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Ethics of the future of chemical sciences

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Abstract
The 2016 Royal Society of Chemistry's report Future of the Chemical Sciences presents four different scenarios for the future of chemistry: chemistry saves the world; push-button chemistry; a world without chemists; and free market chemistry. In this paper we ethically assess them. If chemistry is to solve many of the greatest challenges facing the contemporary world, prioritization of research topics will need to be done explicitly on the basis of moral values, such as solidarity and equity, but also environmental justice, which will have to be central in determining a research agenda for chemistry. The decentralization of chemistry will also present ethical challenges to the research standards established by the scientific community. Ethical education in chemistry may help counteract these risks. We also argue that if chemistry and its subdisciplines are to fulfil their goal of generating knowledge and helping us solve the great challenges of the contemporary world, then it is ethically imperative that scientists from different disciplines be more open to interdisciplinary work. Finally, if the future of chemistry is in free market forms, then it is necessary that we pay more attention to the possible risks that this model has. We call attention to two: first, it is likely that problems that affect the lowest income countries or the most disadvantaged sectors of society, who do not have the means to pay for some of the goods and services, will not be addressed; second, the free market tends to foster unsustainable forms of development.

Keywords Future of chemistry · Ethics · Royal Society of Chemistry · Green chemistry · Interdiscipline · Free market chemistry · Economics of chemistry

Introduction

Recently, interest has been growing in discussing the ethical issues of chemical practices (Kovac 2004; Chamizo 2013; Hoffmann 2015; Llored and Sarrade 2016; Schummer and Borensen 2021). Until now all research has been done on historical cases. In the present work, based on the Royal Society of Chemistry's report *Future of the Chemical Sciences* (Palermo 2016) we assess ethically the possible consequences of the four scenarios

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indicated therein, which are: chemistry saves the world; push-button chemistry; a world without chemists; and free market chemistry.

The *Royal Society of Chemistry* is the oldest chemical society in the world and they celebrated their 175th anniversary in 2016. Among the various activities that took place that year, one of them was to put together a multi-stage programme working with leaders from around the world and across different sectors exploring ways in which the chemical sciences might evolve (Palermo 2018). The result was the aforementioned report with its corresponding four scenarios.

The ethical positions corresponding to each of these scenarios focus on the work of chemical communities as Schummer indicated:

> *Ethics of chemistry is thus the academic field that studies the moral values, norms, judgments, and virtues relevant to chemistry with the aim of providing moral guidance from a general ethics perspective. Because ethics takes, per definition an impartial stance, it may question, criticize, or confirm the moral attitudes of chemists—as individuals, corporations, or local or global scientific society—rather than taking them for granted. In ethics, like in any science, it does not matter what people believe at a certain time and place, but only what rational arguments can be provided to support or oppose a view* (2021 p.14).

Chemistry saves the world

Since its millenary origin, through trades, the main way in which chemists today 'know' is by 'doing', and this chemical practice characterized by action has always increased the complexity of the world. Through the operation of systems that today we would identify as technochemistry (Chamizo 2013), human beings, as voluntary agents, obtain objects that were not in the natural, such as Dynamite, Aspirin, Nylon, Freons and millions of artificial substances, that constitute a supernature. There are no new substances without action and without design. They are not only the result of intentional human action, they also have embedded meaning in a specific historical context. Chemical practices are not neutral (Chamizo 2020).

In this first scenario, the best future we can hope for is that the chemical communities assume their own responsibility. Since the eighteenth century, with the emergence of chemistry as an independent discipline with its own robust scientific practices, accompanied by a powerful and flourishing industry, the word *responsabilité/responsibility* was incorporated into the vocabulary of chemical practices. This philological fact is not trivial. Since the Enlightenment, it was taking over in European and later North American societies, the conviction that we must assume, without excuse or possible remedy, our own horrors, as something we must account for. The foundation of the FDA (Food and Drug Administration) in the United States at the beginning of the twentieth century was an example of the way in which the communities themselves regulated their practices and the trade of the substances they produced. Here it must be specified that there are different levels of responsibility and obligation. In particular, ethical responsibility implies that action requires freedom of decision and summons people, communities, societies, and all of humanity. Each level corresponds to a responsibility and an obligation that can be different and sometimes contradictory.

During the present century when the discussion of a way of proceeding within the chemical communities has deepened. This was the result, among others, of the work of M. Molina and S. Rowland, winners of the Nobel Prize in Chemistry in 1995 and promoters of the Montreal Protocol, unanimously signed by all UN member countries in 1987. Thus, in at least two of the main geopolitical spaces, the United States through the American Chemical Society (Kovac 2004) and the European Community through REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) (Llored 2017) have been holding, with planetary intentions, discussions on the establishment of codes of conduct and regulations, explicitly or implicitly, based on the Precautionary Principle agreed upon by UNESCO (2015):

> *When human activities may lead to morally unacceptable harm that is scientifically plausible*[1] *but uncertain, actions shall be taken to avoid or diminish that harm. Morally unacceptable harm refers to harm to humans or the environment that is threatening to human life or health, or serious and effectively irreversible, or inequitable to present or future generations, or imposed without adequate consideration of the human rights of those affected.*

The Precautionary Principle, which is legally binding only in the European Community,[2] is not a guide for decision-making but clearly recognizes the priority in expert knowledge decisions. However, it does not make clear what is meant by environment since, in addition to being constantly changing, it is subject to various interpretations. Tensions between experts on the one hand, and the general public on the other have been one of the most important factors in debates on environmental protection. Frequently, both groups entered the discussions with divergent backgrounds and objectives, ranging from what is considered an environmental crisis, to the methods to recognize and manage it. For this reason, the need to mediate between the opinions of technical experts and the people affected is becoming clear (Moser and Dondi 2016). Thus, it is essential to specify, at least within chemical communities, the deliberation and action procedures among its members.

Parallel to the work carried out by Molina and Rowland, there has been a consolidation of what is now known as Green Chemistry (Anastas and Williamson 1996). This has led to the fact that in various parts of the world, within laboratories and factories, chemistry practitioners begin to take into account the life cycle of a chemical substance from the beginning (design, manufacture, use, recycling, etc.). That is to say, that they should take into account the consequences of what they do on the world, the time that substances as such remain unchanged, the human societies in which they are integrated, and human- or non-human agency (such as biodegradability, see Latour 2021), which occurs on the same substances. Thus, in an increasingly clear way, chemical substances can be identified in a specific region, that is, in a particular social environment, according to the following trajectory (Guibaudi and Cerruti 2017):

chemical substance → material → industrial product → commercial good → waste.

A trajectory like the previous one will allow to explicitly specify the consequences of the synthesis and production of new substances according to the Precautionary Principle.

[1] The judgement of plausibility should be grounded in scientific analysis. Analysis should be ongoing so that chosen actions are subject to review. Uncertainty may apply to, but need not be limited to, causality or the bounds of the possible harm. Actions are interventions that are undertaken before harm occurs that seek to avoid or diminish the harm. Actions should be chosen that are proportional to the seriousness of the potential harm, with consideration of their positive and negative consequences, and with an assessment of the moral implications of both action and inaction. The choice of action should be the result of a participatory process.

[2] https://eur-lex.europa.eu/EN/legal-content/summary/the-precautionary-principle.html

Despite its undeniable penetration into current chemical practices, some of the great challenges of Green Chemistry is the call for greater integration between academia and industry, as well as a more extensive incorporation into chemistry curricula (Marques and Machado 2021).

The American Chemical Society indicated in 2021 that every day more than 15 000 new substances were added to the more than 150 million already identified. A few years before, it was estimated that just over 100, 000 different substances were used on the market (Kümmerer and Clark 2016). Their effects on humans or the environment depended on their very nature and on the other substances with which they were mixed. In addition, of course, to its concentration according to the Paracelsus maxim: *the dose makes the poison.* In other words, all chemical substances are toxic at a certain concentration. With this consideration, Schummer indicated that on top of adding new substances, what we are adding is a great ignorance about their chemical behaviour, which is making the world less and less predictable. In his own words (2001 p. 110): *With the production of a new substance, the scope of non-knowledge increases enormously, both because of the number of undetermined properties of the new substance, and because of all the possible chemical reactions of the substances, existing substances with the new one.* REACH included in its initial program 30, 000 substances that prioritize their effects on health and the environment over their structure, so there is a huge amount of research to be done that has to do with the impact of chemicals in the creation of a new environment.

Assuming the responsibility manifested by the Precautionary Principle, the mobilized chemical communities, appealing to human beings and all other forms of life, to the present and to the future, will have an outstanding participation in the construction of the future.

Push-button chemistry

Through their laboratory practices, both academic and industrial, focused on analysis and synthesis, since the nineteenth century chemists developed a specific way of thinking and acquired particular points of view on the transformation of substances into what can be recognized as a techno-scientific 'way of knowing' (Pickstone 2000). Briefly, technoscience not only seeks to establish representations of the world, that is, to model it, but above all, and based on scientific knowledge and tacit knowledge (Polanyi 1966), carry out actions that transform it. This has been done by considering a series of criteria and socially accepted objectives. It was at this juncture, particularly in 1876, when the French chemist M. Berthelot enunciated his famous phrase: *chemistry creates its object*. Since then the increase of chemical objects (substances) thrown into the world by chemical communities has gone from a few thousand to hundreds of millions, and the chemical way of thinking (based on synthesis) was integrated into molecular biology and later adopted by synthetic biology. Since we are people, we are naturally artificial…

From the historical period known in Europe as the Renaissance, Western societies, hegemonic or not in their own national states and with innumerable internal contradictions, have accepted that everything that exists in the world is natural or the product of human work, whether manual or mental (Bunge 2007). The so-called humanism was established as a general perspective from which the world can be seen. Humanism, denying beliefs in the supernatural, can be understood as either a broad philosophical anthropology or a secular social philosophy. It represents the passage from fatalism to reason. The first focused on religion and the second on what we have characterized as technoscience.

Through the latter it is possible to know the world, thinking and intervening. That is to say, the perfectibility of human nature, responsibility, and the possibility of progress are accepted. These ideals are complemented by the humanist commitment to different values: resistance, intelligence, moderation, flexibility and sympathy, or also with what during the Enlightenment was summarized as freedom, equality and fraternity, and which politically implies the achievement or maintenance of a Secular state governed by representative institutions.

However, humanism, which can be called Western, despite its enormous discursive success with ambitions of universality, was neither humanism nor universal. Since its constitution, it has not addressed realities such as slavery and the segregation of women in its own western territories, and with great difficulty it was able to account for the horrors that characterized the first half of the twentieth century. Trench warfare with its poisonous gases, the banality of evil located in Nazi concentration camps, and the destruction of defenseless Japanese cities through atomic bombs dropped by the US military, were some examples of these horrors. The masculine and elitist Western universality turned out to be fragile and also exclusive.

With current technoscience, we have the technical and contingent capacity to modify human beings and thus the societies they make up, with their "others" and their "things". Despite our distant centennial ambition, we have passed, in this millennium, from humanism to transhumanism (Hottois 2016).

It was not until after the Second World War, in 1957, that J. Huxley initiated a Darwinian project that, defending biological diversity, would allow human societies to have control over random or negative aspects of their own genetics. He called this project, focused on biology, transhumanist. A few years later, chemists took up the challenge as their own.

At the end of the last century, More and Vita-More published the first transhumanist manifesto, which in its later extropian version rejected all religious influence and, based on liberalism, considered that the current state of humanity represents a transition. This transhumanism develops a kind of cyborg and astronaut technoanthropology, assuming human biology, except for the activity of the human brain, as an obstacle to its destiny, the cosmic mission of the species (Coenen 2014). Likewise, it appeals to the universal engineer, capable of bringing together various "things" in an acceptable and successful way in order to patent them. This was the case of all those who, like Venter, have adopted the chemists' way of knowing and joined the artificial life project. (Harari 2015; Schummer 2016).

Little by little and with the transhumanist backdrop we face unexpected situations as a result of the dense interconnectivity included in chemical practices, as a result of:

- *Digitization* With the incorporation of instruments in chemical practices and the digitization of their measurements, material substances, natural or artificial, pure or mixed, have been transformed into a set of signs and representations. This was indicated by Lazlo (1998): *Chemical analysis, taken more generally, has replaced matter by a spectrum (or by a set of spectra).*
- *Combinatorial chemistry, robotics and artificial intelligence* Combinatorial chemistry consists of a set of methodologies aimed at obtaining the largest possible number of substances generally related to each other (called libraries or chemical libraries), from a minimum number of reactions, using the same reaction conditions and in the most automated way possible, using robots. Thus, hundreds or thousands of substances can be synthesized at once instead of preparing only few of them using orthodox methodology (Rasheed and Farhat 2013). All this accompanied by computational methods based on

quantum chemistry and artificial intelligence capable of establishing problem-solving strategies. However, and as indicated by Han (2021, p.56): *Artificial intelligence is apathetic, that is to say, without pathos, without passion. It just calculates.*

- *Nanotechnology* The intentional construction of nanomaterials through scientific practices. A nanoparticle is the fundamental component in the manufacture of a nanomaterial, which size is in the range of 1–100 nm. A nanoparticle is vastly smaller than everyday objects described by Newton's laws of motion, but larger than atoms or molecules (though not necessarily a macromolecule) which are governed by quantum mechanics. No matter how small and light, imperceptible and ignored, nanoparticles are "things" integrated into material culture. The difficulties that entail have been indicated by Nordmann (2006, p. 71)*: If an advance in technical control produces a type of technology that eludes sensory perception and human responsibility, this technology turns out to be regressive in the sense that it returns us to the state of nature. We cannot trust a noumenal technology.*
- *The new chemical companies* Small, specialized, decentralized, with large capital needs and with the intention of moving away from the restrictions imposed by "tradition". Once R&D and production are not as expensive, they will take risks and go into making "things" that are not yet in the world. The tension between creativity and responsibility will grow as they will be able to escape their own national laws. Langer (2022), founder of Moderna, has said: *Big Pharma abhors risky ideas.*

A world without chemists

According to the prospects for chemistry drawn up by the Royal Society, we are heading towards a world without chemists. Previously, chemistry was a separate discipline and around it there was a community of scientists who identified themselves as chemists. However, chemistry has now expanded and divided into sub-disciplines. Fundamental chemistry has ceased to have the centrality that it used to have as a differentiated subject and as the basis for the training of professionals. There are now fewer people interested in the fundamental areas and more people focused on the sub-disciplines. The future, then, is a world without chemists.

But, isn't the same process happening also with other scientific disciplines and isn't specialization leading to the disappearance of "traditional" disciplines, such as physics, biology, geography or philosophy? In what sense is this unique to chemistry as a discipline? Are the other disciplines equally concerned about this process? To what extent are we simply facing a transformation in the organization of knowledge? Disciplinary fields are not monolithic or immutable, they have not remained the same throughout history. After all, what we call chemistry today is nothing more than the result of the process of shaping a disciplinary field that began in modern times from what was previously called "natural philosophy" and that gradually broke up into different sub-disciplines that then gave rise to autonomous disciplinary fields. Do we live today in a world without natural philosophers, and should we be concerned about that? On the other hand, how important is it that fewer people are trained and work in basic chemistry if many of them will end up specializing in one of the sub-disciplines, where they will apply some of the basic principles of the field that we continue calling "chemistry"?

The development of chemistry, as that of other disciplines, has tended more towards the creation of sub-disciplines. This has gone hand in hand with the need for specialization.

However, although specialization has advantages (Wellmon 2015), it also has practical, epistemic and ethical risks.

Among the practical pitfalls of specialization we would highlight the fact that it usually entails a one-sided, or in any case limited, way of seeing the phenomena studied. There is a tendency to see the phenomenon studied from a single perspective, that of the sub-discipline itself, a failure to appreciate other possible points of view, which almost inevitably leads to a biased or partial, if not distorted, view of the object of study. What is sometimes called "professional deformation" is the result of this form of specialization. It has also been called, following Thorstein Veblen, "trained disability," which is the idea that certain types of training or specialization can lead someone to be unable to think beyond the set of theoretical restrictions and assumptions with which he or she, has been trained. *Specialization […] draws off attention and interest from other lines than those in which the specialization falls; thereby widening the candidate's field of ignorance while it intensifies his effectiveness within his specialty* (Veblen 1918, p. 207).

However, the increasingly complex reality and problems presented to us by the contemporary world are not organized according to disciplines and sub-disciplines. If one of the goals of science is to reach the most complete and objective explanation of reality possible, it seems that the path of superspecialization is not going to lead us to there—or at most it will lead us to reach it in a limited way. If sciences fail, or do so only partially, it will be more difficult for them to help us solve some of the practical problems we face.

Although the requirements of the contemporary world do not allow us to renounce specialization in favour of a generalist position that advocates the individual development of a wide range of skills and knowledge, they do demand collective forms of interdisciplinary work. Interdisciplinary work implies the interaction or combination of two or more disciplinary fields in one activity, such as a research project or the resolution of complex practical problems. It implies fostering collaboration between different disciplines and communities of specialists.

It is possible that the more disciplines unite in the study of a certain phenomenon, and the more plurality there is in the perspectives on it, the less partial the knowledge reached is, and the more comprehensive. This, as we said before, is one of the goals of science. But also *objectivity is maximized … when the community is sufficiently diverse that a broad range of views can be considered* (Oreskes 2019 p.3).

Despite the clear challenge posed by the difficulty of communication across different disciplines, our goal is to attain the most comprehensive and objective understanding of reality. The 19th-century American philosopher William Clifford asserted, *it is wrong always, everywhere, and for any one, to believe anything upon insufficient evidence* (1877, 295). Often, a unidisciplinary approach provides insufficient justification for our beliefs. Therefore, it follows that when interdisciplinary work is likely to lead to better justification of our beliefs and a more complete understanding of reality, we have an obligation to pursue it. If, in addition to this interdisciplinary knowledge, we can reach conclusions that lead us to solve practical problems such as those that arise in chemistry, following a consequentialist position, then we have an obligation to do interdisciplinary work.

Free market chemistry

During the second half of the twentieth century, public funding of science, and particularly biomedical research, increased steadily in high-income countries, to the point that it became the main support for academic research (Nat Methods 2016). However, towards the end of the century, the establishment of austerity policies and cuts in public spending affected the financing of scientific research in high-income countries, but also in low- and middle-income countries. Many scientific research projects which do not receive public funds, run the risk of not having financing if they do not participate in private financing schemes. Thus, in the last three decades we have witnessed an increase in private funding in different areas of chemical research, which leads us to think that one of the possible scenarios for the future of the discipline is that of a "free market chemistry."

The free market has positive aspects, but also negative ones. Free market apologists have argued that there is no more efficient and fair distribution mechanism. There is none that is more respectful of individual freedom, understood as the non-interference of individual action by other people or by the State. The free market is the system in which goods and services are distributed through supply and demand. This generally implies that the State should not interfere by imposing regulation on the distribution of goods, but simply by guaranteeing the conditions for the proper functioning of the market. It has been claimed that the competition generated by the free market tends to stimulate scientific and technological research. The demand for goods and services generated by the needs and desires of consumers encourages scientists and those who finance them to look for solutions that satisfy that constraint. The free market makes companies that develop scientific research strive to innovate and offer new and better goods, services and technologies. The free market will also be in charge of rewarding those who offer the best goods and services, as well as the least expensive.

However, there are risks if future chemistry is developed under a free market model. First, it is likely that problems that affect the lowest income countries or the most disadvantaged sectors of society, who do not have the means to pay for some of the goods and services, will not be addressed; second, the free market tends to foster unsustainable forms of development.

If the research agenda in chemistry is determined by the interests of the market and large corporations, then it is likely that some of the world's greatest challenges will not be met. The needs of the world population do not necessarily coincide with the interests of the market. For example, millions of people die in the world every year due to the so-called "diseases of poverty," such as malaria, HIV/AIDS or some respiratory diseases, such as pneumonia. However, it has been pointed out that only 10% of global health research is devoted to conditions that account for 90% of the global burden of disease, the so-called "10/90 gap" (Stevens 2004). Although today this proportion has lessened (thanks to the financing of foundations such as the Gates Foundation), the problem still exists: big pharmaceutical companies often neglect tropical diseases, which are prevalent in many low-income countries. Trouiller and his colleagues (2002) compiled data from the FDA and European Agency for the Evaluations of Medicinal Products and discovered that of the 1393 new drugs approved between 1975 and 1999, only thirteen were specifically indicated for tropical diseases and tuberculosis, which together account for 12% of the total morbidity rate (Pedrique 2013).

If so little research is done to find remedies for these diseases, it is, among other things, because the affected populations usually do not have the economic capacity to pay the cost of the drugs, which makes it an unattractive market for the pharmaceutical industry. At the same time, much scientific research is devoted to diseases that affect a minority of people in rich countries who can pay for the treatments. Decreasing research attention being paid to diseases in the developing world increases global health disparities (Evans et al. 2014).

Examples like this make it clear that the future of pharmaceutical research cannot be left completely in the hands of the free market, given that—contrary to what its defenders claim—this is not the fairest mechanism for the distribution of goods and services. Let us understand justice not just as a reward for individual effort and investment, but as a mechanism of social distribution designed to guarantee equal freedoms for all, while avoiding the creation of social and economic disparities that favor a minority at the expense of the majority.

A second problem is that the free market tends to foster unsustainable forms of development—understanding sustainability as the preservation of natural resources to preserve life on earth. Since profit maximization is the biggest goal for firms, they usually do not take responsibility for collective goods, i.e., goods for which no one pays and that are financed with taxes. This is the case with natural resources: the free market usually does not take into account preserving the environment or conserving resources, unless it is in the firm's short-term best interests. Surface water, for example, which is purified and channelled is paid for but this water comes from groundwater tables and underground aquifers, for which there is no payment. Whoever pumps and purifies it pays only the cost of extraction and purification. There is no problem if these waters are recovered naturally, but if there is excessive rate of consumption there is damage to the community that the market does not account or take responsibility for (Sartori 2017).

The market usually does not take into account the so-called externalities, that is, the secondary effects that are generated when a company carries out an activity that causes damage to the environment, instead companies transfers the costs of clean-up or compensation to civil society or the state—and then we all end up paying for it. The chemical industry sometimes generates pollutants or uses dangerous substances that are at times discharged into the environment, causing negative impacts on health, crops and ecosystems (Simone et al. 2021). If there is no public intervention to account for externalities and reduce them, the free market alone will not do it.

These cases show that the free market model that is proposed as one of the possibilities for a future chemistry follows serious moral problems that we have to be aware of. If indeed the future of chemistry is in a free market model, attention must be paid to the counterweights to the power of the industry so that these problems do not happen. However, before reaching that scenario, it would be beneficial to insist on the need for public financing for scientific research, and on the basis that it is in everyone's interest to have institutions that preserve the collective public interest above private ones.

Conclusions

The Royal Society of Chemistry has presented us with four possible scenarios for the future of chemistry, but has not considered their ethical implications. If chemistry is to solve many of the greatest challenges facing the contemporary world, prioritization of research topics will need to be done explicitly on the basis of moral values. Values such as solidarity and equity, but also environmental justice, will have to be central in determining a research agenda for chemistry in the future.

If chemistry is going to be decentralized in such a way that small entrepreneurs in different parts of the world are going to contribute more and more to the development of chemical products, then we will also have to think about the ethical challenges that this new way of working presents. On the one hand, it will be necessary to pay more attention to the potential increase in products developed without the research standards established by the scientific community, but on the other hand, it will also be necessary to pay more attention to the appearance of black markets for different chemical products. Therefore, it will be necessary to strengthen ethical education within academic programs in chemistry. If chemistry is going to fulfill its fundamental objective of creating knowledge and helping to solve the great challenges of the contemporary world, the conduct of chemists must be guided by moral values such as integrity, honesty, social responsibility, but also respect for legality. The different regulatory and supervisory agencies will also have to be more alert to this new reality.

The future of chemistry also seems to lie in increasingly interdisciplinary forms of doing research. It is possible that chemistry, as a differentiated disciplinary field, will transform, disappear and give way to a multiplicity of new sub-disciplines. We believe that if chemistry and all these new fields are to fulfil their goal of generating knowledge and helping us solve the great challenges of the contemporary world, then it is morally imperative that scientists from different disciplines be more open to interdisciplinary work. As we have argued, it is an ethical obligation.

Finally, if it is true that the future of chemistry is follows the form of the free market, then it is necessary that the different agents pay more attention to the possible risks that this model has. Private industry, public policy decision makers, public agencies that fund research, but also chemical associations (such as the Royal Society of Chemistry) have to be alert to the insufficiencies of the free market and seek to remedy them: they should try to find solutions to the problems that affect the most disadvantaged social sectors and promote forms of sustainable development. Whether the future of chemistry unfolds according to the scenarios outlined by the Royal Society of Chemistry or takes other paths, it is imperative that those who do research or work in this field realize that their work has an inescapable ethical dimension, that they have a social responsibility and that the future of chemistry is, to a great extent, the future of society.

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