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Chemistry Beyond the Book: Open Learning and Activities in Non-Formal Environments to Inspire Passion and Curiosity

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Abstract. Several scientific channels on TV, crowded scientific fairs, and many serious scientific board games on the market demonstrate that people are curious about science. However, when asked about the perception of scientific subjects, Chemistry in the first place, general public still shows rejection toward "too complicated", "abstract", and "far from everyday life" topics. Unarguably, every Chemist would not recognize Chemistry as neither "abstract" nor "far from everyday life": actually Chemistry, the so-called central science, is all around us. Where is the gap to fill, then? Why are not we able to convert that innate curiosity, which makes people stepping out from their houses to join public engagement activities, into genuine, time-persistent, passion about Chemistry? Such questions will be addressed herein, giving practical examples of possible approaches to address the problem. Special emphasis will be given to new learning means, generically referred as "Open Learning" ones, and interactive teaching approaches typical of non-formal environments, such as Science Festivals. Real examples of activities beyond the formal curricula of chemical study, some carried out by us in the framework of the "*Diffusione della Cultura Chimica – Società Chimica Italiana*" (Dissemination of Chemical Culture - Italian Chemical Society) mission and vision, will be discussed underlining their role in enhancing learning and inspiring confidence and passion toward Chemistry.

Keywords. Open Learning, Chemistry, Society, Gamification, Science Festival, Didactics, Interactive Teaching Approaches.

INTRODUCTION

The *IdeenExpo 2019* in Hannover (Germany) had about four hundred thousands visitors in eight days,[1] the 30th edition of the *Edinburgh International Science Festival* (Ireland) in 2018 had about one hundred seventy five thousands visitors in two weeks[2] and the 16th edition of the *Science Festival*

in Genoa (Italy)[3] in 2018 reached about one hundred fifty thousands people in ten days. These are just few examples of recent big scientific events promoted by scientists and scientific organizations to increase the public engagement and the public understanding of the crucial role of Science in the modern Society.[4] Science Festivals are typical non-formal contexts, where different scientific and technological aspects, innovations and even new scientific concepts, are shown in a spectacular way with several purposes: impressing people about the beauty of science, increasing their interest and curiosity through science, giving the sense of the pervasive presence of science in every-day life.

Among different scientific disciplines, Chemistry is usually present in Science Festival, even if not predominant, except in few cases (see, for instance, the Italian *Festival of Chemistry* organized by the University of Basilicata, since 2009).[5,6]

Despite Chemistry is recognized from the scientific community as a "central science", since it connects different disciplines and most of the basic chemical concepts are fundamental in Biology and Medicine, Nanoscience and Material Science,[7] the general public perception of Chemistry is quite far from this idea.[8]

Chemists have defined a specific word, *Chemophobia,* to describe an "*irrational aversion to or prejudice against chemicals or Chemistry*".[9] "*More specifically it refers to the growing tendency for the public to be suspicious and critical of the presence of any man-made (synthetic) chemicals in foods or products that they make use of*".[10] While demonstrating the various origins of *Chemophobia,* as a quite complex human attitude, goes far beyond the scope of the present work, it is worth noticing that several recent studies have systematically investigated the public attitude toward chemists and Chemistry giving rise to interesting results.[11-14]

According to the survey proposed by the Royal Society of Chemistry (RSC) in U.K., Chemistry is often perceived as "abstract", "difficult" and "far from everyday life".[14] However, most of the interviewers did not declare any pre-conceptual aversion or any *Chemophobic* attitude towards chemicals and chemists, so the general perception of Chemistry among the lay public is more positive than what expected by chemists themselves. Although the RSC study paints a better picture than the chemists themselves had expected, it also revealed a sort of "emotional neutrality" and a "lack of engagement with" Chemistry.[12]

Another interesting result coming from these studies is related to the interviewers' school experiences about Chemistry;[12,13] most of them declared that their experiences at school were indeed crucial in determining their ideas about Chemistry. These are some of the interviewers' statements concerning how Chemistry was taught at school, based on their own experience: "*chemical concepts were too abstract*", "*few examples about every-day life applications of Chemistry were done*", and "*the utility of Chemistry was not addressed*". [12,13]

The evidence of a link between the formal and traditional teaching of Chemistry and the diffuse perception of a distance between chemical concepts learned at school and the role of Chemistry in the Society could be a good starting point to rethink the teaching approaches to Chemistry. Moreover, as suggested by RSC, instead of focusing on the minority of negative views, the scientific community, and in particular the chemists, should try to address the substantial indifference or lack of engagement in order to improve the image of Chemistry.

According to these indications, the biggest challenge seems to be how to convince students and the general public on the relevance and the utility of Chemistry. We need to foster public excitement in Chemistry by making the public aware of the extent to which Chemistry is indeed all around them. However, this ambitious objective can only be reached by working on different parallel targets:

1. Changing the way Chemistry is taught at school;
2. Establishing stronger connections between the research in Chemistry and the Society;
3. Talking more about applications of Chemistry than theory and abstract concepts;
4. Using the digital tools, by exploiting their potentialities to increase the knowledge of Chemistry;
5. Enhance the communication skills among young chemists and take advantages from the non-formal learning environments.[15,16]

A possible mean to achieve these tasks is the so-called Open Learning, concept with a broad meaning usually referred to activities and teaching strategies that enhance learning opportunities beyond formal education systems. Open Learning is just an appendix of the broader Open Science movement, the ongoing transition promoted by the European Union (EU) in how research, knowledge and scientific culture is performed and disseminated by using digital technologies and new collaborative tools.[17] On the other hand, Open Learning is related to the so called *Life-Long* learning strategy, which became central in the EU program for the education of new European citizens since 1985.[18] Several studies have indeed underlined how the learning of science, and of Chemistry in particular, is a complex process extended to the whole life, resulting from a continuous interplay among learning in formal, non-formal and informal contexts.[19] The role of non-formal and informal contexts in learning Chemis-

try, such as the experiences of interactive laboratories in science museums and science festivals or activities about Chemistry through mobile devices (m-learning), internet (e-learning), wikipedia and other digital tools, has been recently overviewed by several authors.[20-22]

In this paper, we will focus on some experiences related to different Open Learning strategies, divided in two subsections: *i.* Chemistry in the Arena and *ii.* Chemistry, new media and gamification. In particular, we will describe and comment real examples on how different Open Learning approaches have been successfully applied to foster trust in the essential role of Chemistry for our Society and ultimately inspire passion and curiosity toward this subject.

OPEN CHEMISTRY AND OPEN LEARNING IN CHEMISTRY

Open Science is a comprehensive reform proposed and promoted by the EU on how science can be practiced in an accessible, transparent and reusable way in the current digital age.[17] Considerations about which technological changes can we expect from this reform and which impact will Open Science, and in particular Open Chemistry, have on both Society and the research community have been extensively discussed elsewhere.[23]

Among the Open-components enabling such historical transition in Science, we find the promotion of free access to scientific literature and data sets (i.e. Open Access and Open Data, respectively), as well as freely available teaching and learning materials, which hold the promise of reducing financial and structural barriers and bridging the gap between the less and more developed countries, especially in fields where small investments can have relevant social impacts, as Chemistry is (see, for instance, the Open Educational Resources[24-27]). As a consequence, such shift also impacts teaching and learning activities, which are being redefined under the concept of Open Learning.

Open Learning, grounded on the work of pedagogues and educational reformers like Célestin Freinet and Maria Montessori among others, emerged as teaching method in the late '70s. Starting from the statement that students of the same age have vast differences in experiences, interests, and competencies, and that such differences play a crucial role in the learning process, the key concept of Open Learning pedagogy is an "independent and interest-guided" learning.[28] This can be achieved by means of interactive learning, interdisciplinary focus activities, hands-on experiences, group-based dialog formats, evidence-based problem analysis, and by developing and using open educational resources. Beside the chosen mean, the final goal is to enable each individual learner to be self-determined, confident, thus genuinely inspired by the learning process.

From the scientists' perspective, this translates into moving away from what has been defined as the "deficit model" of public attitudes towards science.[29] The traditional idea that public scepticism about science is the result of a lack of understanding, and can only be filled by providing information, is nowadays replaced by a "dialogue model" that engages publics in two-way communication aimed at disseminating the social implications of science.[15-17, 30, 31]

In this context, science festivals, open-lab activities, science gamification using new media and similar learning opportunities beyond formal education systems can be applied to bring back the public perception of Chemistry as central science for the development of our Society. These aspects will be discussed in details in the following sections.

Focusing on Chemistry, several examples of Open Learning teaching approaches successfully proposed to students are those related to new open digital environments and platforms, such as the so called Schnaps,[32] which was developed to help students to approach Chemistry with the problem-solving method. Similar strategies have also been explored related to specific topics in Chemistry, such as environmental applications of Analytical Chemistry.[33]

The use of virtual laboratories and digital tools to teach Chemistry has also been object of intense research about the effectiveness of MOOC (Massive Open Online Courses), which were developed for the first time in the 2002, by the Massachusetts Institute of Technology with the OpenCourseWare («MIT OCW») project. Despite of the first official MOOC were open in 2012 by the major American scientific universities and research institutes, the number of MOOC about Chemistry represents less than 5% of all online courses. Nowadays, several studies have been published putting in evidence the role of such interactive and participating learning platforms to enhance the learning of Chemistry among undergraduate and high school students.[34-36]

Besides assessing how interactive and participating learning platforms impact on students, another question arises: are teachers ready and minded to embrace this cultural transition? Luckily, for teachers passionate about and who wants to get trained on such Open Learning and innovative didactics, dedicated initiatives have been proposed in recent years. For instance, "Playing with Protons" is an education initiative led by the CMS experiment at CERN bringing together primary

school teachers, science education specialists and CERN researchers to develop creative approaches, learning activities, hands-on experiments with everyday materials to help all primary students engage effectively in science, discovery and innovation.[37] This growing community of passionate, innovative and creative primary school teachers get free access to learning resources, share classroom activities with like-minded colleagues and create opportunities for school-to-school collaboration, paving the way for a full exploitation of Open Learning.

I. CHEMISTRY IN THE ARENA

Science festivals, nowadays taking place all over the world[1-7], aim at disclosing and disseminating the role of science in the Society and the relationship of science with different aspects of everyday life. This effort in bringing science "out of the laboratory" and in engaging with the public in a constructive dialogue is the key of the success of such "creative, playful and surprising celebration of science".[4]

A typical science festival comprises a wide variety of events ranging from hands-on activities, spectacular demonstrations, workshops and conferences up to the involvement of arts.

The presence of Chemistry in science festival, although rarely predominant[5], is pervasive and undoubtedly among the most spectacular for the general public. Indeed, at first sight, solutions suddenly changing colours or matter changing its state appear as magic and almost unbelievable phenomena. Also simple laboratory equipment, like a magnetic plate with a bar stirring a methylene blue-containing solution, inspires curiosity in the public by evoking a charming world disclosed to only few people.

This is also the reason why the ancestors of modern chemists, the "alchemists", were considered halfway between philosophers and magicians. Indeed, Chemistry became a science only in the middle of the 17th century. Before this date, it was a wide cluster of practical knowledge as leather tanning, metallurgy, fabric dyeing, and many other craft activities. More or less everywhere, several centuries before Christ, the carbonate rocks were heated and milled to produce lime to built houses. The famous painters like Leonardo da Vinci (1452-1519) or Michelangelo Buonarroti (1475-1564), started their careers by preparing pigments for example by roasting and milling teeth (black), or earths (terra di Siena) and mixing them with rock powders, such as the orange cinnabar or the light blue lapis lazuli, and binders in the laboratory of their masters. On the other hand, one century ago, every woman was able to produce soap from grease and ash. Those are just few examples of chemical reactions!

So, science festivals are the perfect occasion to make the general public aware of the central role of Chemistry in our Society and remembering them how pervasive it has been for human life and culture throughout history.

Even with very simple chemical concepts and means, one can inspire interest about Chemistry and research, fascinate kids, and motivate teens to start looking at Chemistry as a key to open the secret behind the technology they are using on a daily basis. In other words, such activities in science festivals increase critical thinking and implicitly communicate that Chemistry is not just a bunch of formulas and numbers wrote on a book, but is a mean to interpret the world around us.

For instance, members of the group Diffusione della Cultura Chimica – Società Chimica Italiana attended multiple editions of the "Festival della Scienza di Genova", where several didactic laboratories were proposed, such as the laboratory about visible absorption spectroscopy("Fare Chimica con la Luce" – "Doing Chemistry with Light" – 2017 edition, theme: CONTACT). More recently the group itself promoted and realized a didactic laboratory using new technology as an appendage of analytical techniques to enable to "see" chemical reactions ("CIAK: (re)AZIONE!" – "CIAK: (re)ACTION!"- 2018 edition, theme: TRANSFORMATIONS).[4] In both cases, visitors were offered the possibility to engage with Chemistry by means of simple, but real experiments in a very interactive environment (Figure 1). For instance, the laboratory "*Fare Chimica con la Luce*" was a very effective activity to introduce students of the secondary school to a quite complicate subject of

Figure 1. Typical setting of didactic laboratories at the "Festival della Scienza di Genova", 2018 edition.

Physical Chemistry: molecular spectroscopy.[38-40] This particular "format" was also tested with students visiting the University under the Educational Orientation programs, such as "PLS" (Piano Lauree Scientifiche), with the aim to get students interested in scientific studies.[41] The use of portable spectrophotometers developed for educational purposes or the development of prototypes of colorimeter to measure coloured solutions directly by the students provided to enhance the understanding of some basic concepts of molecular spectroscopy.[38-41]

"CIAK: (re)AZIONE!", designed by members of the group *Diffusione della Cultura Chimica – Società Chimica Italiana,* was another good example of interactive activity related to the concept of "chemical transformations" and the interplay between Chemistry and technology, where kids (and adults, too!) were captured by the phenomenological changes occurring during a chemical reaction.[42,43] People who participated to the lab was helped in understanding the basic of why and how matters change colours or state of matter, and choose the most appropriate mean to visualize such changings thanks to the digital devices (i.e. tablet or smartphone, Figure 2). In all cases, after a first feeling of surprise and amusement, we notice that students and general visitors focused on what was happening under their eyes and started somehow interiorize the scientific method by making hypothesis, testing, discussing the results and deciding how to proceed.

Similarly, open-lab activities are organized to establish stronger connections between research in Chemistry and the Society and talk about applications of Chemistry in every-day life.

For instance, the "*European Night of Researchers*" is an event organized by the European Commission with the aim of celebrating the work of the researchers.[44] Every year, in the same day in September, every country proposes different communication, dissemination and public engagement activities organized by local universities, research centres, museums and schools. Perfect occasion also to enhance communication skills among scientists, such in-formal learning environments offer the unique opportunity to let the people enter real laboratories, meet researchers in person and feel free to ask them everything about their research (Figure 3). As reported on the official web-site[44], "*from 2018-2019, 55 projects have been implemented in 371 cities across Europe and beyond. During the 2018 Night, over 1.5 million of visitors attended!*". These numbers give the idea of the social impact of these activities and the high demand from the European citizen to participate and get involved in the science processes. Noteworthy, the goal of such activities is not to transfer information, rather to seed confidence and knowledge on how Chemistry could be useful to tackle different real-world challenges.

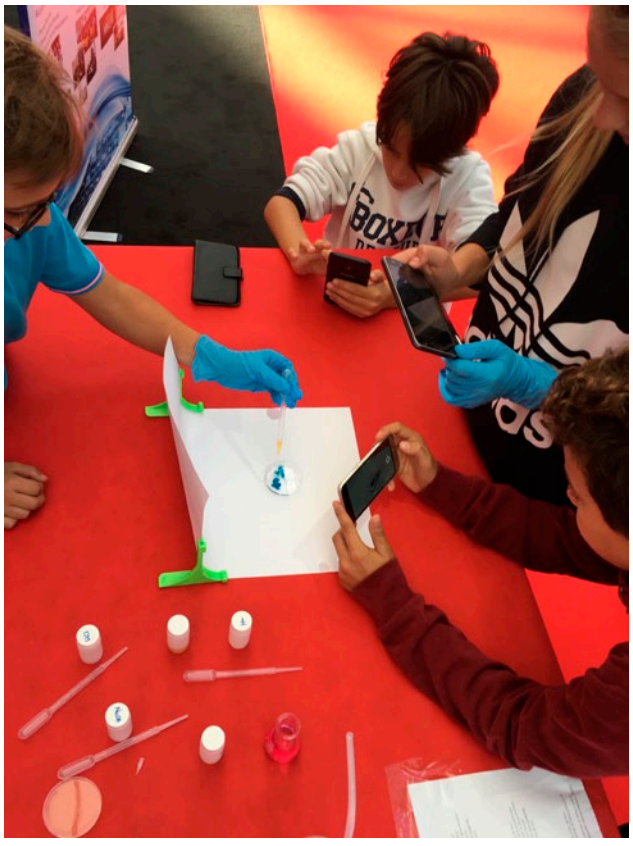

Figure 2. Primary school students performing and filming in slow-motion the synthesis of Prussian Blue during the laboratory "CIAK: (re)AZIONE!" at the "Festival della Scienza di Genova", 2018 edition.

Figure 3. Activities during the European Researcher Night 2018 at the University of Pisa.

To summarize, with the aim of addressing the already discussed issue about the underestimated perception of the role of Chemistry in our everyday life, bringing "Chemistry in the arena" with science festivals and open-laboratories activities fulfil the Open Learning vision and mission.

II. CHEMISTRY, NEW MEDIA AND GAMIFICATION

Knowledge can be considered as static, while the way in which information is transferred and then hopefully converted into knowledge is fluid and, nowadays, incredibly fast. According to a recent study on the Italian citizens habits, the 95% of Italians use smartphone and internet on a daily base, the 32% for most than 5 hours per day (even for longer if we consider teenagers).[45] Such scenario can be perceived in two opposite ways: either as a treat to the traditional, book-based teaching and learning approach, or as an exceptional opportunity for its enhancement. Indeed, trying to convey the interest of such users toward scientific discipline could be an opportunity.

Undoubtedly, the use of technology can help to increase science lesson engagement. Today's technology can provide an immersive experience and make learning a more active experience, stimulating students at a deeper level.

Strictly related to this, we find the concept of "science gamification": an approach for improving students' attitudes toward learning traditionally challenging subjects by proposing games, which increases engagement by means of rewards and feedback.[46] Far from being a simplified version of traditional education methods, the research agenda for the field of science gamification concerns with central aspects of research methodology, including psychometric measurement, experimental design, and generalizability, in order to maximize its trustworthiness and real-world value, as comprehensively discussed elsewhere.[47]

"Gamification" in education and "Cooperative Learning", where most of the activity is related to a team game, have proven successful in many contests.[48,49] Serious games about Chemistry have always existed and seem to be one of the more appealing and prone to popular marketization: in fact, "The Laboratory of Crystals", "Science and Lip-Sticks" and "Chemistry Lab" are only a few we can find in toy-shops.

Nowadays, with the diffusion of technology and the wide engagement of pupils and teenagers with new media and technology, science gamification is moving from the shelf to the smartphone.

An example is the popular Kahoot![50] game-based platform. With the claim "*make learning fun, inclusive and engaging in all contexts*", Kahoot! not only fully embraces the principles of Open Learning, but it also exquisitely merges the benefit of using new media (e.g., tablets, smartphones) for teaching and learning activities. With Kahoot! a teacher can create learning games (kahoots) by typing a series of multiple choice questions and optionally adding videos, images and diagrams to amplify engagement. Then, players (ideally, a class) answer the questions on their own devices, while games are displayed on a shared screen to unite the lesson. This cooperative learning creates what the Kahoot!'s authors define as "*campfire moment, encouraging players to look up and celebrate together*". Whether players are in the same room or on the other side of the globe, such game-based learning platforms also allow to search among millions of existing games and share results, thus enabling "Social Learning" which promotes discussion, pedagogical impact, and encourage players to deepen understanding, mastery and purpose, as well as engage in peer-led discussions.[51,52]

As reported by Jack Quinn, 5th grade teacher at Withcomb Elementary School (Houston, TX, USA), using such game-based learning "got students more plugged into learning, helped them improve mastery of complex science topics, and, as a result, they did 11.4% better in their exams compared to last year and are projected to grow 75% above the district norm".[53]

The *Diffusione della Cultura Chimica – Società Chimica Italiana* group recently used Kahoot! to disseminata the UNESCO international year of the periodic table (IYPT2019). In particular, a dedicated Kahoot! quiz for high school students was created by the *Consiglio Nazionale delle Ricerche* and proposed by the group during open days, career guidance, and PLS activities (Figure 4).[54] For instance, during the "Chemistry Days", a PLS

Figure 4. The "Human Periodic Table", performed by students attending the CNR event celebrating the International Year of the Periodic Table (IYPT).

event organized by the University of Palermo, the *Diffusione della Cultura Chimica* group proposed the quiz to 31 students at the end of a traditional talk on the history and curiosity on the Periodic Table. Questions ranged from simple notions (e.g., What is the surname of the scientist who first proposed the periodic table?) and curiosity on the origin of the elements or their names (e.g., Which among these countries was named by an element?), up to questions related to the presence of elements in everyday life (e.g., Which among these elements is not used to build a smartphone?). We noticed that by using their smartphones, even if for simply answering a question related to concepts they had just listened to or that were already aware of, students were fully engaged and almost anxious to give the right answer. Noteworthy, at the end of every quiz session, a report summarizing statistics on the overall and question-specific performances is available (Table 1). When the quiz is proposed after a lesson, such report can be used by teachers to evaluate the level of understanding of concepts proposed during the lesson. When the quiz is proposed before the lesson itself, in line with the "blind test" methodology which uses the feeling of initial failure as "cognitive need" (i.e., a stimulus to learn), the report can be used to finely tune the content of the lesson.[55]

Another example of interactive and participative activities, where the good use of digital tools and devices is crucial, is represented by the so-called "Citizen Science" programs.[56,57] These programs aim to reach a shared knowledge among citizens (of any age, culture and education) and about specific scientific topics, which are usually related to concrete everyday problems (such as environmental ones).[58] For instance, in the recent years, several "citizen science" programs were promoted by ARPAT[59], in Tuscany (Italy), to monitor the sea status during Summer time. Among these activities, people were invited to participate to the monitoring of a naturalistic area or an environmental phenomenon (such as the nesting of *Caretta caretta* turtles), by recording data, sharing comments, observations, images and videos, but also measuring some significant chemical or physical properties, such as the temperature or humidity.[60] In this way, everybody participating to the process, enhances its own responsibility and knowledge of the complexity and high interdisciplinarity of scientific "problems". "Ariapesa" is an example of "bottom-up citizen science" promoted by a network of free associations of citizens in Bologna (Italy) to monitor nitrogen oxides in the air near the schools through the installation of hundreds of passive samplers. These samplers have been, and will be, analyzed by specialized laboratories and the results compared to the data of three official monitoring stations, giving a punctual map of the pollution all over the school district.[61]

Therefore we believe that, upon appropriate study and definition of shared procedures and metrics to assess the correctness of the information provided, Chemistry should embrace these ways of digital communication and Open Learning.

Table 1. Example of quiz report available in Kahoot!, based on the "Domande Periodiche" (Periodical Questions) quiz proposed during the "Chemistry Days" at the University of Palermo.[54]

QUIZ TITLE	Periodical Questions
Q1:	What is the surname of the scientist who first proposed the periodic table?
Correct answer	D. Mendeleev
Players correct (%)	73.3%
Question duration (seconds)	30 seconds

ANSWER SUMMARY				
Answer options	Mendel	Mandela	Mendeleev	Mandilei
Number of answers received	8	0	22	0
Average time taken to answer (seconds)	8.39		6.77	

CONCLUSIONS

Chemistry, the central science, is often perceived by the general public as "distant from everyday life" and "too abstract". The reasons are manifold and partially addressed herein, however, it is clear that too traditional and content-focused teaching and learning approaches represent an important issue, which may justify the public attitude towards Science and Chemistry, in particular.

In the current digital age, Open Science and, more specifically, Open Learning, offers new paradigms and tools to establish a synergic interaction among science, digital technology, and Society worldwide.

Although the ambitious aim of creating a comprehensive list was beyond our scope, in the present manuscript we reported on successful examples of Open Chemistry, hands-on laboratories during science festivals, and alternative teaching activities based on new media and on the gamification of Chemistry. Some of these activities were developed by us under the umbrella of the "*Diffusione della Cultura Chimica*

– *Società Chimica Italiana*" (Dissemination of Chemical Culture - Italian Chemical Society) activities, others in the broader framework of the EU mission and vision on communication, dissemination and public engagement.

Moving from the "deficit" to the "dialogue" model of public attitudes towards science, we believe that such new way of promoting interaction between Science and Society holds the promise of triggering general public curiosity and fostering trust in the essential role of Chemistry in our Society.

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