Research Article

Ethical Issues in Communication of Chemistry

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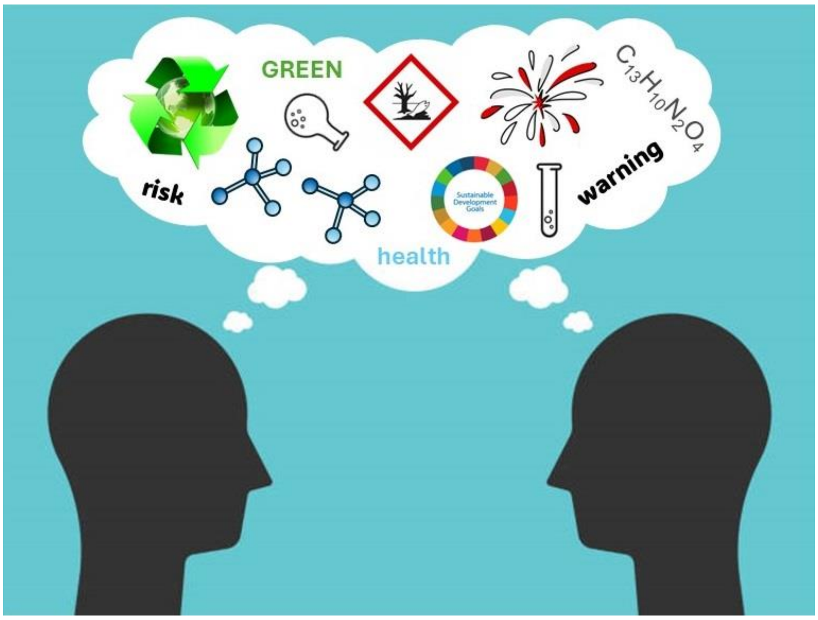
Abstract

The present manuscript aims to present several ideas and reflections about ethical issues in chemistry communication, which represent a deepening and updating of an oral presentation at the Symposium of EUCHEMS working party "*Ethics in Chemistry*", held in Rome the 6th-7th July 2017. These concepts could be useful for the community of chemists to face future challenges concerning the relationship between Chemistry and Society. Some basic features of modern science, communication and communication of science are presented, since they represent an important framework to build a discourse about ethics in chemistry communication. The specificity of chemistry, such as its features as inductive, creative, flexible, transversal and central science, need to be considered by chemists to be aware of ethical issues specific of chemistry. In the present paper I discuss some ethical issues related to the communication of chemists within the scientific community, such as scientific publishing and artificial intelligence uses, and some ethical concerns related to the communication to the general public and the effect on the society of unethical communication related to topics such as sustainability, food, health and environmental impact of chemical research. The manuscript end with some reflections about the need of ethics of chemistry in chemists’ training.

Graphical Abstract



Keywords

Education, Chemistry, Ethics, Chemistry Communication, Ethics of Research; Ethics of Science, Science Communication.

1. Introduction

The present contribution aims to present several concepts and ideas about the communication of chemistry and related ethical issues, that could be useful for the community of chemists. This topic has been object of an oral presentation at the Symposium of EUCHEMS working party "*Ethics in Chemistry*", held in Rome the 6th-7th July 2017.[1] Before presenting and discussing the ethical issues related to the communication of chemistry, a brief introduction concerning science, communication and ethical aspects related to the communication of science will serve as a framework of the discussion.

1.1 What is science?

The starting point of the discussion about ethics in communication of science implies sharing some key features about what science is. Despite several definitions of science exists, and different sociological and philosophical theories still debate about the definition of science, there are several features that characterize science, in particular, modern science:[2-4]

1. Science is a systematic knowledge and a process for producing knowledge, that is characterized by several shared procedures (i.e. ask a question, make an experiment and collect data, interpret data, formulate hypothesis to be validated – or falsified, develop models, theories, and so on…), usually referred to as 'scientific method';[5]
2. Science is a collective human enterprise, since scientific knowledge is built up through the collaboration of scientists from many countries, working in an interconnected way;[6]
3. Science is social, in several senses, either because it is based on social relations among scientists or because of the social values of the research results;[7]
4. Science aims to share knowledge to everybody, without preserving secrets inside the scientific community, but, on the contrary, trying to build the larger consensus in the public and in the society. This is also at the basis of the idea of '*open science*'.[8]

If we accept these basic features, it is not surprizing that scientists need to communicate to the general public, without delegating it to others.

There are also other aspects of the actual status of modern science that support and justify the idea that scientists should take care about communication of science to the general public:[2]

a. Large amount of money is devoted to science and technology (within the national budgets, which varies sensibly from one country to another), so scientists need to justify their work, disseminate their results, and so on.

b. The number of scientists and researchers is increasing rapidly (for instance, with respect to the previous century), so the impact of the scientific community in the society is increasing.

c. The number of publications is increasing exponentially in the recent decades, and this opens several problems in the transfer of new knowledge to the public, who can be disoriented by this large amount of data, results, and information.
d. The presence of private companies and investors in science and technology is a reality, and this implies a major need and care in the communication of scientific results.
e. The scientific community expanded in all competing continents and the scientific knowledge has a global and international dimension.

1.2 Communication as an essential human activity

A second aspect to consider in our discussion is the definition of **communication**. The origin of the term 'communication' is the Greek '*koinon*' which means 'in common', 'shared with others' and the Latin '*actio communicandi*' which can be translated as 'to give something to others, sharing a gift with the community'.[9] The modern theories of communication[10] are in agreement with these ancient terms, since the communication is seen not as a simple transfer of messages from A to B: the nowadays accepted definition of communication implies feedback from B to A. According to this point of view, to communicate means to establish a common space with an exchange of information between individuals through a common system of signs, codes and languages. Communication has the aim to establish a relationship among individuals with shared objectives. The bidirectionality of the communication is indeed related to the social value of the communication. Among the theories of communication,[9] the ideas developed by G. Bateson[11] and later formulated by P. Watzlawick[12] and the Palo Alto school can be considered an important starting point for the development of a discourse about ethics of communication. According to them, five axioms of communication can be defined:
1) It is not possible not to communicate. Communicating is indeed an essential human activity. Even when we are silent, we are communicating something.
2) Communication has always two levels: one is related to the content, and the other one is related to the relationship between the communicant and the others.
3) The nature of the relationship depends on the structure and the sequence of communication itself. This means that the meaning of communication can be influenced by the punctuation of the communication sequence.
4) Human communication involves both digital (verbal, symbolic, …) and analog (non-verbal, emotional, …) forms of communication.
5) All communications can be classified as symmetrical or complementary. The symmetry or asymmetry are referred to the communicant and others.

1.3 Scientists need to communicate

With these premises, it is rather obvious that scientists need to communicate their works, disseminate the scientific results, take care in establishing a good relationship with their publics. Moreover, in the nowadays world, scientists have to face an increased complexity of tools and possible ways of communication. The digital world offers new possibilities, but, at the same time, the variety of tools implies the need of specific expertise. This topic is currently object of several intense research.[13]

Scientists need to communicate in first person, and they cannot delegate to others. At least, they cannot neglect or lose interest about this important activity. This is what Tim Radford, a British journalist, wrote in Nature in 2011:[14] '*the case for scientists as inherently bad communicators is a canard*' or, in other words, there are no reasons to think that scientists are not good communicators and should not communicate. To support this idea,[14] Radford says that scientists have some 'natural gifts' such as enthusiasm, fundamental to engage the public, training in clarity and in observation, and, most important, they have the knowledge. All these aspects are necessary for a good communication of science. However, there are some problematic aspects, too, such as the academic publishing: the style, the formal language and the rules in publishing scientific papers move away scientists from an effective communication to the public. This last point is at the basis of the contribution by Garrett and Bird,[15] dealing with the main challenges of science communication. Scientists need to tackle a complex issue: they need to communicate to many different groups and individuals; not only they are usually concerned with the internal communication, which is characterized by very specialized languages and modalities, either informal (over lunch or in the corridor) or formal (talking during a conference or writing a review paper), but they have to share their knowledge with policy makers, educators, journalists and the general public. According to these authors,[15] the communication of scientific information behind the scientific community is particularly problematic due to the lack of a specific training. Doctoral students and researchers are indeed trained to write papers and grant proposals, not to talk to schoolchildren or to write educational papers. Another limit in the formation of the new generation of scientists is the great specialization of young researchers into tiny sub-disciplines. Social impact of science, as well as epistemological and philosophical reflections on science, and in general multidisciplinary and interdisciplinary approaches are normally not included or even discouraged in scientists' training.

Despite these intrinsic limitations, scientists need to communicate their work and their research to the general public and in doing that they have to front several questions:[16]

- What is the best way to communicate?
- What are the purposes of communication?

- What does it mean a good communication and what are the ethical issues related to communication of science?

1.4 Basic principles of science communication and ethical issues

Several philosophers and experts in science communication tried to give some answers to the above questions, and their suggestions can be of help for scientists. In a seminal paper Pietro Greco,[2] a recognized writer and journalist who left important reflections about science communication, wrote that a science communicator should follow these basic principles: be closer to the truth, try to be impartial, not to be interested and be universal. These features are close to the ethical values of science, as first proposed by Robert K. Merton, with the known "*mertonian norms"*, commonly referred under the acronym CUDOS: **communalism**, **universalism**, **disinterestedness**, and **organized skepticism**.[17] These ethical norms act as guides how science should be carried out and, in some ways, they can be transferred from science to science communication, as suggested by Greco.[2] However, as stated by Medvecky and Leach,[16] these ethical norms are far from being practical and they risk being only theoretical guidelines. As underlined by Burrell,[18] science communicators, either scientists or professional communicators, should consider the principles of **honesty** and **accuracy**, since '*effective science communication bridges the gap between the scientific community and the public, fostering understanding, trust, and informed decision-making*'.[18]

Other important considerations come from the founders of "*ethics of communication*", such as the German philosophers Karl Otto Apel[19] and Jurgen Habermas.[20] In an interview given to the Italian journalist, Enzo Moreno, Apel,[21] explains that a key point of ethics of the discourse and ethics of the communication is a set of basic norms which should guarantee the parity and **co-responsibility** of all members of a community. In the context of scientific and technological discoveries, Apel supports the idea that scientists should be ethical in communicating their works (i.e. by using a transparent communication, by explaining the consequences of the scientific results in the society, and so on…) to help all individuals recognizing their co-responsibility. The theme of **responsibility** of scientists has been object of several reflections by many philosophers and sociologists. A significant contribution comes from the philosopher Hans Jonas, who defined several principles of responsibility that can be applied to scientists too.[22] One of his statements is: '*Act so that the effects of your action are compatible with the permanence of genuine human life*', which underlines the concept of '*responsibility for the future generations*'. This idea recalls other important concepts relevant in the present discourse about ethics of communication, such as the evaluation of risks connected with a research result, and the precaution principle, to make few examples. The scientists need to consider the relationship between "*what they say*" and "*what they really do*" (for instance, in describing scientific results, in showing the potentialities of research, the utility of a scientific result for humans, and so on).

Communication of science is **dialogic** and **social**, and these features are related to the definition of communication itself, as seen in the previous section. According to Bucchi and Trench,[23] in the recent two decades, science communication has been deeply influenced by social media and digital technology, so that different communication strategies have been developed. Interactive and dialogic approaches such as talking about science in science caffè, theatral pieces, TED talks, scientific blogs, open discussion about science and society in informal contests and citizen science projects put in evidence how new trends in science communication are growing, which well fit in the category of 'social conversations'.[23] The dialogic aspect of science communication has several potentialities, as underlined by Lerma-Mayer,[24] in overcoming problems related to the digital communication, such as the pervasive misinformation and the spread of unverified information. To successfully do that, it is necessary to recognise and face cognitive, sociocultural, and technological biases which influence how information is presented and consumed. *'The dialogue*, write Lerma-Mayer,[24] *emphasises the active engagement of the public in scientific discourse, acknowledging the role of the public in knowledge creation, from receiving information to actively participating and co-creating knowledge'*.

Another aspect of scientists' communication is indeed related to the **purpose** of communication. Most scientists disseminate their research results following the so called '*deficit model*',[2] which implies the idea that scientific information and knowledge should be transferred to the public, thus avoiding a dialogic communication. According to König *et al*.,[25] communicating scientific findings can have several purposes: foster trust, assist public opinion formation, support evidence-based decision-making, promote science understanding, elicit engagement and positive attitudes toward science. For instance, if the purpose of communication is to increase science understanding, a scientist should be more focus in educating the public developing a critical thinking rather than transferring dogmatic scientific contents. On the other hand, if the main purpose is to contribute to the formation of a public opinion concerning a scientific problem, such as the need of a medical protocol or a choice related to an environmental issue, social and cultural background of the audience has to be considered carefully. The difficulties in pursuing these goals are evident in some recent issues related to vaccines, stem cells, pesticides, chemical additives in foods, and so on. For instance, the lay public struggle to understand why scientists have different positions on a topic and has difficulties in accepting the complexity and the uncertainty which is inherent of on-going research. Sometimes, there is a big mismatch between "*what scientists think is important to communicate*" and "*what the public is willing to know*" and this aspect has to be taken in mind when analysing the reasons of unsuccessful communication.[25] In addition to different aims and contents, scientists need to consider their audience, choose carefully the communication format and adapt their language accordingly.[26] As underlined in the previous section, one of the axioms of communication is related to the symmetry, or complementary, of the relationship between the communicant and the public. In the case of science communication, a structural asymmetry between the amount of knowledge of a scientist about a specific topic he/she wants to communicate and the lack of knowledge of the lay public is inherently present. This aspect represents a limitation which should be overcame to move towards a more symmetric relationship which is a fundamental aspect of ethical communication.[9]

2. Ethical issues in chemistry and chemistry communication

In the previous section, some basic features of science, science communication and ethics of science communication according to the literature on these topics have been briefly reported to build a framework for the discussion about the specificity of chemistry. As it will be shown in the next pages, some aspects of ethics of communication of chemistry are common with other scientific disciplines. However, chemistry presents several distinctive features which merit to be discussed to understand ethical implications of chemistry communication.

2.1 The nature of chemistry and ethical implications

The first reflection concerns the nature of chemistry and the features that characterize chemistry with respect to the other scientific disciplines. As Jeffrey Kovac asks rhetorically in his work,[27] '*What makes chemistry unique? And how does this uniqueness reflect on chemistry's unique concerns with ethics?*' His answer includes a simple consideration: chemical systems are at the right size to affect humans directly, since the object of chemistry are substances, at the macroscopic level, and molecules, at the sub-microscopic level. In this sense, chemical objects are intermediate between the very small and the vary big, and they interact directly with our perceived world.[27]

Frank *et al.*[28] described the three principal characteristics of chemistry that distinguish this science from other disciplines: the **inductive** character of chemical knowledge, its **creativity** and **flexibility**.

2.1.1 Chemistry as inductive science

The first feature is related to the inherent experimental nature of chemistry: observations and experimentations following the scientific method were at the basis of the understanding of many chemical phenomena, either natural or artificial ones. In particular, some branches of chemistry, such as inorganic, organic and pharmaceutic chemistry, have developed through the history thanks to the inductive approach. The experimentations are related to some important ethical issues, such as the need (or not) of animal experiments to develop new drugs.

2.1.2 Chemistry as creative science

Creativity is probably the most crucial aspect in terms of ethics. It attains to the ability of chemists to design and produce new chemical substances, not existing in nature, with potential negative effects on humans and on the environments. This can be a real big problem, since chemists synthetise thousands of new compounds every year. Even though they are produced to benefit the humankind, to solve problems related to the environment or to the health, nobody can exclude their eventual negative impact after many decades or their use for different, even dangerous, applications with respect to the initial aim. Several interesting cases are reported in the special issue of Hyle published in 2016.[29] Ruthenberg discussed the ontological underdetermination of chemicals, in particular of bioactive compounds, starting from the historical and famous case of the thalidomide.[30] In this story, a role was also played by the way thalidomide healthy effects were communicated. As Ruthenberg[30] reports this drug was advertised excessively, and, in particular, two aspects were emphasized in the marketing campaign: the lack of toxicity and the natural ness of the support of a 'good sleep'. In this case, as Ruthenberg[30] states, chemists had several responsibilities, in fact '*neglecting the underdetermined chemical character of their product, they decided to follow or tolerate an aggressive marketing campaign based on at least incomplete and distorted results and trivialized or neglected all the anxious reports about side effects'*. Another interesting case is the one reported by Martin *et al.*[31] concerning the bisphenol-A risks. This case exemplifies the societal debate over the impact of industrial chemicals, since bisphenol-A (BPA), which was introduced in the market with the production of epoxy resins, is present in many consumer products such as baby bottles, reusable water bottles and food packaging, and it dissipates during multiple consume, thus potentially affecting a great number of humans. The estrogenic properties of BPA have been known since the early 1900s, however there were scientific controversies about their risks for health. This case is indeed an example of the difficulties in defining chemicals toxicity and of the roles of regulatory agencies and governments in the decision about chemicals' regulations.[31]

2.1.3 Chemistry as flexible science

The third feature of chemistry according to Frank *et al*.[28] is its flexibility, which refers to the fact that any new chemical substance or in general any new chemical knowledge open to many possible applications and unpredictable uses in many different areas, such as medicine, electronics, material science and technology, and so on. This concept is also related to the so called 'dual use', which means that a chemical substance synthesized for a particular purpose (to benefit humanity, such as a new drug for a specific disease) can be used for a negative purpose, criminal or military objectives, and vice versa. The duality of the use of chemicals is mostly related to applications, but it concerns either pure or applied chemistry.[28]

2.1.4 Technochemistry

The link between chemical knowledge and technology is nowadays so evident that the new term '**technochemistry**' has been coined by Chamizo to describe this way of generating knowledge:[32] *'technochemistry then, refers to the activities derived from the chemical experiment, which in a fundamental way and based on a specific set of values, transform the reality in which we live'.* According to Chamizo, the concept of technochemistry opens to new questions which span from education to public understanding and finally to ethics.[32] The intimate relationship between chemical knowledge and real products as well as technology implies a high level of interdisciplinarity, and it supports the idea of chemistry as a **transversal** and **central science**.[33]

2.1.5 Chemistry as transversal and central science

The Nobel Prize in Chemistry Carolyn Bertozzi[34] wrote that the term "*central science is now widely used to describe chemistry's focal role in bridging the physical and life sciences, and the basic sciences with applied disciplines like medicine and engineering"*. As argued by Chamizo and Ortiz-Millán,[35] since chemistry and its sub-disciplines '*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.'* Interdisciplinarity of the research, which implies a collaborative work among different disciplines is intimately related to the concept of transversality and centrality of chemistry, since '*chemistry plays a vital role in the materials, biomedical, environmental and energy sciences*'.[34] A consequence of these specific features of chemistry, according to Chamizo and Ortiz-Millán,[35] is that since an interdisciplinary approach is necessary to solve complex problems or to understand certain phenomena in reality, chemists have the obligation to pursue it.[35]

2.2 Domains of ethics in chemistry communication

As reported in the paper by Mehlich *et al.*[36] there are several ways of categorizing ethical aspects of chemistry: good or bad, right or wrong, clear cases or unclear ones. Another way is to distinguish ethical issues in chemistry in two domains: **internal domain** (concerning the individual chemists or the chemical community) and **external domain** (dealing with the impact of chemistry in the societal, environmental and economical levels).[36] In the following paragraphs I have used these two domains to describe the ethical issues related to chemistry communication. In particular, with the internal domain I intend the actions of both individuals and chemistry community having an impact mostly within the chemistry community (such as the misconducts in publishing or in mentoring), while with external domain I refer to those activities that have a direct impact on society (such as the exaltation of a scientific finding in a public arena or through the digital media). As it will be noted by the readers, this distinction is not always so net, and this will be commented case by case.

2.3 Ethical issues in communication of chemistry: internal domain

2.3.1 Scientific publishing

Examples of ethical issues of communication of the scientific results within the scientific community, pertaining to the internal domain, are related to the phenomenon of '*temptation to plagiarise, not acknowledging prior work to make own research appear more novel, falsifying data, publishing before ensuring reproducibility*' as reported by Nina Notman within her commentary.[37] These are ethical concerns linked to scientific publishing, and as a consequence to communication of science within the scientific community. It is known that this is one of the collateral effects of the so-called '*publish or perish*' system, which has determined the exponential growth of published scientific papers in the recent years as well as the emergence of new scientific journals by publishing houses: the so-called predatory journals. This publishing system is threatening the science credibility, and the fact that government institutions has introduced several indexes based on papers citations in the evaluation of scientists for their academic career, has determined some distortions, as reported in a recent paper by Baccini *et al.*[38] These phenomena concern chemists and chemistry, too. The retraction of scientific papers is related to these kinds of ethical concerns. An interesting paper dealing with the retraction of papers in chemistry was recently published by Sevryugina and Jimenez.[39] As shown in this work, the main reason for retraction of manuscripts published in the field of Chemistry is misconduct (58.5%), which includes several behaviours (frauds, plagiarism, self-plagiarism, and so on). In particular, self-plagiarism, such as the publication of part of already published works, or data, or the reuse of some figures or data without citing previous works, represents a relatively high percentage of misconducts (32.3%). However, as the authors underlined, we should consider that not all retractions are related to unethical attitudes by the authors, and that the retraction its-self should not be stigmatized, since it is *'an act of repair, an intrinsic part of the research lifecycle'*.[39] According to Koo and Lin, who performed a bibliometric analysis from 2003 to 2022 using Web of Science, '*retractions play a vital role in maintaining research integrity by ensuring the accuracy of the* *scientific record, promoting transparency and accountability, deterring misconduct, and fostering a culture of continuous improvement within the scientific community*'.[40] Retraction of published papers is a relatively recent phenomenon, which increased in the last 40 years of about 20%, probably due to an increased awareness to scientific misconduct and errors in the research community. Other important aspects in scientific publishing are reproducibility and data transparency.[41] The first feature is a fundamental element of science, since the process of validating and confirming scientific theories, which is a step of the scientific method, is based on the possibility to replicate published results. Transparency is another important aspect of scientific publishing, since, for instance, the description of synthetic procedures and the raw data used to elaborate or validate a structural molecular model needs to be accessible to other scientists. '*Confidence in scientific claims* – says Brian Rosek in ref. 41 - *is rooted in being able to interrogate the evidence for the claims and how that evidence was generated. Without transparency, the self-corrective processes of science are hampered*'. A recent paper by Ciriminna *et al.*[42] reports a study on reproducibility of chemistry research by analyzing papers and reviews in the fields of materials, supramolecular chemistry, electro-organic synthesis, and catalysis. Among the main findings reported in this paper,[42] the awareness of chemists and chemical journals of the need to improve reproducibility emerges. Even in chemistry-related topics - the authors write – '*the "publish or perish" principle contributes to the publication of non-reproducible results'*.[42] However, good practices introduced by several journals, such as the publication of supporting materials, the embedding of videos and photographs of experimental works, and the publication of online pre-print versions, could help in contrasting this problem. Improving scientific publishing in the open science and digital era is indeed mandatory for ethical communication of scientific results.

2.3.2 Artificial intelligence

Among the emergent ethical problems related to scholarly communication of science is the use of artificial intelligence (AI), such as ChatGPT,[43] which is largely used for educational and professional writing. As underlined by Brian L. Frye, the use of ChatGPT or any other AI text generators to produce academic writing is subject to several problems, such as plagiarims, which is defined as *the act of copying or closely imitating the work of another person or source without proper attribution or permission.*[43] Ethical considerations regarding the use of AI in writing and communicating science concern copyright, dishonesty, security and privacy issues. The acritical use of AI could decrease human creativity and engagement, and it could also exacerbate the digital inequality, disadvantaging people with low access to high-quality technology. A recent paper concerning the use of AI tools in chemistry and physics education has been published[44] showing the high potentialities as tutee, to solve problems, give comprehensive descriptions, support teachers in the assessment of students' knowledge. However, these tools can originate misinformation or create misunderstanding among students.[44] This topic will be probably at the basis of deep investigations in the next future.

2.3.3 Mentorship

Another ethical aspect related to the communication within the internal community regards the relationships among professors, scholars, researchers and students, and it is intimately connected with the general hierarchic structure typical of the academy. These imbalanced relationships brought to unethical behaviours, such as the episodes of abuse, bullying and discriminations that represent a problem '*in almost every country and every cultural realm'*.[36] However, these issues seem to be common with all academic disciplines with no specificity of chemistry with respect to other sciences.

As a final comment, what is interesting is that these ethical concerns, which are mainly related to the internal domain of chemistry communication according to the initial definition, affect the public image of chemistry, too. In this sense, controverses, misconducts and unethical behaviours have severe implications in the external domain.

2.4 Ethical issues in communication of chemistry: external domain

2.4.1 Chemists and Society

The communication of chemistry to the general public and the perception of chemistry in the society are considered crucial by most of Chemistry Societies, from the national ones to the international IUPAC (International Union of Pure and Applied Chemistry).[45] The image of chemistry in the society changed during the history, in particular, in the last two centuries when this science has become central and strongly interconnected with technological developments.[32] The reasons at the basis of the perception of chemistry in the society nowadays are quite complex and they have been object of several investigations in the recent years.[46-48] Despite of this inherent complexity, several reasons have been identified,[49,50] such as the way chemistry and chemical concepts are taught at school levels, the history of chemistry as modern science and the intrinsic nature of chemical concepts, the intimate relationship between chemical research and the chemical industry as well as the way chemistry-related topics have been communicated in the past and in the present. As previously reported,[29-31] there are some significant historical cases, such as the thalidomide story, the Bhopal disaster[51] and the Seveso accident,[52] which strongly affected and modified the public opinion toward chemicals and chemical industry. These events had a great impact on the society and the way they were communicated to the public had consequences on the perception of risks associated to chemicals and chemical industry. Since the sixteenth, with the fundamental book titled '*Silent Spring*' by Rachel Carson, the sensitivity of the publics towards the environment and the effect of human activities on it, raised and this change in behaviour affected the perception of chemicals and their potential negative effects on the environment.[53,54] In this case, the role of communication is very exemplary, for the media resonance of Carson's study on one side, and for the silence or, even worse, for the incoherent reaction of the chemistry community on the other side. Based on these cases, chemists should reflect on the role of communication of chemistry-related topics having a strong impact on the health, environment and safety.

As underlined by Mehlich *et al.*[36] the role of chemistry on sustainable development should be communicated in a more responsible and accurate way. Moreover, when communicating their research results, chemists should be aware that the public image of chemists is different from their self-image, as pointed out by Laszlo.[55] In fact, the goodness of research aims, the honesty of chemists, their attention to the environment and to the safety and the utility of chemistry researches are far from being obvious to the general public, instead these aspects should be communicated. As pointed by Hartings and Fahy,[56] to improve the effectiveness of chemistry communication, chemists should build a positive and trusting relationship with the public. The diffuse lack of public engagement with chemistry is indeed a well-known problem, as it will be treated in the next paragraph.[57-59] A suggestion for chemists could be to adopt the '*mertonian norms*', not only when doing their research but also when communicating chemistry results. The choice of an adequate language, without oversimplification of the real problems, without hindering the risks and implications of new forefront research results are additional ethical implications.

2.4.2 Fake news, misinformation and conflict of interest

Fake news represents one of the biggest problems in science communication due to the exponential grow of information with internet and social networks.[58] The diffusion of misinformation and false news about science is not new: there are some famous historical cases, such as the publication of pseudoscientific information reporting positive and negative effects on health related to the new discovered X-ray.[60] However, the amplification of pseudoscience and misinformation through the web and with the social networks is certainly increasing the impact of fake news in the Society. Fake news affects chemistry too, and chemists are directly involved in the important work of reducing the spread of misinformation concerning chemicals and mitigating the discussion around the potential positive or negative effects of chemistry. A known problem which was reported by several authors[48,58,61] is related to food chemistry. Misinformation about healthy or unhealthy properties of food and agricultural products (see the case of pink salt) are often related to scientific publications which hinder unethical behaviours, such as conflicts of interest, in the case one or more authors received funding from private companies which profit based on those scientific results. The public perception of chemicals, such as food additives,[61] and of natural products, such as organic food, is highly influenced by marketing communication, which tends to introduce scientific terms to justify or make stronger a message, by using communication strategies, such as logic constructs and inferences, that have not a scientific basis. Chemists should be not complicit of this unethical way of communicating, especially when presenting their scientific results to the public, through interviews or institutional press releases. Moreover, as put in evidence by Shim *et al.*,[61] since safety perceptions of chemicals are affected by consumer awareness and knowledge, more efforts in chemistry communication and education are necessary.

At the end, some simple suggestions for chemists who wish to get a better and more ethical communication could be: 1. Before starting the communication: ask themselves some basic questions, such as: what is the aim of my communication? Who is my target? Why the public should be interested in my research? 2. Spend some efforts in building a critical approach in the public, thus avoiding dogmatic speeches and idealistic description of science, talking about the scientific methods, the complexity of a phenomenon, and the intellectual controversies around a scientific topic; 3. Communicate the research works and activities as a human activity, trying to establish an empathy with the public, preferring a dialogic and interactive approach; 4. Put more attention to the choice of language to communicate to the public (i.e. the use of less technical words instead of very specific ones); 5. Be honest.

2.5 Ethics of chemistry and chemistry communication in chemists' training

Before concluding this paper, it could be useful to reflect about the presence of these topics in **chemists' training**, since, as stated by several authors, chemists are expected be prepared to reflect on the social values related to chemistry results.[29] To this aim, ethics of chemistry should be included in the training of chemists as an obligatory undergraduate course in all Universities.[36,62,63] Few good examples of preparing ethical chemists through courses at university level have been reported,[64-66] however these are rather isolated cases. Several years ago, the *EuChemS* working party about *Ethics of Chemistry* developed a modular course entitled '*Good Chemistry: methodological, ethical and social dimensions*' and a very useful book containing theory and practical examples was published by Jan Mehlich.[67] Part of these materials was experimented at the Jagiellonian University in Krakow within a MOOC course.[64] Among the selected topics, scientific misconduct, responsibility, risk, uncertainty and precaution principles were declined to deal with ethical issues in chemistry. As stated by Maciejowska,[64] the module dedicated to science communication was particularly appreciated by students: '*Students comments on the forums of this MOOC showed that there is a continuous need to develop communication skills, including engaging in scientific discourse about responsible research and innovation, particularly within STEM programs*'. Communication skills was one of the topics addressed in the chemistry courses described by Singiser *et al.*[65] and by Baker Jones and Seybold:[66] the objective of the lessons and activities was to provide students adequate tools for communicating within the science community (internal communication). For instance, some sections were dedicated to the scientific presentations (oral, written or poster types) and the scientific discussions among peers.[65] More specific ethical reflections about the scientific research and its historical, political and social implications, are addressed in the course of '*History of Chemistry and Didactic aspects*'[68] which is hold at the University of Pisa since 2018. Within this course,[68] the history of the disputes around the discovery of several chemical elements is taken as representative of several critical aspects of ethics in chemistry, such as the gender discriminations and discriminations based on the nationality, the ethics of publishing and communicating the scientific results.

3. Final considerations

In the present contribution, I have discussed some aspects about ethics of chemistry communication, starting from the analysis of specific features of chemistry and ethical implications. The discussion of ethical issues concerning communication of chemistry was divided between the communication of researchers within the scientific community, covering, in particular, the ethical aspects of scientific publishing, and the communication of chemists to the public, with a direct impact on the image of chemistry in the society. The role of misinformation, fake news, conflict of interest and dishonest communication on the perception of chemistry and chemists in the society has been discussed. In the recent years there have been several signs in the community of chemists of an increased attention on chemistry communication. The Royal Society of Chemistry[54] was pioneer in 2015 with a first systematic and detailed investigation on how chemistry is perceived in the general public, with the aim to produce a practical communication tool kit for chemists. More recently, the Italian Society of Chemistry[55] started a program of innovation in the communication of the role of chemistry in the society, trying to contrast to the diffusion of fake news and putting more attention to the education of young students to get them involved with chemistry. However, in the academy, these topics are still considered marginal with only few exceptions, revealing a substantial lack of a specific training of the academic staff in science communication and a relatively low sensitivity toward communication and education, probably because these topics are still not considered central and not adequately recognized.

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