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Chemistry and health: the need for a comprehensive approach

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Was there not some golden age, before human beings began the industrial development of the planet, when people lived healthy, clean and long lives close to nature? No, actually: at the dawn of human history, life expectancy was less than thirty years – and, strikingly, average global life expectancy remained below 30 years until the second half of the 19th century. It then began to increase very rapidly and more than doubled during the 20th century.[1] Over the past 150 years, average global life expectancy at birth has increased by roughly 3 months per year.

So, what roles might the chemical sciences have played in this dramatic increase in average global life expectancy?

- An important underpinning development was the Agricultural Revolution, which ensured that, on average, people were better fed and not malnourished.
- The field of immunization began with the demonstration that cowpox could be used to inoculate against smallpox. Subsequently, the chemical sciences have been fundamental to the development vaccines against a wide range of deadly diseases.
- The demonstration around 1830-50 of the anaesthetic effects of certain volatile liquids and gases that had recently become available by chemical synthesis was a vastly important step for medicine, enabling advances in surgery and dentistry that were completely impractical before the development of anaesthesia.
- The era of public health dates from work by John Snow and others in the mid-19th century on contaminated public water supplies. Water purification and analysis remains one of the cornerstones of modern public health.
- The foundations of biochemistry and of our understanding of the bacterial origin of infections were laid by the work of Louis Pasteur in the 1860s.
- The foundations of medicinal chemistry were laid around 1900 with the first syntheses of analgesics and antibiotics.
- The basis for metabolic medicine came from work by Casimir Funk, who isolated the first vitamin compounds and published his vitamine theory in 1912; 10 years later Frederick Banting showed that diabetes was the result of a deficiency of the hormone insulin, which he isolated and successfully used to treat diabetic patients.
- The modern antibiotic era really took off with Alexander Fleming's discovery of penicillin in 1928 and the introduction by Gerhard Domagk of the synthetic sulfa drugs in 1935.
- The anti-cancer era began in the 1940s with the work of Louis Goodman and Alfred Gilman on nitrogen mustard agents and anti-folate compounds.
- The transplant era was initiated in 1954 when Joseph Murray carried out the first successful human organ transplant – a transplant of a kidney between identical twins – but the real benefits could not become more generally available until the natural product cyclosporin was isolated in 1969 and its immunosuppressive properties were discovered. It first began to be used clinically in 1980 to prevent organ rejection.
- 'Science-based' drug development began in the 1960s, as a more systematic, experiment-led approach to discovering compounds with desired biological activities.

- And the new era of gene-based medicine that we are now witnessing can trace its origins, among other things, to the development by the 2-times Nobel Prize-winning chemist Frederick Sanger – and others – of methods for the chemical sequencing of DNA, which enabled the inception in 1990 of the project to map the human genome.

But average life expectancy is not evenly distributed around the world among different countries. As the chart shows, national average life expectancies for some countries now exceed 80 years (and for girls born in S Korea its now above 90 years), while for others national average life expectancies can be as low as half that.[2]

Alongside this chart of increasing average global life expectancy, let's place a chart that shows how overall human wealth has changed over time: this graph plots average global Gross Domestic Product (GDP) per capita, expressed in constant dollars, over the last 2000 years.[3] We can see that global GDP per capita remained pretty constant until just a couple of hundred years ago, but then began to rise increasingly steeply. The similarity between these two plots is striking and it may lead you to wonder whether the improving life expectancy is, in fact, just a product of increasing human wealth and overall economic development.

However, it turns out that this is not the case. We can examine the question by exploring the Preston curve, which plots average national life expectancy against GDP per capita for a particular year. The plot is named after Samuel Preston, U Pennsylvania. The first thing that you notice about the Preston Curve is that it's not linear – it rises steeply for poor countries and then begins to flatten out, so that beyond a certain wealth you don't go on getting an increase in average life expectancy.[4] This is an important indicator that wealth cannot be the only factor involved. But perhaps it is just that at a certain point you reach the natural lifespan of human beings?

Plotting a set of Preston curves for the last century covering different time periods and in constant dollars, you find something very interesting. In any one time period, there is a similar trend for the relationship between life expectancy and GDP per capita – but between each succeeding time period there is an overall increase in life expectancy. So in constant dollars, the same amount of national wealth correlates with more life in a later period.[5]

Preston himself attributed 75% to 90% of the increase in life expectancy to improvements in health technology, while income growth was responsible for the rest. This conclusion was supported by other eminent economists – for example, Richard Easterlin concluded that the decline in 20th century mortality had its origin in *technical progress* – where the term 'technical progress', as used by economists, refers to technological advances; their diffusion and uptake in different countries; and the capacities of the countries themselves to conduct and apply research.[6]

Ismail Serageldin, the Director of the Library of Alexandria in Egypt, has commented[7] that, increasingly, a nation's wealth will depend on knowledge and that the 'haves' and the 'have-nots' will be synonymous with the 'knows' and the 'know-nots'. And clearly, for the poorer countries, not acquiring and using new knowledge is not only a matter of economics – it is also a question of life and death. To put it simply – *"ignorance is fatal"*.[8]

So there is clear evidence that, beyond any general effects of increasing wealth, there is a substantial contribution being made by technical progress to the increasing life expectancy we are seeing across the world. And there are at least three strands that are important for this: of course, the biological sciences, as well as the chemical sciences, are major contributors; and so are the so-called 'social determinants of health' – a term that is generally understood to include a range of economic, environmental, political and social factors.

So, at least as evidenced by increasing life expectancy, human health has unquestionably been improving for the last couple of centuries. But in the 21st century, there are some major oncoming global health challenges that threaten this improvement. Some of these are to do with the state of the body,

including challenges in the diagnosis, prevention and treatment of a range of old, new and re-emerging diseases. There are growing threats of epidemics and pandemics, as well as from a range of non-communicable diseases including heart disease, stroke, diabetes and cancer; increasing importance of diseases associated with ageing, including degenerative diseases of the brain and skeletal system; and challenges we are setting for ourselves in new health goals such as personalised medicine.

But this forms only part of the picture, because we also face health challenges that come from the state of the world. These include a whole range of factors in the global environment (pollution in the land, sea, air; climate change, water, food, etc); and a host of economic, political and social factors (such as globalization, conflict and violence, health equity, population and urbanization).

The wide range of challenges that the planet faces have been summed up in the UN Sustainable Development Goals (SDGs) for 2030, which were agreed by all countries at the UN in 2015. One of the goals (no 3) specifically deals with health and aims to *"Ensure healthy lives and promote well-being for all at all ages"* and to *"leave no-one behind"* – but all the goals are inter-connected and have health implications.

When these SDGs emerged from the UN General Assembly in 2015, a group of us working with the International Organization for Chemical Sciences in Development (IOCD) published an article drawing attention to the fact that chemistry has a central role to play in sustainable development and in helping to achieve the SDGs.[9] But we noted that chemistry itself would need to undergo some major reforms, amounting to a new orientation, if it is going to be able to make its optimal contribution to tackling these challenges.

We followed this up with a paper in 2016 in which we proposed what this new orientation might be – which we called 'one-world chemistry' and which offers a framework for how to achieve this reform.

OWC emphasises that, as well as being a broadly based pure and applied science, chemistry should focus on becoming – and being seen as – a science for the benefit of society. In our view, this means that it needs to be governed by ethical practice, infused with systems thinking and embracing cross-disciplinary approaches.

OWC recognises that the Earth is a single system in which the health of human beings, animals and the environment are all strongly interconnected: and consequently that all three must be taken into account in considering the <u>impacts</u> of chemistry.

The OWC approach has implications for chemistry and health. It emphasises the need for comprehensive approaches that see the relationships between chemistry and health in the broad context. It requires thinking about systems and how they function and interact to influence health; and the importance of using cross-disciplinary approaches to tackle health challenges.

Let me just elaborate for a minute on what I mean by cross-disciplinary approaches. There are a number of terms that people use to describe working across disciplines. There are sometimes used interchangeably, but it's useful to distinguish between different modes of working that are possible. So there is the traditional disciplinary approach of disciplines working alone in silos; multi-disciplinary modes involving disciplines working 'side-by-side', with some exchange of knowledge; interdisciplinary modes that develop expertise in working across boundaries and transferring methods between disciplines; and transdisciplinary modes that create new synthesis of subjects in which knowledge, methods and solutions are developed holistically: recognizing that valuable knowledge can be found in the spaces between defined disciplines.

To illustrate the need for systems thinking in relation to chemistry and health, there is no better place to start than with the global problem of growing resistance to antibiotics by bacteria. Many people see this as the biggest single challenge to global health in the 21st century.[10] In the early 20th century, before antibiotics came into use, infections caused around 43% of all deaths. Fleming's discovery of penicillin

in 1928 began to change that dramatically – but Fleming was among the first to warn that development by bacteria of resistance to antibiotics was going to be a serious problem. But many new antibiotics were discovered or synthesised during the 20th century and by the end of this period we enjoyed a golden age when fewer than 7% of deaths were being caused by infections. WHO estimates that, on average, antibiotics and vaccines add 20 years to each person's life.

However, during this period ARB has been growing and spreading and is now causing serious health problems and serious economic loss in every part of the world. For example, ARBs cause the majority of the 100,000 deaths a year from infections acquired in hospitals in the USA and result in additional health care costs amounting to tens of billions of dollars. Australia is by no means immune from this global problem – as highlighted by last year's report from the Government's Commission on Safety and Quality in Health Care, on Antimicrobial Use and Resistance in Australia.[11]

At least 4 major factors are driving this crisis in ARB:

- Antibiotic misuse
- Massive veterinary use of antibiotics, especially to promote animal growth and to prevent disease in healthy animals[12] (growth promotion use banned in Europe since 2006 and from 1 Jan 2017 in USA; still under consideration in Australia[13]).
- Environmental contamination
- We are also living in a period of a discovery void.

Many new antibiotics – and whole new classes of antibiotics – were discovered or synthesised during the 20th century, so that chemistry provided a steady pipeline of new drugs as the old ones gradually lost their effectiveness against the evolving strains of bacteria. But we then entered a 'discovery void', where not a single new class of antibiotics was discovered in the period 1987-2014.

And at least 3 major factors have contributed to this discovery void:

- The first of these is a failure in science. Some people argue that the *"low-hanging fruit has all been picked"*; and meanwhile the promising new life science technologies have so far failed to yield new classes of antimicrobials.
- A second factor is a failure in the market system that drives the investment in creating new medicines. On one hand, drugs for chronic diseases offer a far greater potential return on investment for pharmaceutical companies; and on the other hand it has been the case for many years that any new antibiotic discovered is likely to be reserved for use as a last-resort treatment, which greatly reduces the size of the market and the profit to be made. This has been summed up as a *"systemic global market failure"*.
- And there are also regulatory burdens – it has become increasingly difficult over time to get new drugs, including new antibiotics, registered. This acts as a further disincentive to the market in an area where the economic returns are already poor.

Some better news came in 2015, with the discovery of a new antibiotic named teixobactin, which is in a new peptide class and for which Gram-positive organisms appear to show no resistance, so far. The discovery of this natural product followed a breakthrough in developing a new way of screening for antibiotic activity in bacteria that cannot be cultured in the laboratory. Of course, it will take several years before we know whether teixobactin will make it into the clinic. But it's also notable that this promising candidate drug did not come from industry but from research that was publicly funded and the patent is held by an early-stage biotech company. 2018: Phase II clinical trials funded by NIH.[14]

There are still a range of systems issues that need to be sorted out if the world is going to get better at discovering and developing new antibiotics. To quote[15] from latest Nature Biotechnology: *"Addressing the commercial failure of the antibiotic market should be a priority for governments seeking to encourage development of new drugs against resistant bugs."*

And the extent of this systems thinking needed becomes more evident if we look at the way that the determinants of AMR cut across the whole spectrum of human, animal and environmental factors. Antibiotics enter these highly interconnected systems at many different points. They enter the water systems to which human beings are exposed; they enter the food chain through the ways that animals are reared and meat is produced for consumption; and through the ways that food crops are grown; and people are also especially exposed to antibiotic-resistant bacteria through the infections they acquire in hospitals. It will clearly not be possible to reduce the evolutionary pressures that lead to resistance without simultaneously tackling all these systems together.

So the picture summarised[16] in *The Lancet Infectious Diseases* journal in 2013 was that "*we are at the dawn of a post-antibiotic era"*. And as we look towards the middle of the century, we are faced with the prospect that without action, infection-related mortality may return to pre-antibiotic levels. If this happens, the whole practice of medicine will have to change and any kind of surgical procedure will carry a high risk of infection. As we saw on an earlier chart, ARBs already cause the majority of the 100,000 deaths a year from hospital-acquired infections in the USA alone.

On the science side, there is a critical need for better tools to be able to recognize resistant organisms and diagnose their type. Then there is the challenge to develop new classes of antibiotics.[17] In 2016, the US government nearly doubled the federal funding to combat AMR to US$ 1.2 billion. The EU has launched its own Action Plan on AMR and has established a public-private partnership with the European pharmaceutical industry called the 'Innovative Medicines Initiative', one of whose areas of work is to develop new antibiotics in the '*New Drugs for Bad Bugs'* programme.

It is evident that there is need for a coordinated global effort to counter antibiotic resistance:

- May 2015 World Health Assembly: Global action plan on antimicrobial resistance (AMR)
  - ✓ governments all committed by May 2017 to put in place a national action plan on antimicrobial resistance, aligned with the global action plan
- USA+EU: Trans Atlantic Taskforce on Antimicrobial Resistance
- WHO, UN's Food and Agriculture Organization and World Organisation for Animal Health collaborating closely

Contaminants in environment, food & pharmaceuticals

Let's look at another example of the overall environmental challenge that the world now faces – which is with the levels of contaminants in environment, food & pharmaceuticals – and some of those contaminants are themselves pharmaceuticals. For example:

- In 2006, the Indian government banned use of the anti-inflammatory drug diclofenac for veterinary purposes after it brought vultures to the brink of extinction. Vultures were being poisoned after eating the carcasses of cattle that had been treated with the drug. However, a study[18] reported in 2011 showed that the ban was widely being ignored and numbers of the Asian vulture had continued to decline after 2006.
- Another report in 2011 in *Nature*[19] discussed high levels of pharmaceutical ingredients in treated effluent from wastewater-treatment plants and in effluent downstream from pharmaceutical factories, with examples coming from the European Union, India and the USA. Evidence of the environmental impact included the effect on fish and the appearance of very high levels of intersex characteristics.

Environmental contamination with pharmaceutical ingredients is very widespread – and it's important to recognise that there has been a systemic failure, at both national and global levels, to deal with these problems. As the Nature report observes, contrary to what many people believe: *"The USA and Europe do <u>not</u> have regulations limiting the concentrations of pharmaceuticals released into the aquatic environment in either municipal wastewater or in effluent from manufacturing facilities."* So there is a need for better regulation – and equally importantly, such regulations and their enforcement are meaningless without very good analytical techniques. The whole system of environmental protection, monitoring and enforcement needs improving in this area.

A complementary area of very serious concern is the contamination of pharmaceutical products themselves, and also of foodstuffs, with harmful ingredients. Just to take a couple of representative examples:

- Illegal use of diethylene glycol in various pharmacy products has caused hundreds of deaths across several countries in recent years.[20] The Nigerian case in 2009 was traced to deliberate fraud by a chemical dealer in Lagos supplying diethylene glycol instead of glycerine.[21,22]
- In China, widespread adulteration of infant feeding formulas with melamine (a trimer of cyanamide, added to boost the measured nitrogen content) caused serious harm on a large scale.[23,24,25]
- In the UK, an example of deliberate contamination of a pharmaceutical product occurred in 2011, when a man was prosecuted and subsequently jailed for adulterating packages of the painkiller Nurofen Plus.[26,27]

And of course, if we look at contamination of foodstuffs more broadly, beyond pharmaceuticals, in 2013 there was a scandal in the UK and a dozen other countries across Europe, when foods advertised as containing beef were found on analysis to contain as much as 100% horse meat instead.

A paper by Brown & Brown in 2010 overviewed the global picture and looked at lessons that could be learned. Regarding the extent of problem, they concluded that

- Toxic results from contaminated food and drugs are often only identified when there are large numbers of cases and numerous deaths;
- Deliberate contamination may be widespread, but it is likely to escape detection in poorly regulated markets; and
- Contaminated materials from poorly regulated places may cross national boundaries and end up in numerous products, including in more well-regulated markets.

The review also looked at the capacity for solutions and concluded that

- It is not clear that regulatory organizations have the capacity to identify significant contaminations, despite their best efforts. And therefore
- The [relevant scientific] communities, in cooperation with regulatory agencies, should develop cooperative programmes designed to detect and limit these global outbreaks. But,
- while addressing regional or national outbreaks remains an important role for regulatory agencies, the [relevant scientific] communities must develop proactive <u>global</u> approaches. This is a global problem and needs global solutions.

Clearly, the chemical sciences can play a major role in tackling these adulteration challenges, but this requires that scientists engage in an organized way with one another and with the public, with legal systems and with policy makers for this to be effective.

And then there is the massive problem of counterfeit drugs. This is a global business worth many tens (if not hundreds) of billion dollars a year. Counterfeit medicines are estimated to constitute more than 10% of the global medicines market, with a range up to 50% in some LMICs. It remains a big challenge even in well-regulated pharmaceutical markets like that in the USA, because c. 40% of drugs in USA are imported and c. 80% of the active ingredients in US drugs come from external sources. About 10% of all counterfeit seizures made by US customs in 2014 were counterfeit medicines.[28]

Of course, these types of fraud have been made very much easier by the use of the internet as a source of pharmaceutical products and globally a high proportion of all drugs sold on the internet are counterfeit.

WHO has shown that a very wide range of drug types are involved, and a whole range of faults from little or no active ingredients to substitution with potentially harmful substances.[29] The lack of effective treatment can result in death.[30] Examples include fake treatments for malaria; it is estimated that every year hundreds of thousands of people die as a result of counterfeit malaria medications – and a study in Nigeria in 2011 showed that close to 2/3 of all antimalarials available were counterfeit.[31]

While such problems are a lot more common in low- and middle-income countries, they are also found in high-income countries:

- In March 2008, the US FDA recalled batches of heparin, a widely used injectable anticoagulant. It was found that the bulk ingredient, which had been manufactured in China, had been mixed with a much cheaper material made from chondroitin sulphate. The FDA received 785 reports of serious injuries and at least 81 deaths were believed to be associated with this fraud.[32]
- In 2012, a counterfeit of the anti-cancer drug Altuzan was found being prescribed in the USA which had no active ingredient – a Turkish man was jailed for this fraud in 2014. [33,34,35]

It is clear that the problem is also one with global proportions and needs a global approach; but in many places there is absence of, or weak, drug regulation. As the World Health Organization stated[36] in 1984: *"every country, regardless of its stage of development, should consider investment in an independent national drug quality control laboratory".* But: at present, of 191 WHO member states, only about a fifth have well developed drug regulation. Of remainder, about half implement some drug regulation while another 30% either have no drug regulation in place or a very limited capacity.[37] The world market for pharmaceutical anti-counterfeiting technology was estimated to be worth around US$3.4 billion in 2015 and is growing rapidly.[38] It's predicted that the combined pharmaceutical and food anti-counterfeiting market may exceed US$ 160 billion by 2020.

So, looking across the whole problem related to contaminants in the environment, food and drugs, some general conclusions are:

- There are major scientific challenges and opportunities; and the public and policy makers need to understand the problems and support the systemic solutions required. This presents challenges for developing both the science and the appropriate science literacy.
- And there are also challenges for regulation, which is failing to deal fully with issues that have global dimensions and require systematic solutions on a global scale. And developing these solutions also gives rise to a need to develop appropriate capacities for science literacy, communication and diplomacy.

So we have argued that the chemical sciences have been good for health, but that, faced with the oncoming global challenges, even greater efforts are required.

And we have applied some systems thinking the relationship between chemistry and health and have concluded that the chemical sciences are not able to function optimally in helping to deliver better health and health equity.

And this is because we see three systemic fragmentations that act as inhibitors. These are disconnections in:

1. the science discipline
2. the functioning of the related industry
3. the regulatory systems related to health

So, let's take a look at the picture. The chemical sciences support health through multiple channels.

- They support education, research and practice in 'the chemical sciences for health'.
- They support pharmaceutical and other health science industries; and also agriculture & fisheries
- and they provide the basis for monitoring, protection, preservation and cleaning of the environment

Together, these activities

- provide us with safe, effective, affordable pharmaceutical products and other medical products and devices:
- they contribute to our access to safe, nutritious food;
- and they enable us to be able to work for good quality of the environment

And there are regulatory systems that are intended to oversee each of these three areas which are so vital for our overall health.

Together, these activities have a central contribution to make to the overall ambition of sustainable development that supports healthy people, animals and planet.

But we are arguing that there are fragmentations in three critical areas – highlighted here. Let's briefly look at each of them in turn,

1. Compartmentalization in the science discipline

The discipline of chemistry itself is highly compartmentalised, with a host of sub-disciplines that often work in silos in departments that are structurally divided. And the same is true for the adjacent biological sciences – and for the sub-disciplines that are constantly emerging at the interfaces. The same is also true at the interfaces with adjacent areas like the materials sciences.

And amidst all these compartments and silos, the reality is that 'chemistry and health', does not exist as a recognised subject.

We propose that 'chemistry and health' should be created as a recognised subject, in order to:

- create an overall vision
- provide the intellectual underpinnings for education, research and practice
- and also to promote convergence of diverse knowledge streams that can be harnessed to enhance innovation for health

This means new degrees; and it will require efforts to change existing curricula.

Of course, we all know how difficult it can be to change curricula that have become embedded in institutions.

2. Dis-integration in the pharmaceutical industry

The second fragmentation we are concerned about is one which has been developing in the pharmaceutical industry

The pharmaceutical industry located in high-income countries has been/is:

- undergoing a massive consolidation that is concentrating the industry increasingly in the hands of a few mega-players, focusing on high-profit 'blockbuster' drugs
- undergoing a dis-integration – a shift from 'vertical' to 'horizontal' structures, including the separation of discovery research from development

And in order to feed the emptying drug pipelines, they have been

- Buying intellectual property rather than creating it (and this has included, in many cases, buying and 'absorbing' the innovative small companies that create the candidates)
- Experiencing a shift to the East and South (China, India) in production, consumption and R&D.

Well, the question is: Does it actually matter where and how the science gets done, as long as new products are created to meet the world's growing health needs? Analysts differ:

- For some: the metamorphosis has had 'mixed results'
- And for others: it has not been to the advantage of people's health
  - decline in numbers of new drug entities coming into use annually
  - narrowing of focus on block-buster drugs while 'diseases of the poor' neglected
  - there may be a shift in job opportunities in the relevant sciences accompanying the geographic relocation of pharmaceutical R&D to South and East Asia;
  - and in the longer term this may decrease the popularity of these sciences in Europe and North America, weakening their traditionally strong capacities in research for health

It's interesting to look at the report issued in 2016 by the Association of British Pharmaceutical Industries on 'The changing UK drug discovery landscape'. This suggested that, while discovery investment was increasing globally, the UK might be proportionally losing out to other places. And this report made no reference to Brexit, which had just been voted for while the report was in production.

The report concluded that the UK needs to consider how it can best work to keep its position as a central player in the global landscape.

So, it seems that the model needs revisiting, since the world definitely needs

- more drugs and other health products
- a system that improves health and health equity for all.

But it's clear that finding solution(s) will not be straightforward, because the current trends are driven by economic forces originating outside the pharmaceutical sector itself.

If the high-income countries with traditionally strong pharmaceutical development capacities wish to retain their industries and their leadership roles in the field, they need to play close attention to systemic elements involved and bolster critical ones, including:

- ensuring strong, robust and well-designed education programmes, including relating to the chemical sciences, that create a pool of talent with skills honed in conducting inter-disciplinary and trans-disciplinary research
- well-funded academic centres that can create new leads to health products
- innovation hubs that foster early-stage drug development
- national innovation systems and innovation financing that encourage the growth of independent middle-size companies that have options beyond buy-out when they create promising candidate products and high-value new licensed drugs

We can argue that all of these things are being done to some extent at present. But the comments by the ABPI and others suggest that they are not yet being done sufficiently to arrest and reverse the trends that are happening.

3. Disconnections in the regulatory sector

It's a dirty world (full of pollution) and a fake world (full of counterfeits and adulterated materials). And this affects pharmaceuticals, food and the environment.

There is need for more effective regulation, requiring attention to a combination of:

- Licencing
- Quality of products procured
- Quality of products in circulation
- Counterfeits
- Contamination of environment
- Contamination of foodstuffs

Regulation is, in practice, the sum of laws, policing and the criminal justice system working in tandem. Analytical science feeds into all three – it sets the position for what is possible; for what is detectable; and for what is enforceable.

Here we see that interaction between science system and human systems plays a central role. Dialogue essential: between scientists, policy makers, legal system, public, media. This dialogue requires developing skill in the use of

- a shared, non-technical language
- and in effective communication – for example, about the meanings of terms like 'certainty' and 'risk'.

So what is needed is communication that creates productive dialogue, leading to decision-making and effective regulation and enforcement. This process needs to involve people working in the diverse but, as we have just seen, interconnected fields of pharmaceuticals, food and the environment as well as policy-makers and people from an array of national, regional and global organizations.

But there are quite a lot of these. There are diverse organizations that represent groups of professional analysts and different analytical techniques; and there are national and occasionally regional bodies involved in the regulation of registration, quality and enforcement. So, with such a complex array of actors, how is the world going to be able to create a coherent dialogue, reconcile different views and make sense of the field? How are the scientists, policy makers and regulators going to be able to communicate with one another and act effectively together?

Well, perhaps it's time to consider whether we need a World Organization for Regulation of Food, the Environment and Drugs – a truly global solution to a global problem?

The central points in this presentation have just been published[39] in the journal ACS Omega, which you can find at this location:
http://doi.org/10.1021/acsomega.7b01463

Thank you for listening.

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