Communicating Chemistry Innovation to the Public

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Abstract
Very few scholarly studies have been published on communicating chemistry to the public, and even less on publicly communicating chemistry research. Ccommunicating achievements in chemistry research, on the other hand, is an important component of research (and technology) management. New chemical products and new synthetic and analytical chemical processes often have a broad and lasting societal, economic and environmental impact. This trait, differentiating chemistry from other basic sciences, is reinforced by the sustainability challenge to make economic growth compatible with long-term well-being for all people and the environment. This study fills a gap in the literature and suggests avenues on how to conduct said communication based on the methodological autonomy of chemistry as scientific discipline.

Keywords: chemistry innovation; public understanding of chemistry; science communication; research management

Introduction

Amid the so-called "basic sciences" (mathematics, chemistry, physics and biology), chemistry is the only one originating a global and diversified industry (Aftalion, 2001). The industry's products and productions have a broad societal impact, often of global relevance. Hence, one would expect a vigorous public engagement activity of chemistry scholars.

"When the public embraces what happens in research labs, they will support federally funded research" wrote in 2018 academic chemists based in the USA (Mirsaleh-Kohan et al., 2018). Similarly, recognizing "the value and importance of chemistry in addressing societal challenges and its potential to stimulate wonder and interest about our world" in the early 2010s the National Science Foundation of the same country asked the National Academies of Sciences, Engineering, and Medicine "to develop an evidence-based framework to guide chemists' communication activities in informal settings" (National Academies of Sciences, Engineering, and Medicine, 2016). The outcome was a book including a five-element framework for effective public communication activities for chemistry (National Academies of Sciences, Engineering, and Medicine, 2016). Previously, in 2011, chemistry scholars had concluded that for engagement-focused communication it is "impossible to predict in advance which strategy will be the most effective" (Hartings and Fahy, 2011).

In the subsequent decade communication with the public through the "social media", namely social networking websites used by billions of people worldwide, will emerge as one of the new key communication means to engage with the public also in scientific research (Mollet et al., 2017); often combined with the use of personal academic websites (Ciriminna and Pagliaro, 2024). Very few scholarly studies have been published on communicating chemistry to the public, and even less on publicly communicating chemistry research. This study contributes to fill knowledge gaps in the field.

Chemistry is a subject difficult to learn (Cardellini, 2012), and even more to communicate to the general public due to the abstract and symbolic nature of the science (Pagliaro, 2010). Worsening matters, chemists tend to adopt the counterproductive one-way top-down, communication process (Miller, 2001; Miller, 2010). In the words of Edwards, communication manager at the Royal Society of Chemistry in Great Britain:

> "Our efforts need to be less of a one-way lecture and more of a conversation. To communicate effectively we need to know our audience, their motivations, and their existing level of knowledge. We have to ask questions, find out where they are coming from and what they are worried about, and work out what they want to get out of the conversation. One-way 'engagement' is not engagement at all" (Edwards et al., 2016).

Communicating to the public achievements in chemistry research is an important component of research (and technology) management. New chemical products and new synthetic and analytical chemical processes often have a broad and lasting societal, economic and environmental impact. This trait, differentiating chemistry from other basic sciences, is reinforced by the sustainability challenge to make economic growth compatible with long-term well-being for all people and the environment. This study fills a gap in the literature and suggests avenues on how to conduct said communication based on the methodological autonomy of chemistry as scientific discipline.

2. Results and Discussion

A bibliometric search in the literature restricted to "communicating chemistry" within "Article title, abstract, keywords" carried out on June 2024 on Scopus research database returned only 19 documents in the literature in English (Scopus, 2024). Polishing the list after visual inspection by eliminating two editorials, one book chapter (not pertinent), and three other documents (one review of general chemistry books, one conference report and one note), the list shrinks to 13 documents. Table 1 lists said documents by the article title, year of publication and number of citations in the scholarly literature up to early June 2014.

Table 1. Articles dealing with "communicating chemistry" (source: Scopus, 2024).

Entry	Article title	Journal	Year of publication (citations)
1	Beyond exploding balloons - bringing the science of chemistry to the public	Canadian Journal of Chemistry	2022 (0)
2	Communicating chemistry through cooking and personal health: everyday applications increase perceived relevance, interest, and self-efficacy in chemistry	Journal of Chemical Education	2021 (6)
3	Collaboration for chemistry communication: Insights from a research-practice partnership	Journal of Science Communication	2021 (0)
4	The literature discussion: a signature pedagogy for chemistry	ACS Symposium Series, 1370	2020 (5)
5	Communicating chemistry: an introduction	ACS Symposium Series, 1327	2019 (2)
6	Why Communicating Chemistry Can Be Complicated	ACS Symposium Series, 1327	2019 (1)
7	Pre-service chemistry teachers' understandings of symbolic representations used in chemistry instruction	Turkish Online Journal of Educational Technology	2016 (1)
8	Communicating chemistry in informal environments: a framework for chemists	Journal of Chemical Education	2016 (7)
9	Communicating chemistry for public engagement	Nature Chemistry	2011 (52)
10	Communicating chemistry	Nature Chemistry	2009 (19)
11	Communicating chemistry from molecules to international efforts: an interview with Peter Atkins	Journal of Chemical Education	2008 (0)
12	An innovative model: Undergraduate poster sessions by health profession majors as a method for communicating chemistry in context	Journal of Chemical Education	1997 (20)
13	An exhibition on everyday chemistry: communicating chemistry to the public	Journal of Chemical Education	1986 (10)

The outcomes of the bibliometric investigation are revealing.

First, the field is relatively new with the first study describing an exhibition on everyday chemistry published in 1986 (entry 13 in Table 1).

Second, with the exception of *Nature Chemistry*, a journal established by its publisher in 2009, neither *élite* chemistry journals nor *élite* general science journals such as *Nature or Science* publish studies dealing with the topic of chemistry communication.

Third, the few articles published on the topic are poorly (or never) cited. The only study (entry 9 in Table 1) with a significant number of citations was published by *Nature Chemistry* in 2011. This does not mean that these studies do not attract scholarly interest, but only that since scholarly debate in the field by research chemists is nearly non-existant, these studies are seldom or never cited. For example, the study "Beyond exploding balloons - bringing the science of chemistry to the public" published in early 2022 in the *Canadian Journal of Chemistry* by early June 2024 has never been cited, but it has been downloaded 714 times.

The contrast with physics, the scientific discipline closest to chemistry, is self-evident. Here, the writings (novels and textbooks) of Asimov, Sagan, Feynman and Gamow motivated generations of students to start undergraduate studies in physics. Physicists in general are aware of the relevance of communicating physics to the public (Smith and Lincoln, 2022).

The American Physical Society (APS), for example, operates a Joint Network for Informal Physics Education and Research whose members share best practices, and learn from other physicists, and track the impact of public engagement (American Physical Society, 2024). In physics furthermore, research articles on physics communication and public engagement are regularly published in old specialized prestigious journals such as *Physics of Plasmas* established in 1958 (Fracchiolla et al., 2024). Finally, prestigious general science journals too regularly publish articles on physics public engagement even in particle physics (Kahle et al., 2016), with the same study being highly read and debated in the scholarly literature, as shown by the 56 citations reached in 8 years (Google Scholar, 2024).

Prior to 2014 survey carried out in Great Britain on behalf of the Royal Society of Chemistry to investigate and understand the public attitudes to chemistry, chemists were not aware that even in a industrially advanced country hosting one the world's oldest and most important chemistry schools, the public confused "chemist" with "pharmacist", with 76% of respondents (2,104 adults aged more than 16)) mentioning a pharmacy when answering "where do you think chemists work?" (TNS BMRB, 2015).

The objectives of communicating chemistry research achievements to the public are often wrongly set by research chemists because they assume that the general public is interested in their sophisticate findings. In general, however, this is *not* the case. The public will only be interested when said findings are relevant to their lives and wellbeing. Assuming that the public would be interested in chemistry is a common mistake that can make the communication process irrelevant and even counterproductive. The way to make the communication of chemistry research findings to the public relevant and purposeful is to relate said findings to the interests of people and to the real world: "both real world issues people care about (eg, food shortages, clean water and renewable energy) and the real world that people inhabit day-to-day (eg, how food is processed and cooked)".[20]

Writing in 2016 in the chemistry journal published on behalf of IUPAC in publicly available (Open Access) format, Edwards and co-workers rightly emphasized the need for chemists willing to communicate chemistry to the public to start from evidence, and replace the will to "teach chemistry to the public" with communication capable to show the potential of chemistry "to improve our lives" (Edwards et al., 2016). Said evidence emerged from the seminal public survey carried out in Britain in 2014-2015, whose main outcomes are *i*) people barely know what chemists do and who they are, and *ii*) the public is only interested when chemistry facts recounted are connected to their daily life.

> "We should also try and find out what the other person is interested in and relate our work to that. For example, in our workshops we had a hugely positive response to engagement materials around the concept of everyday chemistry - things like cleaning and baking… After viewing our video that related chemistry to baking, one participant said, 'It doesn't feel above me now… it feels parts of everything, not an academic subject' (Edwards et al., 2016)"

Following the public survey on how chemistry is actually perceived by the public, the RSC in 2015 published a 9-page communication toolkit (Royal Society of Chemistry and TNS BMRB, 2015). Showing evidence of the absence of intellectual debate amid research chemists, this valued resource (still fully available online for free download) nine years later is mentioned in two web pages and in two PDF documents indexed by Google, a comprehensive search engine (Google, 2024). The toolkit, furthermore, has been mentioned once on Twitter (X, 2024), the social network most frequently used by scientists to share research outcomes and ideas with the public and with peers (Collins et al., 2016). The aforementioned OA study of Edwards and co-workers in *Chemistry International*, in its turn, to date has been cited twice (Dimensions, 2024).

This paucity of intellectual debate amid chemistry scholars is in line with the "variety of concerns suggestive of some underlying uncertainties and self-doubts" (Heylin, 1998) amid chemists identified by Heylin in the late 1990s. By communicating to the public socially relevant research achievements, research chemists overcome also said “uncertainties self-doubts” (Heylin, 1998).

2.1 Benefits of communicating research achievements

The following examples illustrate how communicating socially relevant research chemistry achievements to the public provides research chemists with two main benefits: unexpected new collaborations with research groups and companies; and raise the social status of chemistry, a benefit whose positive consequences go well beyond the aim “to secure public support to taxpayer money funding research” (Mirsaleh-Kohan et al., 2018).

Prior to start their public engagement activity concerning research achievements, however, a word of caution is needed. In Ackoff’s words:

> “It is much better to do the right thing wrong than the wrong thing right, because when errors are corrected, it makes doing the wrong thing wronger but the right thing righter” (Ackoff, 1999).

Doing “the wrong thing right” here is to set and pursue wrong communication objectives based on the naïve assumption that the public should be “interested in science” and “educated” by disseminating knowledge devoid of social relevance. If that is done, using “effective communication guidelines” or quality management tools such as the plan-do-check-act (PDCA) cycle (Figure 1) for continuous performance improvement (Johnson, 2002) will only help in “doing the wrong thing wronger” (Ackoff, 1999).

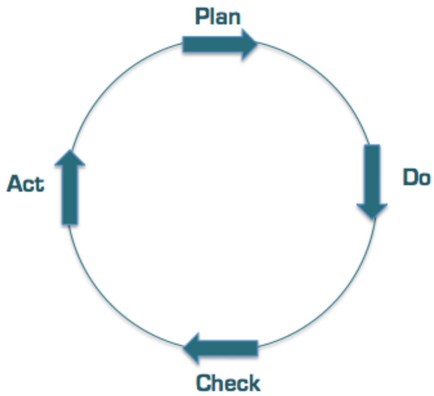

Figure 1. PDCA cycle for continuous performance improvement.

Following said approach communication is planned with ambitious goals, conducted, evaluated and eventually modified to improve it in subsequent communication activity.

2.1.1 New collaborations

On May 4, 2022, a national radio broadcasted in Italy an interview to Mario Pagliaro reporting the joint discovery of the new “CytroCell” micronized cellulose obtained from industrial citrus processing waste (Maurizi and Melis, 2022).

A listener whose daughter was mate to a PhD student at Milan’s Polytechnic working with nanocellulose in construction materials stopped the car and listened carefully. The same evening he informed his daughter. Three weeks later, on May 27th 2022, one of us received an e-mail from the Polytechnic’s chemistry professor mentoring the aforementioned PhD work enquiring about possibility to collaborate. The PhD student in Materials Engineering was indeed investigating the use of both nanocellulose and microcrystalline cellulose as suitable additives for an old and ecofriendly construction material. Collaboration was quickly established.

Remarkable results were obtained. The whole broadcast lasted 7 min and 51 s, with the interview taking slightly more than 5 min. No jargon terms were used, and the journalist emphasized how the peel of a daily life product known to most listeners (the orange fruit) upon squeezing to extract the orange juice actually provided the source of the cellulose. The team, he further explained, used “cavitation, the same phenomenon that shapes air bubble around the propeller of a boat rotating at high speed, and uses only water and electricity" (Maurizi and Melis, 2022).

The CytroCell used by the Polytechnic's team in its turn is derived from lemon industrial processing waste. In other words, the raw material used is not lemon "peel" as it is often read in the citrus biorefinery literature, but rather industrial citrus processing waste (CPW) comprised of peel, seed, and inner fruit parts residue of the industrial squeezing process. The citrus company supplying our Labs in Sicily (and in Tuscany) with CPW derived from organically grown fruits is based in Sicily's Siracusa. One company's manager and co-owner contacted one of us upon reading on August 2019 in a newspaper widely circulated and read in eastern Sicily about the joint discovery (Guccione, 2019). The manager visited the Labs in Sicily shortly afterwards, and since then his company has kindly donated the CPW obtained from several citrus fruits (lemon, red orange, grapefruit, blond orange) used by some of us to extract the IntegroPectin and the CytroCell biomaterials whose remarkable and unique biological, physical and structural properties are reported in over 30 research papers published between 2019 and early 2024.

In the late 1990s the British Broadcasting Corporation (BBC, the government television of Great Britain) broadcasted an interview on "doped" sol-gel glasses with their inventor, the Israeli chemist David Avnir (BBC, 1999). The interview was part of one episode of "Tomorrows World" a long-running television series on new developments in science and technology transmitted on BBC1 for 38 years between 1965 and early 2003. The journalist and the chemist sat on a beach in Israel. In less than a minute, the inventor explained the functionment in practice of a sunscreen lotion formulated with sol-gel microspheres functionalized (doped) with an organic species adsorbing the UV rays (Lapidot et al., 2003).

A few months later, also thanks to the significantly enhanced visibility of the technology, the spin-off company established by the inventor along with a former doctoral student, raised enough private capital to fund construction of the first plant in Israel to manufacture the silica-based "UV Pearls" subsequently supplied to cosmetic companies to formulate safe sunscreen lotions (the encapsulation of the active UV adsorbing organic molecules within silica microspheres reduces the amount of free radicals generated and keeps the organic filters on the top layers of the skin, decreasing the risk of contact dermatitis).

In the subsequent two decades, the company will become a leading company in nanomedicine, with the first innovative acne treatment (based on tretinoin and benzoyl peroxide microencapsulated within silica-based microcapsules to stabilize tretinoin from being degraded by benzoyl peroxide and to slowly release each of the active drug ingredients over time) approved after many years (U.S. Pharmacist, 2021).

These two examples show why, when communicating with the public, scholars should not underestimate communication with the general public. The general public includes shop floor workers and the elderly along with entrepreneurs, scientists, politicians and many other categories of people. Communicating chemistry research achievements to the general public audience via a plain and attractive language may lead to new scientific collaborations as well as to new collaboration with companies, investors and public institutions interested in the communicated research.

2.1.2 Raising the social status of chemistry

Chemistry is by far the science with the most widespread and profound impact on the daily life of people since the early 1800s when first biobased chemical productions became widespread, to be quickly replaced in slightly more than a century first by carbon-based productions starting from acetylene, and then by oil-based industrial productions starting from ethylene. Regardless of its unique social relevance, due to the ubiquitous presence of chemical products, chemists suffer from a poor social status that makes them unknown to the general public even in the country where industrial manufacturing of chemical products actually started in the early 1800s (Great Britain).[18,19]

Communicating the achievements of chemistry research to the public contributes to change this unfortunate situation. From the use of a simple and direct language ("speak as a parent, a sports fan or a gardener, not as a chemist") (Francl, 2013) to the use of illustrations and videos, there are many ways to effectively communicate said findings. Readers can access a vast and updated literature on science communication that includes excellent books (Bowater and Yeoman, 2012; Kearns, 2021) and scholarly journals (*Journal of Science Communication*, *Science Communication*, *Public Understanding of Science* etc.). Another way to increase the social relevance of chemistry resides in the ability to establish connections between chemistry and other subjects such as history and economics, placing chemistry in the broader context of culture.

Explicitly formulated in the early 1980s for chemistry (Paoloni, 1981), this idea will form the basis of Levy-Léblond articulated insight for which science (and not only chemistry) urgently needs to be brought back into culture from which it separated during the second half of the 1900s due to increased specialization (Levy-Léblond, 2004).

Aldo Steinfeld has been a professor of thermodynamics Zurich's Polytechnic ETH till late 2023. The scientist has advanced the solar energy harnessing technology based on concentrated solar power coupled to catalysis to produce hydrocarbons from only H_2O and CO_2 feedstocks up to the point to make it technically and economically viable (Loutzenhiser, P. G. et al., 2023).

On May 10, 2024 he posted on Twitter the news of world's first industrial-scale solar fuel plant (Steinfeld, 2024). To announce the forthcoming inauguration of the plant "later this summer", he illustrated the tweet with a photograph wherein he and the co-chief executive officer of the company Synthelion hold a flask with solar-made synthetic fuel (Figure 2).

Figure 2. Tweet from Aldo Steinfeld, ETH Zurich, posted on May 10, 2024.

At the bottom of the tweet, Steinfeld inserted a link to the company's website. Accessing the linked web page one learns that the plant (dubbed "DAWN") is located in Jülich, Germany, and serves to demonstrate the solar fuel technology and its robustness at industrially relevant scale, whereas future solar fuel plants, such as one already planned in Spain, will exceed the size of the German plant and offer significantly higher production capacity.

Accessing the Twitter account of the company, one can easily find a tweet where the company shows where such solar fuel plants could be built in the future "as our technology needs a lot of sunshine" (Synthelion, 2024). Since solar energy is one of the most abundant renewable energy resources and is evenly distributed around the world, solar fuels can be produced around the globe. In brief, two tweets show members of the public user of Twitter (now X) that chemical and engineering research rather than causing further environmental damage, may actually benefit the environment and society by completely new, ecofriendly technologies relying, such as in this case, of abundant, clean and free solar energy.

Similar use of social networks has the ability to shift the public perception of chemistry research as something that practically benefits society (Ciriminna et al., 2023). As shown by the survey commissioned by the RSC in Britain in 2014, the work of chemists, indeed, is worse than ill-considered by the public: it is entirely unknown, leading the RSC communication manager to suggest that chemists rather than saying "I am a chemist" should rather say "I am a scientist, working in chemistry" (Edwards et al., 2016).

Chemistry is a technoscience, namely a science whose practitioners besides investigating existing substances, create and investigate new ones, such as polymers derived from olefins and ultimately from oil. Industry selects said chemical substances based on their ability to meet societal (medical, agricultural, industrial, transport, construction etc.) needs and start manufacturing them (Chamizo, 2013). As such, chemicals are intermediate substances "between nature and society" (Chamizo, 2013). For this reason, communicating chemistry with the aim to bring it in the public debate "does not merely consist of doing publicity, but actually in promoting clarifications having to do with the implications of productive and societal choices when assimilating products from its industry" (Zaterka and Marcelino, 2021).

For example, while carrying out research on biofuels at the University of Amsterdam in 2010 Rothenberg and Alberts accidently discovered the first biobased thermoset polymer: the polyester resulting from the polycondensation reaction between citric acid and glycerol (Alberts and Rothenberg, 2017). When meeting the press along with the board of the University of Amsterdam in 2014, they presented the new bioplastic sitting around a table (Figure 3) made from "glycix" (the name the new polymer) (van der Hoeven, 2014).

Figure 3. The inventors presenting glycix to the press along with the board of the University of Amsterdam, around a table made in glycix [Reproduced from Bio Based Press, with kind permission].

Communicating with the public via the press, Rothenberg focused on the environmental advantages offered by the new biobased resin: "Glycix is 100% biodegradable. With water it breaks down into its monomers, i.e. glycerol and citric acid, two compounds which are completely natural and will be absorbed in the natural cycle" (van der Hoeven, 2014).

A company was established that in the subsequent years combined the resin with natural cellulose-based fibres such as hemp, wood and flax, for a range of applications. Nearly ten years later, the first kitchen made from wood panels containing the novel bio-resins as a binder that can be reused, refurbished or recycled was commercialized in the Netherlands (University of Amsterdam, 2023).

Traditional construction materials for kitchens (as well as for furniture and cabinets) consist of pressed wood products, such as particleboard, plywood, and fiberboard that contain formaldehyde-based resins to make them stable and durable. Formaldehyde, alas, is toxic to man, plants and animals. In China, world's most populated country, a systematic review of the geographical and temporal distributions of indoor formaldehyde concentrations in residences, schools, and offices recently found that the concentration of indoor formaldehyde during 2011-2015 in newly renovated residences, schools, and offices were 153 $\mu g/m^3$, 163 $\mu g/m^3$, and 94 $\mu g/m^3$, namely 82%, 46%, and 91% higher than the maximum threshold of 100 $\mu g/m^3$ (Fang et al., 2022). The threshold, furthermore, has been subsequently reduced to 80 $\mu g/m^3$

3. Conclusions

In conclusion, the general public is interested in chemistry research findings when said discoveries are relevant to their lives and wellbeing. The way to make communication of chemistry research findings to the public relevant and purposeful, thus, is to relate chemistry discoveries to the personal life of people and to the real world.

Connecting chemistry communication to people's daily life and to culture, the outcomes of the communication process provide two major benefits for chemistry scholars: *i*) enhanced case for collaboration with companies, public institutions, investors, and other research teams; and *ii*) raising the social status of chemistry. Other benefits include the fact that evaluation of scholarship for recruitment and career advancement decisions increasingly takes into account also societal service, and no longer achievements in research and teaching only (Pagliaro, 2021). Furthermore, we agree with physicists at the APS that the reflective thinking needed to prepare for communicating research achievements aids in streamlining concepts and can even lead to new ideas for research (new research directions) "in a way that differs from traditional mechanisms" (Smith et al., 2021) such as examining the work of peers or discussing with the research team's members.

Asked to provide advice to amateurs, photographer and journalist Robert Capa said "tell them to like people and let them know it" (Capa cit. in: Becker, 2018)). The same advice can be given to research chemists concerning the need to communicate socially relevant achievements in chemistry research to the public.

The examples selected for discussion in this study show that communicating achievements in chemistry research towards sustainable development has the intrinsic ability to further raise the status of chemistry promoting the role of chemistry innovators as "social entrepreneurs" (Ruskin et al., 2021). The creative work of research chemist indeed may result in a new process or in a new product meeting industrial, health, environmental, agricultural or technology specific needs, eventually benefiting the whole community. When this is the case, chemistry research achievements need to be communicated to the public, because the public ultimately becomes the beneficiary of chemistry innovation.

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Conflict of interests

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Communicating Chemistry Innovation to the Public

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Communicating to the public achievements in chemistry research is an important component of research work in chemistry. New chemical products and new synthetic and analytical chemical processes, often have a broad and lasting societal impact. This trait, that differentiates chemistry from other basic sciences, is reinforced by the sustainability challenge to make economic growth compatible with long-term well-being for all people and the environment.