedness of chemistry and related chemical sciences with local and global systems. The concept of one-world chemistry is summarized in Table 1.

Systems thinking

The concept of one-world chemistry demands that the role of systems be embraced. Chemistry cannot be separated from the context in which it is conducted and its practice must be considered in relation to its impacts on many interconnected systems. For example, all chemical reactions, on whatever scale they are conducted, require the efficient, clean, safe and sustainable sourcing of materials, use and disposal or recycling of solvents, spent reagents and by-products, and the safe handling, use and appropriate disposal or recycling of the primary product itself. Materials and processes must be rigorously evaluated for their biological and environmental safety and potential impact within and beyond the uses for which they are intended. It is therefore important that the chemistry system is considered in relation to many other systems with which it interfaces, including the biosphere, the environment, human and animal health, economics, politics, psychology and the law. Chemistry should not be taught or practiced without pointing to the need to be aware of the potential for these relationships — that is, education and practice in chemistry must be informed by systems thinking.

The following three examples illustrate the way that systems thinking has come to be understood as an essential component of chemistry's progress.

Chlorofluorocarbons. Because of their chemical inertness, low toxicity and flammability, and suitably low boiling points, low-molecular weight chlorofluorocarbons (CFCs) were widely adopted for use as refrigerants in domestic refrigerators, as propellants in aerosol cans and as fire-fighting agents. However, the later discovery of the accumulation of CFCs in the atmosphere, their damaging effects on stratospheric ozone levels and the resulting threats to human health and ecosystems led to the Montreal Protocol to phase out their use and to replace them with safer substitutes. This highlights our evolving recognition of the need "to bridge traditional scientific disciplines and examine the Earth as an interrelated system of physical, chemical, and biological processes"[26]. Persuading the world's governments to adopt the Montreal Protocol was a clear example where systems thinking was central to understanding and responding to a global challenge — with chemistry being a key part of both the recognition and solution of the problem.

Antibiotics. During the golden age of antibiotics, between Fleming's discovery of penicillin in 1928 and the late twentieth century, chemistry provided a steady stream of new antibiotics in diverse structural classes, while deaths from infections fell from around 43% of all deaths to fewer than 7%. However, antimicrobial resistance in microorganisms has developed and spread and it is regarded as one of the greatest current challenges to global health[27] now causing serious health problems and economic losses in every part of the world. Several factors are driving this crisis, including clinical misuse and massive veterinary use of antibiotics and environmental contamination. There is also a 'discovery void', which is partly due to a failure in science, with neither the traditional synthesis and natural-product screening approaches nor the promising new life-science technologies yielding new classes of clinically useful antimicrobial agents since the 1980s. It is also partly due to a failure in the market system that has resulted in investment to create new antibiotics becoming unattractive. The necessary action to avert the antibiotic crisis must include recognizing that human health, animal health and the environment are very closely and interactively linked together and must draw on chemistry's contributions to create new diagnostics and treatments, cleaner processes for antibiotic manufacture and procedures for the treatment of wastewaters to avoid environmental contamination[28], as well as cheaper, faster and more convenient analytical tools to detect antibiotics in the environment.

Plastic waste in the sea. Plastics such as those based on polymers of alkenes have transformed materials in everyday use during the twentieth century, providing convenient carriers and packaging for food and beverages and structural materials for household uses and a host of other applications. But these valued applications of chemistry are now understood to have some long-term disadvantages, including that they create plastic waste that does not easily break down and is accumulating in the environment both on land and in the sea[29]. Larger items of plastic waste affect marine wildlife, which can become entangled or choked by it. Plastic microbeads[30] and submillimetre particles that are generated when plastic products degrade cause problems for smaller organisms when ingested and can accumulate in the food chain with adverse physiological and metabolic effects. The problem of plastic waste has arisen because of lack of systems thinking — a failure to look beyond the immediate utility of a product during its active life. In all areas of product manufacture, systems thinking requires that recycling considerations should be included from the outset, taking an overview of the beginning-to-end life of a product, including its life as waste and as recyclable material.

These three examples illustrate what can be learned from complex interactions between systems on the planet — learning that is essential for the Earth to move towards a pathway that is sustainable and that does not harm people, the biosphere or the physical environment. It is now time for chemistry to incorporate these principles

Table 1 | The concept of one-world chemistry.

Roles	Goals	Approaches	Orientations
Creating new scientific knowledge	Being a science for the benefit of society	Adopting sustainability principles	**Internal and external** Aligning the internal content, practice and teaching of chemistry and its external orientation, connections and engagements with other disciplines and the world at large with the goals and approaches of one-world chemistry
Translating knowledge into useful applications	Being a 'sustainability science'	Embracing systems thinking	
Helping to meet the challenges of multiple unfolding world crises	Being an ethical science	Working across disciplines	
		Strengthening the productive interface with industry	**External** Engaging strongly with the public and media, projecting chemistry's creativity, its past contributions and its future potential to be a science for the benefit of society
		Taking an ethical approach	

and to ensure that it is taking its share of responsibility for the future of the world.

Working across disciplines

Many of chemistry's greatest opportunities for contributing to human progress have been — and in the future will be — at the interfaces with other subjects. Both the fundamental scientific problems and the challenges that the world faces are complex and often require cross-disciplinary solutions. These approaches are not new and have been much discussed hitherto. We highlight them here because they need to be fostered within chemistry and embedded within one-world chemistry for it to contribute most effectively. However, chemists in academia traditionally have been trained largely, if not entirely, in their own discipline and only later drawn into engagement with scientists from other disciplines, for example, when they are employed in industry. There are major disadvantages to this lack of early training:

- Within a complex and mature discipline such as chemistry, both the inspiration for research (whether 'blue skies' or 'applied') and the capacity to tackle problems often originates through interdisciplinary convergences when knowledge or challenges come from outside. It increasingly depends on the use of sophisticated techniques that often originate in other fields — such as analytical instrumentation, bioanalytical and biotechnology processes, methods of observation, measurement and manipulation, and advanced computing. The history of advances in chemistry and the stories of many of the Nobel prizes in the field abound with examples of chemists who became aware of a problem or puzzling observation and of novel techniques that could be adapted for its investigation.
- Each stand-alone discipline has created 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 construct and test hypotheses, what standards they apply to concepts such as proof or material purity, and what are considered to be 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 synthesize information of diverse kinds, working in teams) that should be inculcated from an early stage of chemistry education.

In addition to challenging the capacities of individual chemists to adapt to working with scientists in other disciplines, there are also major systemic barriers to working across disciplinary boundaries. These include: factors intrinsic to the nature of chemistry itself; structural factors in academic institutions and the persistence of traditional attitudes towards discipline-based subjects; difficulties in securing research funds and in publishing work; and the relative lack of value that some institutions place on cross-disciplinary and multi-authored research, which can hamper career progression.

Nevertheless, chemistry has increasingly been drawn into engagements across disciplines, the nature of which can take a number of different forms:

- Multidisciplinary — bringing together 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.
- Interdisciplinary — developing expertise in working across the boundaries between chemistry and other disciplines and transferring methods from one discipline to another.
- Transdisciplinary — beyond interdisciplinary (which still implies the autonomy of subjects working in cooperation), creating a new synthesis of chemistry and other subjects in which knowledge, methods and solutions are developed 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; and representing a transition from compartmentalized, corrective, problem-solving approaches to systemic approaches that seek to prevent the occurrence of problems[31,32].

Chemistry as 'sustainability science'

One-world chemistry reflects chemistry's evolution towards becoming a central 'sustainability science'. Sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs[33]. In the field of chemistry[34], it requires: that raw materials are derived without severe depletion of natural reserves; that their manipulation and transformations are conducted in eco-friendly ways[35] that minimize environmental damage or ecological impact; that concern for recycling (wherever possible) or safe disposal of both the waste products and the products themselves at the end of their useful life are factored in from the outset; and that chemistry seeks applications of its knowledge to overcome major contemporary sustainability challenges, such as those relating to food, water, materials, energy and the environment. Positioning chemistry as 'sustainability science' means that it needs to start addressing emergent global challenges and requires that this ambition be projected to a wide audience through engaging with the public and the media.

Taking an ethical approach

It may not be entirely predictable at the outset of a new discovery in chemistry how it may be applied for good or bad, but an ethical principle should be a core reference for all those in and beyond chemistry who engage in the application. Chemists do not have the equivalent of the physician's Hippocratic oath, although the medical principle of 'do no harm' should be a first guiding principle for any field of human activity and certainly provides a good starting point for all practitioners of chemistry. More elaborately, a group of chemists (including one of the authors of this Commentary, H.H.) convened by the Organization for the Prohibition of Chemical Weapons has recently developed a consensus in the form of The Hague Ethical Guidelines[36] based on 'norms of the practice of chemistry'. The key elements of these guidelines (Box 1) align closely with the principles of one-world chemistry that we are advocating.

An agenda for one-world chemistry

A number of the guiding principles outlined here for the future of chemistry have been in circulation for some time. However, we believe that, taken collectively, their synthesis into an overarching framework amounts to a fresh idea of the field that we term one-world chemistry and that this offers an opportunity to align chemistry with twenty-first century circumstances in the field of science and in the wider context in which it is practiced.

What needs to be done to achieve the transformation to one-world chemistry? We do not believe that the expressed vision will be achieved simply by publishing papers and by a variety of organizations adopting new slogans. It will require considerable effort to overcome the well-recognized constraints of individual and institutional inertia and systemic barriers to change. We argue, therefore, that a vigorous and concerted effort is necessary by groups of

Box 1 | Key elements of the Hague Ethical Guidelines.

Core element. Achievements in the field of chemistry should be used to benefit humankind and protect the environment.

Sustainability. Chemistry practitioners have a special responsibility for promoting and achieving the United Nations Sustainable Development Goals of meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Education. Formal and informal educational providers, enterprise, industry and civil society should cooperate to equip anybody working in chemistry and others with the necessary knowledge and tools to take responsibility for the benefit of humankind and the protection of the environment, and to ensure relevant and meaningful engagement with the general public.

Awareness and engagement. Teachers, chemistry practitioners and policymakers should be aware of the multiple uses of chemicals, specifically their use as chemical weapons or their precursors. They should promote the peaceful applications of chemicals and work to prevent any misuse of chemicals, scientific knowledge, tools and technologies, and any harmful or unethical developments in research and innovation. They should disseminate relevant information about national and international laws, regulations, policies and practices.

Ethics. To adequately respond to societal challenges, education, research and innovation must respect fundamental rights and apply the highest ethical standards. Ethics should be perceived as a way of ensuring high-quality results in science.

Safety and security. Chemistry practitioners should promote the beneficial applications, uses and development of science and technology while encouraging and maintaining a strong culture of safety, health and security.

Accountability. Chemistry practitioners have a responsibility to ensure that chemicals, equipment and facilities are protected against theft and diversion and are not used for illegal, harmful or destructive purposes. These persons should be aware of applicable laws and regulations governing the manufacture and use of chemicals, and they should report any misuse of chemicals, scientific knowledge, equipment and facilities to the relevant authorities.

Oversight. Chemistry practitioners who supervise others have the additional responsibility to ensure that chemicals, equipment and facilities are not used by those persons for illegal, harmful or destructive purposes.

Exchange of information. Chemistry practitioners should promote the exchange of scientific and technical information relating to the development and application of chemistry for peaceful purposes.

chemists working in different settings and also collectively at national and global levels, as well as involvement by the public and the media, to achieve the key dimensions of chemistry reform required.

Academia. Achieving the goal of chemistry being a science for the benefit of society must begin with a re-orientation of teaching, learning and research in the field in academic institutions. It necessitates the inclusion of ethical and sustainable principles and practices as part of the mainstream approach to the subject. It further requires an emphasis on chemistry being taught through problem-solving approaches that encourage and test understanding and deductive reasoning, rather than as a collection of facts that require rote learning. Moreover, these problems should bring with them a systems' perspective to develop skills in seeing the wider picture that includes physical, biological, environmental or other systems as appropriate. Chemistry needs to be taught in context — not just the context of 'applications', but also the relevance to society and contribution to meeting global challenges, while fostering skills in cross-disciplinary working. Researchers need to be able to adapt and respond to the evolving needs of society. Interdisciplinary and transdisciplinary research should be encouraged, with efforts made to reduce institutional structural barriers, improve funding, and provide a level playing field for career progression and rewards for those engaged in these cross-disciplinary endeavours.

Industry and its interfaces. Industry has a central role to play in one-world chemistry as an innovator and translator of knowledge into processes and products. Like academia, it must include in the mainstream consideration of ethical rules and sustainable principles and practices and employ systems thinking that considers the desired and potential impacts of processes and products at all stages from the sourcing of inputs at the beginning to the final stages of recycling and waste disposal. It needs to engage in responsible chemicals management and responsible innovation. Sustainable or more eco-friendly chemistry is not an extra burden for the chemical industry but rather a new opportunity for effective management[37] and for efficient and cost-effective, as well as socially responsible, practice.

Industry should further enhance key interfaces with academia, the media and the public — investments that can yield rich returns in both substance and image. One-world chemistry offers major opportunities for reinvigorating these interfaces. Industry can use academic partnerships to strengthen the flow of ideas and challenging problems in both directions and drive the innovation demanded by sustainability and the need to address global challenges. Historically, leading chemistry figures such as Justus von Liebig played a key role in the transfer of knowledge to fields such as the agricultural and food industries[38], but currently chemistry career interchanges between academia and industry are still rare[39]. Industry can also use the appeal of applying 'science for the benefit of society' to become less removed from consumers, to have frank conversations with a society that demands transparency and has deep concern about risks, and to project a positive image to the world at large.

Professional bodies. As well as serving the needs of their members, national and international chemistry associations also have a responsibility to orient their organizations towards the global challenges and concerns of wider society. The adoption of one-world chemistry provides a compass for the professional bodies to steer their policies and practices in ways that will guide the field and promote a positive image. In taking this forward, there is no need for the professional bodies to reinvent the wheel. For example, some efforts of the German, UK and US chemical societies to bring chemistry to school children can be built on and there are already excellent materials available that could be better harmonized and in future given a stronger focus on one-world chemistry principles.

Public and media. The image of chemistry is determined by engagements involving the chemistry practitioners in academia and industry, the general public and the media. All sides have duties and obligations. The practitioners must communicate clearly about their ambitions, discoveries and successes, but also inform the public in an open, transparent and timely fashion about any unintended consequences, chemical accident or toxicological or environmental problem caused by chemical processes and products. They need to assist the public to make a serious effort to understand the problems that occur, based on evidence and reason, with the media playing a responsible and unbiased role in communicating the facts and background. The adoption of one-world chemistry offers a fresh opportunity for a debate among all sides about the purpose, goals and values of chemistry.

From individual to collective and global action. Moving forward must involve the collective and collaborative effort of the entire community engaged in the chemical sciences:

- At the individual and institutional level, chemical scientists should reflect on the objectives of one-world chemistry and the changes needed in structures and processes, in education, research and practice, to achieve these objectives. They should communicate their ideas through formal and informal publications and through the channels of the professional societies and bodies to which they belong.
- At the national and international levels, relevant professional academic and industry associations should come together to debate the objectives and institute processes to reach consensus on the nature and content of one-world chemistry.
- A mechanism for discussion and reaching consensus at the global level and for the subsequent promotion of one-world chemistry would be highly valuable. This debate can have many loci and might be led by an existing single agency or consortium of agencies (for example, International Union of Pure and Applied Chemistry, International Council for Science, United Nations Educational, Scientific and Cultural Organization or national professional associations), or it might be orchestrated at the global level by a newly formed international committee or commission, with voluntary support from existing international and national agencies.

Conclusions

Chemistry needs it mission and focus overhauled to make it fit for purpose in the twenty-first century — both as a central science that must constantly expand its horizons and as a crucial contributor to meeting global challenges, including those associated with sustainable development.

We propose that a central characteristic of a redesigned chemistry must be that it enables those who learn and practice chemistry to be aware of and respond to the interconnectedness of chemistry and related chemical sciences with local and global systems. This interconnectedness, including with the biosphere, the environment, human and animal health, economics, politics, psychology and the law, is summed up in the concept of one-world chemistry. We argue that a key requirement of the necessary redesign in chemistry is that both teaching and practice are informed by systems thinking and consequently embrace approaches that cross disciplinary boundaries.

Achieving the transformation we propose will require the collective and collaborative effort of all sections of the community engaged in the chemical sciences at local, national and global levels. We have indicated steps that can be taken to initiate this process and hope that the global chemistry community will take up this challenge, for the benefit of both the field and the society that it serves. ❐

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