SCUOLA INTERNAZIONALE SUPERIORE DI STUDI AVANZATI
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CHEMOPHOBIA

A SYSTEMATIC REVIEW

Candidato: Ruggero Rollini

Relatore: Prof. Luigi Falciola

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INTRODUCTION

For a chemist, even going to the supermarket can be a pain. Shelves are full of products that flaunt their naturalness and their lack of certain chemicals – if not all chemicals. As a chemistry graduate myself, I feel – and so many of my colleagues – the urge to defend my discipline, as if it was under attack. This common feeling of a public aversion towards chemistry has even resulted in the creation of a new word, chemophobia, used to indicate the fear laypeople have towards what is perceived as chemical.

The underlying idea that moves the fight against chemophobia is that this kind of paranoia could shape the public opinion toward chemicals, which can be intercepted by policymakers, and ultimately drive policy[1–3]. Since it is clear that chemistry is fundamental for a functioning society and for its development[4], it is easy to see how chemophobia-driven policies could seem rather scary. Some areas that are said to have already been affected by chemophobia are the flame retardants indusry[5–7], water safety[8], metalworking fluids usage[9], food production and consumption[4,10–13], cosmetics[4], and even chemistry kit for children featuring «60 fun activities with no chemicals»[14]. Some chemical industries eliminated «chemical» or «chemistry» from corporate names or activities' descriptions[15]. Another possible (and fascinating) result of chemophobia could be the fact that books about chemistry seem to have to avoid using the term «chemistry» in the title in order to become popular[16]. It has also been suggested that chemophobia, and the consequent stigma, could have a negative impact on chemists' psychology and wellbeing[17]. At the same time, there is the idea that chemophobia could cause a decrease in students deciding to obtain a degree in chemical sciences[4,18].

After seeing chemophobia as a «rampant» phenomenon[19], which even gained the appellation of «hysteria»[3,20], in 1981 American Antichemophobic Society was founded[21] (its fate is unknown).

At the same time, the idea of a fight against chemophobia could be used as a pretest to undermine legitimate worries of the population about certain compounds[22]. In this cases,

chemophobia could be used as a denigratory term to describe environmentalist thought to exploit public ignorance to whip up hysteria against modern technology[22].

Global media sensationalization of chemical accidents and a simultaneous marginalization of the major developments in science and technology (and the benefits they bring) is believed to be one of the causes of the negative perception of chemistry and chemicals[2,4,15,18,23–25]. At the same time, chemistry is often seen to be a complex and difficult science, which is even harder to communicate[3,16,26,27]. For example, it lacks most of the fascination inspired by the philosophical implications of grand themes dealt by cosmology or evolutionary biology[16]. From this perspective, chemophobia seems to emerge and prosper from an insufficient, inefficient, and inaccurate chemistry communication. When reading the literature about chemophobia and how to solve it, the dominant narrative has all the characteristics of the deficit model (where the problem is believed to be the lack of understanding about chemistry and toxicology)[28]. There is little data about public attitudes towards chemistry and way more anecdotal evidence of low public awareness towards chemistry, chemicals, and chemists[28].

In order to understand what chemophobia really is, if it even exists and to what extent, when it started and what are the reasons of its origin and prosperity, and – possibly – how to solve it, a systematic literature review has been carried out and its results are hereby reported.

METHODS

Three different databases were screened for the keyword «chemophobia». The query carried out on Scopus (https://www.scopus.com/ - last accessed on 13 October 2020), PubMed (https://pubmed.ncbi.nlm.nih.gov/ - last accessed on 13 October 2020) and Web of Science (https://webofknowledge.com/ - last accessed on 13 October 2020) resulted in a total of 115 results, between articles, notes, conference papers, letters, editorials, book chapters, reviews, errata, short surveys, news items, proceedings paper and meeting abstracts. Of these, 36 were excluded because they were not present in both SISSA and Università degli Studi di Milano libraries, and it was not possible to find them even through NILDE (Network Inter-Library Document Exchange). Of these, 2 were excluded because they were written in in Czech language and 6 because they were duplicates. Through a reading of the abstracts of the remaining 71 results, 10 articles were excluded from the review. 4 of which were not considered relevant for the purpose of the review and 6 considered chemophobia as a different phenomenon, that is the anxiety derived from chemistry courses. Although it is an interesting topic to elaborate, these 6 articles were excluded during the in-depth analysis. The final sample was then composed of 61 results, which were entirely read, summarized, and whose results and opinions are hereby condensed. The «Public attitudes to chemistry» research report[28] by TNS BMRB and the Royal Society of Chemistry (RSC) is also included in this review, despite not being indexed in the three considered databases since is one of the most comprehensive work on the public perception of chemistry, and so it deeply relates to chemophobia. Bibliography is reported in order of appearance, using the American Chemical Society (ACS) style of citation, to better consult it.

What emerged was a preponderance of anecdotical and opinion-based articles, with most of the data-driven research being conducted during the last decade. Nevertheless, this permits us to start drawing some contours to this topic. In the following pages, we will try to answer some questions about chemophobia: *what is it? When is it born? How bad is it? Why is it so pervasive? How to solve it?* There will be not many conclusive answers, but hopefully some foundations for future research on chemophobia will be laid.

WHAT IS IT?

In the literature, many definitions of chemophobia are given. Some authors define it as «the fear of chemistry»[18] or as «the irrational fear of chemicals»[2,27–36], some others as «the exaggerated fear of anything 'chemical'»[10] or the «fear of chemicals and our concerns about chemicals and cancer»[12] and – on the same line – as «the popular belief that all chemicals are toxic and probably carcinogenic»[9]. Other definitions are also proposed, such as «a long lasting and persistent irrational fear of chemistry and chemical substances and a strenuous effort to avoid them, causing people to become hypersensitive or even intolerant in this respect»[17,37,38] or «a persistent, irrational fear of substances perceived as having chemical properties»[25]

Chemophobia could also be considered as a different phenomenon, defined as the anxiety linked to chemistry courses[39,40]. Even narrower definitions are proposed and chemophobia has been described as the pupils' dread to perform certain chemical experiments[41].

The oldest article found in the literature (1981)[2], gives an interesting and impressively up-to-date explanation of what chemophobia is.

> The term generally is being used now to describe the almost spontaneous, negative response that occurs when the people hear the words chemicals and chemical company[2].

This permits us to make three important considerations:

1. It says that the term chemophobia was already in use. This shows us how no discussions can be made in this review about the birth of the term chemophobia. Which remains an interesting topic to study in deep.
2. It already gives a hint on how chemicals and chemical companies are the main victims of chemophobia. We will see that the public opinion about chemistry as a discipline and chemists is rather positive – or, at least, neutral.

3. It is a «spontaneous response», which suggest that is not due to rational thinking, but probably to some heuristics and mental shortcuts.

Many definitions have been given, but for our purposes we are going to consider chemophobia as «the irrational fear of chemicals». This definition will be proven to be the best one yet in the course of the thesis.

Chemophobia is said to lead people to avoid chemical-containing products that could be beneficial, such as medicines, or advocate for the removal of certain chemicals from the market, even without scientific evidence of alleged unsafety[29]. The health risk of low dose chemical exposures is then exaggerated and unnecessarily restrictive laws and regulations are invoked[3,42]. These could derive from the idea of a no-risk entitlement to good health and the overwhelming predominance of the precautionary principle over a cost-benefit analysis[30,42]. This worries even seem to lead to cases of somatization (the propensity to experience and report somatic symptoms that have no pathophysiological explanation, to misattribute them for disease, and to seek medical attention for them)[42] or at least compromise a correct toxic injury evaluation[25].

There is also a flip side to chemophobia, that could lead to neglect the risk associated with ‘natural chemical’, perceived as less threatening than ‘synthetic chemicals’. For example, consumers underestimate the riskiness of prescription drugs, eco-cleaning products or wild plants and overvalue the potential hazards of food additives (i.e. Aspartame)[4,11,35,37].

In a recent review, which analyzed the common causes of 24 drinking-waterborne disease outbreaks[8], it emerged that all of them were preventable and that personnel – who was supposed to be knowledgeable – had failed to recognize the public health risk. The idea that a raw water source is pristine, a preponderance of documents discussing chemical contaminants rather than microbial pathogens and an enormous attention directed to disinfection by-products led to inadequate disinfection. The fear of chlorination and the opposition to chlorine disinfection was a major factor in the studied outbreaks[8].

WHEN IS IT BORN?

In a report[31] presented at the Scientific Session of the General Meeting of The Russian Academy of Sciences it is suggested that chemophobia derives from the acknowledgment that human civilization and its progress, driven by human activities, can produce a significative effect on the world around us. Humankind has become a “geological force” so that we are said to live in the “Anthropocene”.

> When increasing the productivity of crops, protecting then form pests, manufacturing new materials and products, developing transport, and creating medicines, humanity has caused unintended harm to the planet[31].

Many authors[10,12,18,27,30,43] suggest a precise turning point on the development of chemophobia: the publication of Rachel Carson’s Silent Spring in 1962 and the consequent battle for the ban of dichlorodiphenyltrichloroethane (DDT). It is the same period (1960-1970) in which many papers devoted to the exhaustion of natural resources and the impact of human activities on the planet and public health started to appear[26,31]. In the following years many chemical accidents happened and immediately gained media attention, arguably mining the already unstable reputation of chemical industry[23,44].

During the 1960s thalidomide was a commonly prescribed drug to treat morning sickness of pregnant women[45]. Thalidomide was then recognized to be a powerful human teratogen, that caused the abnormal development of many children in that period[45]. This pharmaceutical disaster had probably contributed greatly to the development of chemophobia and skepticism towards chemical industry[16,20,43].

In 1964 Surgeon General Luther Terry announced that cigarette smoking caused cancer which also could have contributed to a shift on the public image of chemical compounds[27].

In 1971 the was the dioxin exposure in Times Beach, Missouri[10,43] after spraying waste oil in order to reduce dust formation on roads. The town was quarantined, and inhabitants relocated by the government.

In 1974 a paper by Molina and Rowland[46] appeared on Nature about ozone depletion caused by chlorofluorocarbons (CFCs) that could have also reinforced the notion that chemical compounds are harmful[27,47].

In 1976 in Seveso (Italy) 2 kg of 2,3,7,8-tetrachlorodibenzoparadioxin were spilled. Even if the event didn't have any human victim, it raised the level of consciousness about dioxins[10,18,47].

The chronic pollution of the Rhine brought France, Germany and Netherlands to sign a treaty in 1976 that should have guaranteed healthier waters, but that didn't prevent a dump in the Basel area of 30 tons of fungicide and mercury that killed 500,000 fishes[16,18,47].

In 1978 Love Canal in Niagara Falls, New York[10,16], an abundant rainfall triggered the leach form waste disposal drums that were covered with soil. Before about 100 homes were built there, Love Canal was used as a municipal and chemical dumpsite. Residents were evacuated and relocated[43].

1984 saw the tragic release of 40 tons of methyl isocyanate gas by a pesticide plant in Bhopal, India[10,16,18,47]. It was the result of a series of workers' errors and safety issues unaddressed that resulted in the death of 3787 people and more than 100000 people are still suffering from symptoms[43]. This is remembered today as the worst insecticide accident ever happened.

It can be said that there was a lack of admission of guilt by the industry and the were many pushbacks and lobbying pressures. Industry's reaction was belligerent and obscurantist: personal attacks and artificial controversies were setup, which were met with skepticism and accusations of covering up the truth[16,18,27,47]. This could even lead today to view Antichemophobic campaigns as another product of those who manufacture pesticides[48], seen as mainly driven by profit rather than societal good[12,28].

Some authors[49] place the origin of chemophobia in the early 1980s with the detection of pesticides in food products. Since then, consumers have been suspicious regarding the roles of regulatory agencies and manufacturers, unsure on whether these institutions

perform their duties properly in ensuring consumer safety[49]. Concerns about the exposure of farmers and non-occupational exposure to residues found in food and water are still relevant[10,24,26].

It has also been suggested that another contribution to the exacerbation of chemophobia has been the publication of another book, Our Stole Future by Theo Coburn in 1996[10].

For some, the birth of chemophobia was much older that ‘60s or ‘80s and it has been hypothesized that it coincides with First World War, often referred to as the “Chemist’s War”, and its connections to chemical warfare[16,18,26,47,50]. A precise date has even been suggested: 12 April 1915, with the release of 150t of chlorine gas by the German army[18]. The use of dynamite, explosives in general and poison gases was a dramatic turning point in our civilization that has certainly left a mark.

Chemophobia could have an even older origin: some old and mythical factors could be

> the destruction of Sodom and Gomorrah from the befouling of air for breathing and water for drinking, or the twin medieval anguishes over the cognate poisoning of wells or polluting of air[47].

In a 2018 article[38] authors draw a parallelism between the skepticism towards medieval alchemy and chemophobia, showing how the preference for natural-perceived products has deep roots.

> Whatever good created through natural powers cannot be imitated artificially; human industry is not the same as what nature does.
>
> Avicenna (approx 980-1037)

This comparison is derived by “The Secrets of Alchemy”[51] in which it is stated:

> […] some issues raised about medieval alchemy regarding technology and the relation between the natural and the artificial remain unsolved today[51].

From this, one can suggest that the origin of the “natural-is-better heuristic” and the “technological stigma” (that are going to be discussed later) can be traced so far back in

time, but proposing to pinpoint the birth of chemophobia (or even a proto-chemophobia) before the birth of modern chemistry could be a long shot.

Despite everything we have just said, we can still say the fear of chemicals is irrational (everything that surround us and compose us is made of chemicals, after all). Nevertheless, we can find some rational bases from which chemophobia could have developed. During the last century we witnessed many chemical disasters took place and these could justify a suspicion toward chemicals by the population.

A more recent example is the “Oxy accident” that took place in South Korea and gave rise to consumer’s anxiety and distrust about chemicals in that country. Many pregnant women and young children died from lung disease and asthma because of a toxic substance contained in some humidifier sterilizer[52].

It also must be considered that it is not an easy task to develop procedures and protocols to determine a precise amount of pollutants and contaminants that could be considered safe for human and environmental health[3,9,22,31,53].

With the 2018 data addendum to the WHO “Public health impact of chemicals: knowns and unknowns”[54] it has been estimated that

> 1.6 million lives and 45 million disability-adjusted life-years were lost in 2016 due to exposures to selected chemicals[54].

In the “UN Environment Global Chemicals Outlook II”[55] is clearly state that

> The global goal to minimize adverse impacts of chemicals and waste will not be achieved by 2020. Solutions exist, but more ambitious worldwide action by all stakeholders is urgently required[55].

It cannot be denied that some chemicals are indeed dangerous and that, over the years, some chemicals have caused many environmental and health problems and that there is the need for better regulations. Because of this consideration, it can be said that what has become “the irrational fear of chemicals”, started and has its roots in rational and justifiable worries. Of course, we must remember that these rational bases should not

justify an aversion towards chemistry, chemists, chemicals or the chemical industry as a whole – especially since modern society would be unthinkable without their precious contribution.

REPRESENTATION OF CHEMISTRY

The stereotypical picture of the chemist is that of a mad scientist that works in his dark laboratory between flasks and alembics, creating chemical weapons and polluting the environment[28,30]. Such depictions have the scientist as the gatekeeper of some sort of forbidden knowledge and recalls characters like Faust or Frankenstein, individuals who suppress human emotions and whose work in search of scientific truth led to disaster[30]. This idea of the chemist as a careless, eccentric and mad scientist is often thought to have been reinforced by the media coverage of chemistry, typically focused on chemicals, pollution, and industrial accidents[2,4,18,20,28,56].

During the 90s, in what could have been an attempt to dissociate themselves from the negative image carried by chemistry, some subdisciplines were renamed. Examples of this could be «surface science» or «nanoscience» and «nanotechnology». This rebranding brought with itself some issues, especially in a period in which the government was closing chemistry departments in British universities[47]. As a possible result, today we record a limited recognition of chemistry in various industries or sciences – that are not labelled 'chemistry', leading to low awareness of chemistry's applications[28] and the tendency to credit other fields with the advances that chemistry makes[44]. This could also be seen as an effect of the suggested «crisis of identity of chemists»[17]. This idea is based on the assumption that chemophobia could limit the willingness of chemists to admit that they practice their profession[17].

Not only is chemistry believed to be misrepresented but also underrepresented. Its lack of visibility in relation to other disciplines puts chemistry in danger of becoming a forgotten science[36]. To support this thesis it has been reported that chemistry findings are the least likely to be shared by both scientists and the public[36].

CHEMISTRY AT SCHOOL

When asked unprompted UK's people top-of-mind association with chemistry, the most common response (mentioned by 21% of the sample) related to school or teachers[28]. This strong relation between chemistry and school is supported by qualitative workshops, where respondents imagined school laboratories to come up with associations with chemistry[28], and by an analysis of chemistry-related tweets, where the «learning environment» topic was the most prominent.

They did not see it as personally relevant and lacked concrete examples of its applications; finding it much easier to specify and visualize negatives or stereotypes[28]. For some, who did not enjoy chemistry at school, or found it difficult, this can also produce a sense of inferiority and disengagement. 24% of people agreed that school put them off chemistry. Three in ten (31%) said that chemistry learnt at school proved useful in their everyday life. There is also the idea that chemistry is a hard, potentially inaccessible science. That it lacks the fun and energy of science[28]. Although difficulties found at school could play an important role in the development of chemophobia, it is difficult to draw a direct connection and the aforementioned factors may play a major role in the amplification of chemophobia following graduation[26].

HOW BAD IS IT?

If you are a chemist, the answer is probably “less than you think”. In fact, from the TNS BMRB and RSC research report[28] about public attitudes towards chemistry emerged that chemists thought that laypeople would have had a way worst perception of chemistry, chemists, and chemicals that what resulted from both public survey and workshops[28]. This idea is further confirmed by the fact that sometimes chemists seem to see chemophobic behavior even when there isn’t[57].

So, to better understand if chemophobia exist and to what extent, some distinctions need to be drawn. The public perception of chemistry (as a discipline), chemists and chemicals will be singularly analyzed, and this will give us some interesting insights to help us circumscribe what chemophobia is really about.

ARE WE SCARED OF CHEMISTRY?

In a survey[28] conducted on 2104 UK adults emerged that the overall feeling toward chemistry is neutral, with 51% of the respondents saying that «neutrality» is what best describes how they feel about chemistry[28]. Overall, people were positive about the impacts of chemistry and believed it to be beneficial to society. Many respondents (59%) believed that the benefits of chemistry are greater than any harmful effects and 72% agreed that chemistry research and developments make a direct contribution to the UK’s economic growth. Also, 75% of the respondents said that chemistry has a positive impact on wellbeing placing it second only to medicine (87%) and biology (76%). These findings agree with what emerges from another survey[29] (which will be discussed later): when the term «chemical substances» is associated with «science», neutral feelings emerge. Another confirmation arises from a recent analysis of the public perception of chemistry on Twitter[32]. In this study, a total of 256 833 tweets, form 1st January 2015 to 30th June 2015, containing the words «chemistry», «chemical» or «chem» was gathered (and then filtered down to 50 725) and clustered; Each cluster was then categorized into six topics: human activity, scientific knowledge, learning environment, entertainment, human relationships and undefined. The most prominent categories were human activity (with

9159 tweets) and learning environment (with 19 804 tweets) and a lexicon-based sentiment analysis was carried out on those tweets (***Figure 1*** and ***Figure 2***).

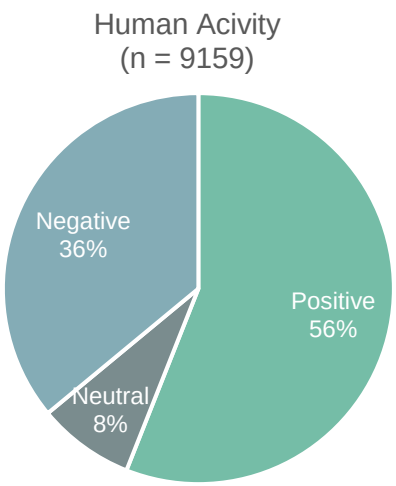

Figure 1 *Human Activity's tweets classified by their polarity (adapted)*[32]

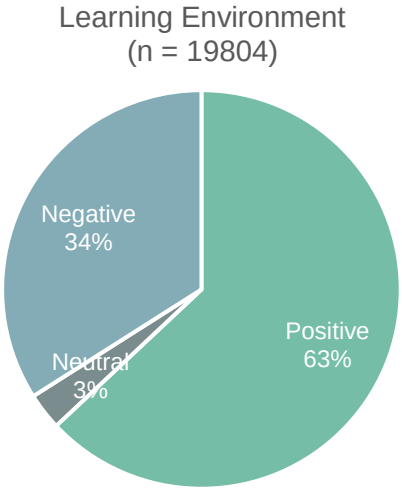

Figure 2 *Learning Environment's tweets classified by their polarity (adapted)*[32]

A higher percentage of positive rather than negative tweets was obtained[32]. Also, if we consider that, in relation to a number of world problems, the majority of individuals stated that chemistry was part of the solution rather than the problem[28], it seems to be clear that chemistry – as a discipline – is well perceived. This allows to say that laypeople seem not to be afraid of chemistry. If chemophobia was to be considered as the «irrational fear of chemistry» it would be – at most - a minor phenomenon. Chemistry as a discipline does not appear to be under attack.

ARE WE SCARED OF CHEMISTS?

Opinions about chemists recorded between UK's adults were positive, with 95% saying that chemists made a difference in the world, 93% that they were honest and 88% that they were approachable[28]. While this is certainly good news, there is a caveat to be considered. What emerges from the survey is that chemists are typically associated with pharmacists (***Figure 3***). This is due to the historical use of the word chemist in British English, which conflates with that of a pharmacist.

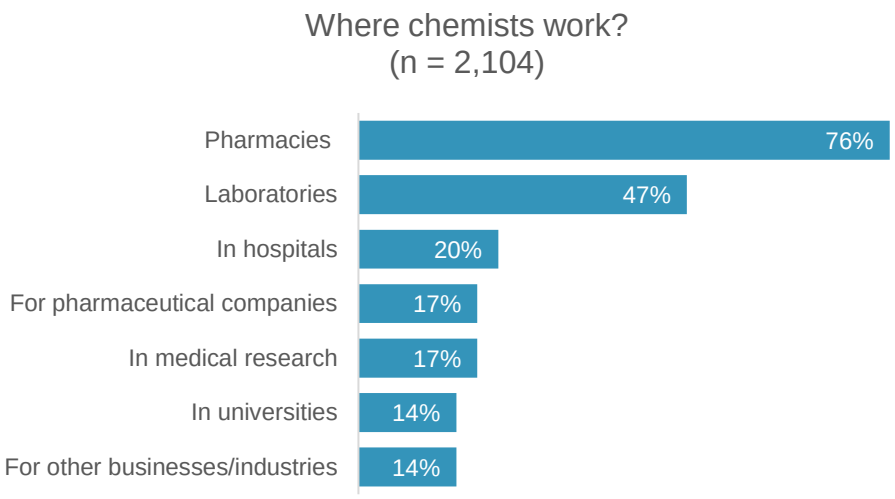

Figure 3 *Top of mind associations on where a chemist might work (adapted)*[28]

The confusion about what profession chemists actually have[23] is confirmed by the people's idea of chemist's workplaces[28]. It seems that laypeople lack alternative examples of the different kind of industries chemists work in. After in depth discussions, people were surprised and interested to learn in how many different fields the chemists' work. Sometimes, some skepticism emerged that jobs depicted were really related to chemistry[28]. In the light of these considerations, the positive perceptions of chemists could be the result of people's esteem of the medical research and pharmacists. That is supported by the fact that in-depth discussion in workshops revealed some negative perceptions of chemists (for example, they were not seen as approachable). Respondents said that chemists would be intelligent, but conscious of the 'intelligence gap' between themselves and the general public and were described as «clever to the point of fastidiousness»[28].

ARE WE SCARED OF CHEMICALS?

In an online survey conducted on 663 persons from the German-speaking part of Switzerland[29] (of which 546 composed the final sample), participants were asked to provide the first two associations that came to their mind when reading the term «chemical substances». They were then asked to rate their feelings related to the associations from

0 to 100 (where 0 is «extremely» negative and 100 is «extremely positive»). The most prevalent first associations categories were «science», «toxic» and «specific chemicals». If the affect rating for «science» suggest neutral feelings (M = 54.39 [SD = 19.72]), the rating for «toxic» was very negative (M = 19.10 [SD = 15.56]) and for «specific chemicals» was negative (M = 41.97 [SD = 26.54]). The affective rating of first and second association were negative, and the overall affect reported for all associations was negative (M = 37.85 [SD = 22.26]). It should also be noted that «synthetic», «unnatural», «health danger» and «environmental danger» were also quite prevalent associations[29].

A Mokken scale was developed regarding natural and synthetic chemicals and basic toxicological principles[29]. This reliable one-dimensional scale (scalability coefficient H = 0.35 and a reliability of ρ = 0.72) provided for the participants a mean knowledge score M = 4.08 (SD = 2.13) on a scale from 0 to 8, where 8 indicates high knowledge. In the same study[29] chemophobia has been assessed with a six point Likert scale, and so have been general health concern and risk-benefit perception of synthetic chemicals. What emerges is that there is a negative correlation between chemophobia and overall affect towards «chemical substances» ($r = -0.35$, $p < 0.001$, $N = 523$), their risk-benefit perceptions of synthetic chemicals ($r = -0.38$, $p < 0.001$, $N = 546$) and knowledge of basic toxicological principle ($r = -0.36$, $p < 0.001$, $N = 546$). The study suggests that chemophobia is fueled by negative associations and affect stemming from the stigmatized term «chemical substances»[29]. From this survey emerged some misconceptions regarding natural and synthetic substances; like the insensitivity to dose-response relationship and the underestimation of the toxicity of chemical of natural origin.

It must be said that the respondents[29] reported similar levels of negative affect regarding the terms «chemical substances» and «synthetic chemical substances», whereas the term «natural chemical substances» was associated with a more positive affect[29]. This seems to highlight a key difference between scientific language and everyday speech. When laypeople use the term «chemical substances» there could be an implicit «synthetic» before it. If so, the definition of chemophobia could assume a slightly different connotation, becoming «the irrational fear of (synthetic) chemicals».

These considerations emerged also from the report about UK's public attitudes to chemistry[28] (***Figure 4***). When asked to state whether they agree or disagree to statements about chemicals (to test possible misconceptions), most of the respondents answered correctly.

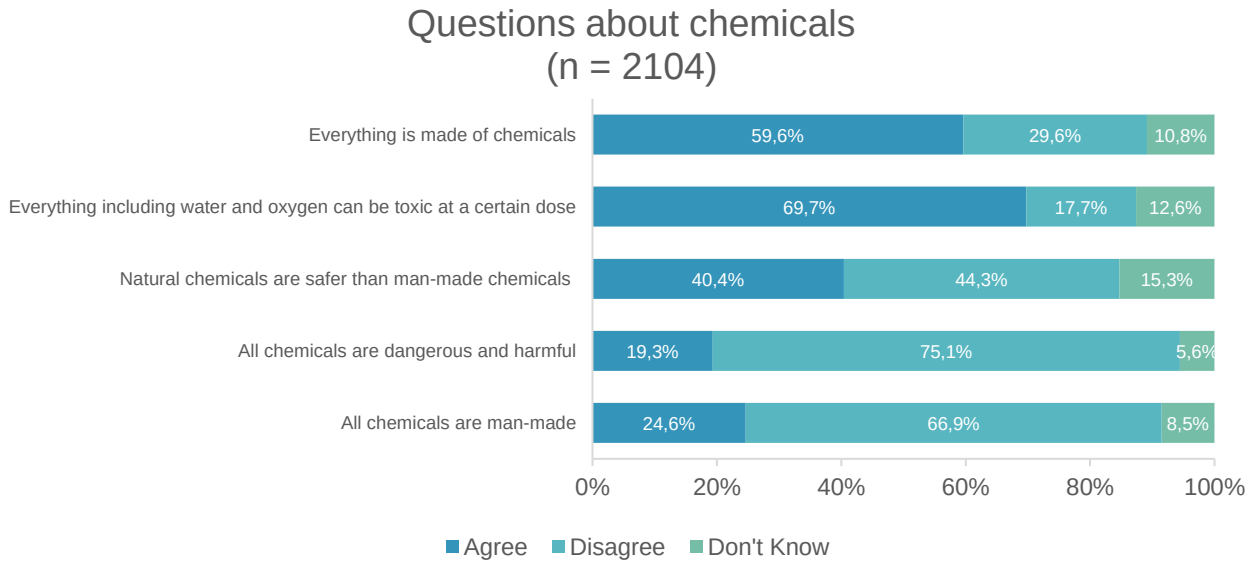

Figure 4 *Respondents were asked whether they agreed or disagreed with the statements (adapted)[28]*

Two out of five people (40%) agreed that natural chemicals are safer than man-made ones. This seems to reinforce the idea there are indeed some misconceptions about natural and synthetic chemicals and that the latter are perceived as more dangerous and harmful. When asked to describe their overall feelings towards chemicals, respondents expressed a rather neutral view (55%), with just under one-in-five (18%) reporting a positive view (happy or excited)[28]. During qualitative workshops[28], two interesting insights emerged:

- The way in which the word «chemical» was commonly understood did not mirror its scientific use. What participants were usually referring to, was a subset of chemicals with the characteristics of being synthetic or man-made and potentially toxic or harmful to people and the environment.
- There were some strongly negative views, particularly relating to chemicals encountered or potentially eaten every day, like food additives or pesticides.

People recognized a general “media scaremongering” about chemicals and inconsistencies in advice about certain foods or products and overall did not feel particularly informed about chemistry and chemicals (with 41% and 54% of people feeling very or fairly well informed)[28].

There is another thing to be considered.

> A clear finding of this research was the associative separation that existed between chemicals and chemistry for respondents[28].
>
> Even among those who were most negative about chemicals, many had positive views of chemistry overall[28].

In the public survey, of the 19% group that agreed with the statement «all chemicals are dangerous and harmful» 53% agreed that benefits of chemistry are greater than any harmful effects.

It is interesting to note that in the study analyzing the public perception of chemistry on Twitter[32], even if sentiment analysis showed an overall positive affect towards chemistry with more positive tweets than negative ones, chemophobia emerged as well. The analysis of unigrams and bigrams clouds showed the presence of many terms related to chemical war, chemical toxicity and chemical disasters that suggest an attitude of chemophobia and that could be found in both positive and negative classified tweets[32]. The presence of chemophobia-related terms in positive classified tweets – which could seem odd at first sight – can be easily understood once one notices the presence of the bigram «chemical free» in the positive word cloud. That is a clear example of how there could be found tweets that express positive affect towards chemistry-related topic, but that are still chemophobic. The authors suggest that the presence of these terms might create or reinforce chemophobia perception on Twitter users[32]. The fact that these chemophobic terms are mainly found in the «human activity» tweets support the idea that chemophobia is mainly related to synthetic chemicals rather than chemical substances as a whole.

Chemistry (as a discipline) and chemists are viewed to have little to do with the harm perceived to be associated with man-made chemicals.

> Though chemists might work with chemicals, it was “corporations” who made decisions that could impact the public negatively, driven by profit rather than societal good[28].

The public image of the chemical industry is also commonly associated with its production of «nasty» odors, colors, tastes, and textures[23].

In 2019, large-scale survey was conducted on 5631 persons from eight European countries[35]. Its scope was to measure knowledge of toxicological principles, chemophobia, trust in public authorities, health concern alongside with sociodemographic and control variables. To evaluate the knowledge of toxicological principles, the previously discussed scale was used[29]. While, to measure trust in public authorities, health concern and chemophobia was used a six-point Likert scale (1 = do not agree at all, 6 = strongly agree). Chemophobia and health concern scales were also used in the aforementioned study[29]. Here are reported the chemophobia-statements ($\alpha = 0.86$):

1) Chemical substances scare me.
2) I do everything I can to avoid contact with chemical substances in my daily life.
3) I would like to live in a world where chemical substances do not exist.
4) I believe that chemical substances are the main reason why people suffer from cancer.
5) I believe that chemical substances are the reason for most environmental problems.

The authors noted that this scale comprises potentially rational items, like statements 4 and 5, which depend on the chemical that respondent think of.

The survey[35] - carried out in Austria (AT), France (FR), Germany (DE), Italy (IT), Poland (PL), Sweden (SE), Switzerland (CH) and United Kingdom (UK) – has brought up some unfounded fears evoked by chemicals among the public in these countries, which resulted in the impossible desire of many respondents to live in a world without chemical

substances[35,58]. Graphs are reported showing some responses to question designed to measure chemophobia and toxicological knowledge (***Figure 5*** and ***Figure 6***).

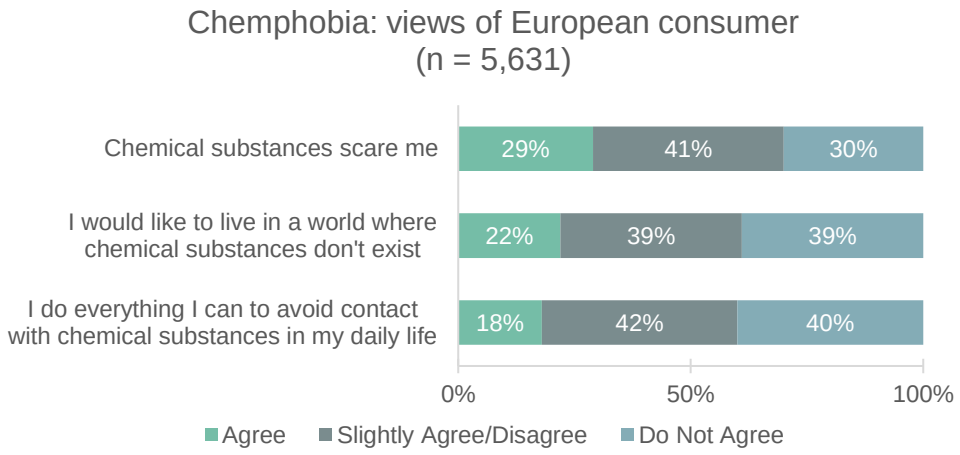

Figure 5 *Responses to three questions designed to provide a measure of chemophobia (adapted)[35,58]*

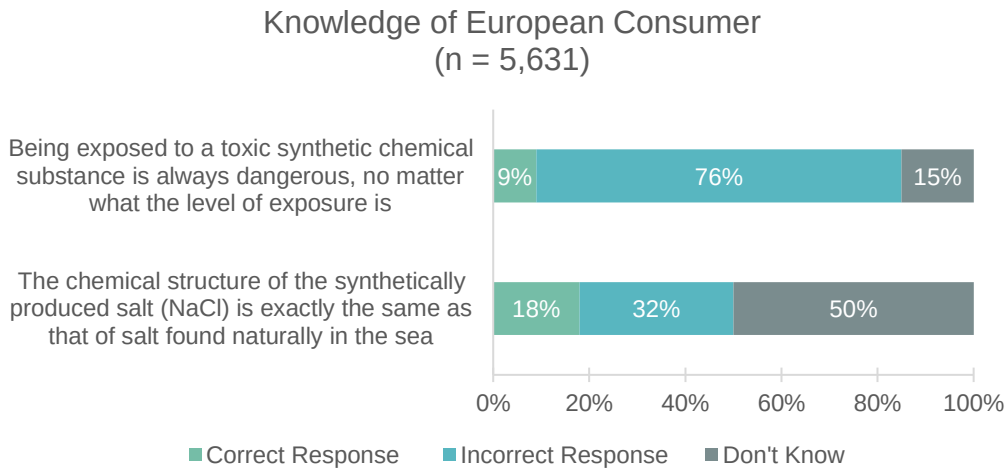

Figure 6 *Responses to two questions designed to gauge the chemical knowledge of the consumers taking part in the survey (adapted)[35,58].*

In all countries, the knowledge of toxicological principles was negatively related to chemophobia (the more toxicological knowledge people have, the less they tend to be chemophobic), whereas health concern was positively related. German speaking countries and France had chemophobia negatively related with trust in public authorities. In Switzerland, Austria, Germany, and Poland, chemophobia was associated with higher age. Only in Italy there was a strong negative correlation between higher education and

expressing less chemophobia, but the correlation persists in all the countries (more educated people tend to be less chemophobic).

There were some differences in chemophobia between countries (***Figure 7***).

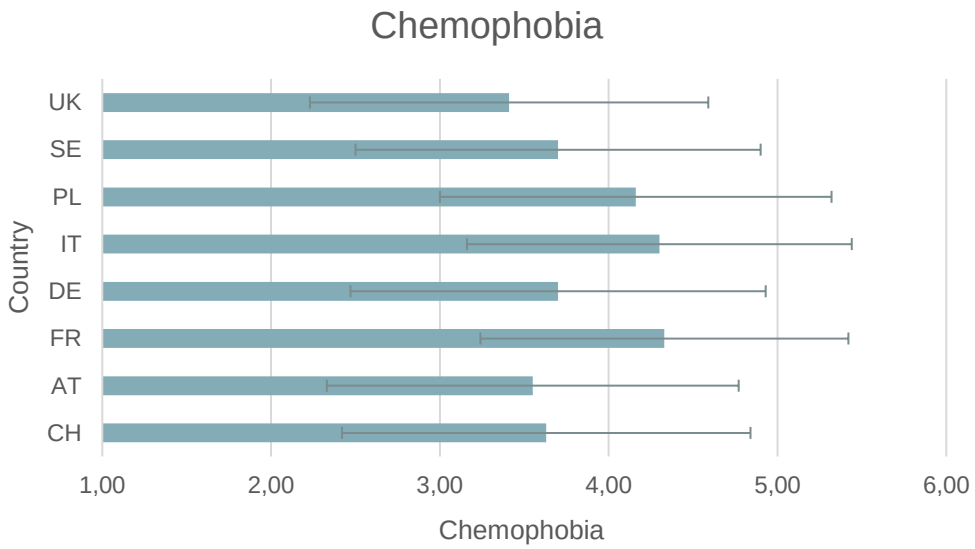

Figure 7 *Chemophobia per country (adapted)*[35]

THE GENDER GAP

When it comes to chemophobia and the perception of chemistry, it seems to emerge a prominent gender gap. 55% of UK's women said not to feel confident enough to talk about chemistry (compared to 45% of men)[28]. Similarly, women reported to have had a worse experience with chemistry in school[28]. In the same survey, emerged that women were more likely than men to say that «natural chemicals are safer than man-made chemicals». Another survey, conducted on 600 Korean consumers to evaluate their risk perception about chemicals, found the women have a higher risk perception about chemicals than men[52]. In the aforementioned survey on eight European countries, this trend seems to be confirmed, with women found to be more chemophobic than men, especially in Switzerland[35].

WHY IS IT SO PERVASIVE?

The underlying reasons of such a pervasiveness are many, and not so simple to identify. Nonetheless, understanding what exacerbates the irrational fear of chemicals in general is critical to provide an effective response[1]. Laypeople's risk perception is not only guided by rational and analytical judgments. If experts tend to assess risks based on scientifically proven facts, consumers risk evaluation is more subjective and mediated by their personal experience, knowledge and information gained from various sources[52]. It is a combination of psychological and cultural forces that lead different groups of non-scientists to process information very differently[1]. In fact, in a society more and more complex, consumers tend to lack the knowledge of how products are made. So, when evaluating risk and benefits of said products, they tend to rely on mental shortcuts[58]. It must also be remembered that people are biased not only in the information they retain, but find it easier to recall information that support their position[1].

THE AFFECT HEURISTIC

The affect heuristic postulates that consumer's feelings regarding a given product drive their risk evaluations. So, if consumers experience a positive affect towards a certain product, they will tend to perceive that its benefits outweigh the risks and vice versa. An evaluation based on affect is quick and efficient, but relying on it for decision-making could lead to biased and dangerous behaviors[29]. A negative affect toward an issue could lead to a higher risk perception and a lower benefit perception of that issue and vice versa[34].

NATURAL-IS-BETTER HEURISTIC

In the aforementioned survey which investigated the affect towards «chemical substances»[29] emerged that people affective reactions to «synthetic chemical substances» were negative (M = 42.70 [SD = 17.41]), whereas their reactions to «natural chemical substances» were positive (M = 67.30 [SD = 19.40]). It seems that laypeople consider the origin of a substance to be an indicator of its toxicity. This agrees with the fact that respondents seemed not to be familiar with the similarities between natural and synthetic chemicals in terms of basic toxicological principles[29].

CONTAGION HEURISTIC

There seems to be an insensitivity to the dose-response relationship. The contagion heuristic applies when people rely on the act of contamination when assessing the properties of a given substance[58]. The simple act of containing minor doses of a toxic chemical can lead people to perceive a given product as “contaminated”. Minor doses or exposures to said chemical are associated with a certain likelihood of harm. A substance can either be seen as safe or dangerous[29]. The contagion heuristic is in direct conflict with the fact that there are safe limits of exposure to a toxic substance and that the dose-response relationship is a fundamental toxicological principle[58].

The contagion heuristic could derive from (or have been exacerbated by) the Ames proposal of the «one molecule theory» (1971) which state that just one molecule of a mutagen is enough to cause a mutation[30]. It is interesting to note that Ames later softened its stances, describing, in 1983 how large numbers of potent carcinogens can be found in natural products and that our dietary intake of natural pesticides is probably 10000 times higher than the intake from man-made pesticides[30,59].

TRUST HEURISTIC

When people do not possess enough knowledge for judging a certain risk, their judgments and decisions are often guided by their trust in regulation bodies[29]. The fact that people rely on their trust in stakeholders and communicators to determine the associated risk is known as the trust heuristic[58]. Perceived similarities in intentions and values, rather than competence, determine where people’s trust lies. This does not only count for governments or (inter)national agencies, but also for NGOs, celebrities and the chemical industry itself[58].

TECHNOLOGICAL STIGMA

Man-made chemicals, even if they are offering multiple benefits for consumers, suffer from technological stigma. For stigmatized technologies, public discourse focuses more on the potential risk than on the benefits[35]. Laypeople perception of risk of man-made chemicals are amplified and benefits underestimated.

HOW TO SOLVE IT?

Once we understand what chemophobia is and how it operates, it is possible to suggest some possible solutions. In doing so, it is important to remember that, considering everything we have said until now, solving chemophobia and its implications will not be easy. This is especially true, since researches on how to counteract chemophobia are scarcer than those that try to define and quantify it. Anyway, among opinions and some data-driven research, there are few things we can say on the matter.

INFORMATION PROVISION AND BASIC TOXICOLOGICAL KNOWLEDGE

Since there is a negative correlation between chemophobia and understanding of basic toxicological principle and (natural and synthetic) chemicals[29,35,58] and since people seems not to feel informed enough about chemicals[28], it could be suggested that knowledge provision about these topics should be a feasible strategy to counteract chemophobia[60]. This idea has brought many authors to hypothesize that improving chemical literacy could be a cure to chemophobia[4,23,31]. It is also suggested that an understanding of chemistry fundamentals would assist people in critically evaluating many pseudoscientific or conspiratorial claims[36]. This idea, and the usual lack of toxicology classes in the curricula of a training chemist, brought IUPAC to the creation of a distance learning program in toxicology for chemists[61]. Chemist should be the first line of defense against chemophobia and their preparation to communicate should be part of their training to become professional chemists[37].

Considering the importance of basic toxicological knowledge in the fight against chemophobia, one must not fall into the idea of a knowledge deficit model approach since, alone, it does not adequately explain how people grasp science[1]. If it is true that a basic understanding of toxicology, dose-response relationship, and the risk assessment process might improve laypeople's ability to make fact based decisions related to chemicals, a purely informational and educational approach might not be the solution for all the issues as a more intuitive layer of influential factors might also play a role. Science should not be only - and simply - broadcasted to the public by experts. People's concerns

are a product of genuine moral, social and political deliberations and are not dictated only by a lack of knowledge[28]. Noted that, it can be suggested that chemists should not view communication as solely a mean to improve scientific literacy, but as a way to engage audiences with their work[16].

Laypeople tend to reject products containing synthetic chemicals simply because they are man-made, and this might be one of reasons why information provision is insufficient[35].

Also, a clarification of the differences between experts' and laypeople's use of the terms «chemical substances», «natural» and «synthetic» could help reduce the stigma associated with the terminology[19,29]. This lexical approach might prove useful at least to find a common language, which is the ground base for an effective communication.

> «An important first step to improve the communication between toxicologists and laypeople, could be to find a common wording of the term 'chemical' or at least to clarify what exactly these terms mean to someone»[35]

Another strategy that could be pursued is to communicate the benefit derived from chemicals, which could improve people's acceptance and promote a more positive perception of chemical substances[2,29,30].

Medical doctors should also be aware of chemophobia, its origins and possible consequences when prescribing drugs and they should establish a deep and emphatic doctor-patient relationship in order to avoid possible exacerbations of the problem[42].

TRUST IN INSTITUTIONS, SCIENTISTS, AND THE INDUSTRY

People's trust in the agent of communication is an extremely important factor in their acceptance of the communicated message[29]. This is true for regulatory bodies, since trust has been proven important in combating chemophobia[29,35,58,62]. The role of government is to secure consumer safety through laws and regulations aimed at reducing toxic chemicals levels (even in traces) in consumer products prior to reaching the consumer[49] and at granting a proper formation on chemical's handling[63]. Regulators should then

provide believable and transparent information and provide cues of competence as the recipient of the information[35].

Products certifications and chemists code of conduct could also be an important way to grant the public access to safe and environmentally-friendly products[18,64]. Industries should also realize (and many already did) the importance of «the implacable law»: accident prevention is cheaper than compensation[18]. The law comes with four corollaries:

- Chemical accidents and disasters will inevitably happen, and they will always be unpredictable.
- To keep such to the level of minor inconvenience, all responsible operatives must be trained to the highest possible level of competence to know how to react to the unpredictable.
- Only the most modern computerized instruments and control systems should be used in high technology plants.
- When the inevitable and unpredictable happens, as is likely in the lifetime of a chemical plant, a highly efficient and fully trained rescue service must be available.

Toxicologist should also improve their communication[56]. Differences between *in vitro* and *in vivo* studies and what implications can be deducted for human safe exposure levels must be clarified to the public[9,22,53]. Also, since analytical techniques are always improving and so is our ability to detect chemicals in traces, a communicative effort should be undertaken in explaining how assessing the influence of such extremely small quantities of chemicals on humans is realistically difficult[11,24,49]. It could prove useful to stress the need to take into account risk-benefit considerations and – aware of the contagion heuristic – continuously reiterate the idea that doses and exposures are what make a substance dangerous, and that sometimes small amounts of chemicals are, indeed, safe[30]. This is, of course, not an easy job to do. A reasonable apprehension towards chemical risk must be taken into consideration in order to develop policies and communicate this risk to the public[22]. Interesting questions have been proposed – which are even more interesting from a communication point of view:

> Should chemicals have rights, in the sense of an assumption of nontoxic properties in the absence of evidence to the contrary? If so, how strong must such evidence be to "convict" an existing chemical? Should the evidence vary the with the economic importance or production volume of the chemical? Upon what party does the burden of proof fall – industry, government, or the public (including environmentalists)?[22]

These seem to be some of the underling questions of many of the chemophobia-related discussions and it would be useful to understand which of the worries about certain chemicals are legitimate and which others are chemophobic.

In an analysis[62] of the measures taken by the U.S. Environmental Protection Agency (EPA) after dioxin contamination in Missouri it is clearly state that:

> Without a full discussion of exposure, doses or pathways of exposure, the public was left to assume all dioxin in any setting posed danger and was deadly to people[62].

Without a clear, honest, and correct communication by the authorities, people were left with only media stories about the danger and harmfulness of dioxin. Thus chemophobia prevailed. The (perceived or real) chemophobia was then contained and very well handled by a coordinate effort between many regional, national, and federal institutions and agencies. The strategies focused on the communication of facts (and no speculation), the removal of barriers to communication (making it easy for the people to reach the government), demonstrating action and answering to questions (admitting when there were no answers), quick sample analysis and consequent actions, and demonstration of sensitivity to affected public concerns[62].

Improving information on how to responsibly handle chemical products in our daily lives may be another feasible way to reduce chemophobia[31]. It has been found that giving information about safe usage of chemical products increased risk perception of Korean consumers[52]. The authors also pointed out that the provision of risk response guidelines, alongside with increasing risk perception, could be effective in reducing consumers anxiety and increasing rational safety behavior[52]. It is also remembered that

> Consumers' risk perception induces self-protective behavior, but in excess, it can result in social problems. Accordingly, consumers risk perception should be managed at the public level[52].

What is then suggested is to provide risk management methods along with risk diagnostic information whenever risk information about a product is presented to consumer[52]. Thus the importance of the labeling of products that should give sufficient hazard warning in an easy-to-understand way, but at the same time must not overstate the hazard[61].

There is no point in supporting the idea that all chemicals are good. They are not. In a sense, it could be said that chemicals are like people – some are good, some are bad, and most are in between[27]. This could be a useful metaphor to explain the complexity that lies behind chemicals and to counteract the predominant manichaeistic vision. Following this idea - and expanding it to include not only molecules, but also the chemical industry – it has been stated that public engagement with chemistry must not be confused with self-promotion and that

> it involves ensuring that chemists do not provide "a falsely benign image of the world — where chemical plants are only associated with the production of goods that yield 'better living through chemistry' and never with the realities of chemical pollution and toxicity". And there has been an unfortunate tendency for chemists to avoid addressing these darker aspects of their field[16].

Especially considering that the chemical industry is thought to put its own interest before societal good and that any accusation pushback tends to be seen as a way of covering up the truth. It could prove very important to admit chemical limitations[30] and past and present industry wrongdoing.

Years of persistent chemophobic marketing are difficult to counteract. There is money to be made by convincing the public that a particular brand of foods contains no pesticides, making it safer to eat[27]. If we push back on such issues it could seem that we are defending the indefensible. What people already "know" overweight what they are being told[27]. When communicating chemistry to the public one should aim to displace existing knowledge without engaging intellectual defensive mechanisms.

> We cannot simply use the facts. We need to remember there are already facts in people's minds we must displace or overwrite. In communicating chemistry, we must always remember it is a teaching exercise and we are rarely starting with a blank slate[27].

While communicating chemistry with the idea of counteracting chemophobia, it is interesting to remember that what can give chemists credibility is not only their knowledge, but social affinities with the public[1].

> When confronting chemophobia, we need to take off our lab coats and let our other personas take the floor. Speak as a parent, a sports fan or a gardener, not as a chemist[1].

WATCH YOUR LANGUAGE!

Chemistry has a certain code, which is not easy to get familiar with[26].It has been suggested that chemophobia could also be linked to the language chemists use to talk about molecules[1]. Take, for instance, chemical structures. For someone who is initiated to chemistry they are an amazingly powerful way to convey many information about the chemical properties of any compound. At the same time, for a non-specialist it could seem like un untranslatable code[16]. Structures, formulas, chemical equations should not necessarily be avoided, but they must be used with caution since people tend to be deterred by them[28].

HOW ABOUT MYTH-BUSTING?

There is a diffuse idea that one of the main strategies to combat chemophobia would be correcting misinformation about chemicals. Scientists and engineers should «[…] correct the outrageous, distorted or incorrect statements of 'apocalyptic' scientists […]»[30] and state the facts[7,12,15].

> Flat-out denials of the harm a compound can cause, for example, do not lead to reasoned understanding. We forget our opponents already have knowledge they believe is true. Simply asserting facts will not remove this knowledge. If anything, it will further cement the knowledge in their mind[27].

When a myth-busting-centric communication is carried on, mixed responses could develop. When misconceptions about chemicals are talked through rationalistic

arguments, many people can feel disempowered or even attacked in what they strongly believe it is true. Noted that, one must myth-bust with caution.

ANALYTICAL CHEMISTRY AND THE 5-E PRINCIPLE

It has been proposed to integrate analytical chemistry into communication[38]. The analytical problem-solving process can play an important role in the strategy to reduce chemophobia. The authors have identified 5 steps to this process:

1. Identify and define the problem.
2. Design an experimental procedure.
3. Conduct an experiment and gather data.
4. Analyze and treat experimental data.
5. Propose a solution to the problem.

This analytical method is said to play a key role in science and analytical chemistry enables obtaining information for (partially or totally) solving a great variety of societal problems and seeds. This information should be presented responsibly and in an engaging and understandable way. From this need follows the 5-E principle.

> Because chemophobia is an emotion, we argue that it can only be cured by an emotion[38].

The authors propose the 5E-principle which can be summarized as follows: Educate, Emotionally Engage, Entertain and Energize. The communication should avoid technical terms. and the communicated message should be introduced by relating it to everyday life. Unusual explanation or unconventional point of view are encouraged. Chemists should adopt an energizing, proactive, and tension-free manner and maintain a high level of energy during the dialogue[38].

THE MAGIC BULLET

A parallelism between chemophobia and poisoning is drawn and «chelation therapy», with the idea of a «magic bullet» that can selectively attack the toxin is used as a metaphor to describe the fight against «chronic chemophobia»[37]. Chemists should be thought to be good communicators; they should be able to select which knowledge to transfer, to put it in the right context and to find the best way to transfer said information. Chemist ought to

become preceptor, knowledge broker and imparter. This strategy refers to chemists working in industry and is founded on the idea that employees are the most effective disseminators of corporate communication messages and that, in time of crisis, internal communication should precede external communication[37].

HEROES OF CHEMISTRY

Since a prerequisite for a dialogue with the public is to gain its attention, the "heroes of chemistry" approach is suggested to be an effective way of grabbing attention, focusing on the human side of chemistry[17,28]. This strategy is proposed to serve two purposes: on one side, providing a storytelling-centered communication, it should capture the public's imagination; on the other side, it could counteract the proposed "crisis of identity of chemists". An illustrative and emotional language should be used in presenting stories about chemists portrayed as heroes of science. This should support a positive perception of the profession of chemistry and should also offer a positive example for self-identification, thus strengthening the identity of the chemist[17].

GREEN CHEMISTRY

Over the last two decades, the chemical industry has undergone a major restructure, following the principles and practices of green chemistry, and forming the bases for a sustainable chemistry[23,47]. Green chemistry has been defined as «a kind of antichemophobic cure created by the chemical community»[31], as its principle are in direct contrast to what we have suggested to be the rational roots of chemophobia. Green chemistry provides an approach to discover new ways of producing the same or similar molecules with desirable properties but with zero waste and zero pollution[43]. Green chemistry is more of a new philosophy of chemistry, rather than a new type of chemistry, one focused on the reduction of risk, and especially on the reduction of hazard[43]. Implementing green chemistry principles in laboratorial experiences, could also help pupils overcome chemophobia and the anxiety of handling chemicals[41].

SCHOOL AS A SOLUTION

It has been proposed that strategically-structured chemical education programs, focused on the basics of chemistry and with emphasis on the benefits brought by chemical

products, should be put in place in order to empower chemical literacy - and so counteract chemophobia[18,23]. The role of teachers is said to be fundamental to fight chemophobia[18,26]. They should dispel some of the most common chemical myths, they should explain the difference between synthetic natural compounds, and they should emphasize the contribution of chemistry to the modern society[26]. When approaching chemical education, it has been suggested to include, along with the core chemistry knowledge (composed of the macroscopic, symbolic and molecular dimensions), the human element of chemistry (which is usually overlooked) and the environmental sustainability dimension[23]. This approach should focus on simple ideas and provide students with the basic understanding of chemistry needed to take part constructively on current debates on scientific issues: a «chemistry for all vision»[23]. Since chemistry learnt at school tends not to be perceived as relevant in everyday life[28], it could prove useful to teach a more essential and pragmatic chemistry , trying not to put people off chemistry during their learning years[37].

In Russia, two strategies proved to be quite efficient in attracting young generations of students towards the study of chemistry[4]. The first strategy consisted in the *Chemical Olympiads* at a national and international level; city winners received the right to be registered as students of the Moscow State University's department of chemistry – and other institutions - without previous examination. The second (and most effective) way to attract youth to chemistry was the organization of special chemical groups for students in their last two school years. It consisted of seven weekly hours (lectures, seminars, and laboratory sessions) organized by the Moscow State University's department of chemistry and carried out by associate professors. These classes where completely free of charges and, together with the *Chemical Olympiads,* helped a gradual increase in students wanting to study chemistry in university[4].

Adult learners are also a public that must be considered. They actively make decisions that affect their community and would immediately benefit from scientific knowledge and critical thinking[65]. A mentorship program developed by universities aimed at adults seeking a high school equivalent degree and focused on hands-on activities, has proved to be a feasible and appreciated way to communicate chemistry[65].

Hands-on activities are also a successful way to communicate science to young children[50]. They allow children to get a direct and visible reaction to their actions and, when combined with storytelling and drawing, they proved to be a useful instrument of informal learning for elementary schools[50].

Schools can also be a way to target adults[66]. Students can be invited to attend lectures or demonstrations in the evenings, which could be a way to hook the parents into accompanying them. Finally, the use of hands on activities has proven helpful to counteract the adult's apathy and passiveness especially if combined with the peer-pressure of other pupil-parent groups. Marketing events to school children achieves widening participation as a by-product and evaluations through questionnaires recorded it to be a highly positive experience[66].

When assessing undergraduate students, the realization of YouTube videos was found to be a powerful educational tool[67]. Students reported a better recall and a more enjoyable experience compared to the colleagues who wrote an article. This approach serves both education and outreach and should be considered when discussing didactic of chemistry. Similarly, cross-disciplinary summer art programs proved useful to students and were very appreciated by the community[33].

INFORMATION VS AFFECT

To understand which communication (or teaching?) strategy is more useful in reducing chemophobia, informational of affect-based, researchers carried out an experiment[34]. Both were hypothesized to be useful since an understanding of basic toxicological principle was negatively correlated with chemophobia and since in the absence of knowledge people rely on heuristic – such as the affect heuristic – for risk evaluation.

A final sample of 448 participants was divided in three groups: control, affect and knowledge. Every group was shown a different 2 minutes and 40 seconds' video:

- The control group was shown an unrelated video about black holes.
- The affect group was shown a video about the widespread use of chemicals to portray their beneficial role in everyday life and destigmatize chemicals.

- The Knowledge group was shown a video explaining basic toxicological principles based on the authors previous findings[29,35,58].

Then the researchers measured chemophobia, knowledge of basic toxicological principles[29], affect towards chemicals benefit perception of the use of chemicals and preference for natural substitutes (***Figures 8-12***). Chemophobia was assessed adapting the previously used measure[35]; a Likert scale (1 = “strongly disagree”; 6 = “strongly agree”) was used and the seven items were:

1) I do everything I can to avoid in my daily life contact with chemical substances.
2) I would like to live in a world where chemical substances don’t exist.
3) Chemical substances scare me.
4) I am scared of chemical substances I cannot pronounce.
5) In a world with no chemical substances, there would be no environmental disasters.
6) The chemical industry is responsible for more people suffering from cancer
7) I would like all chemical substances to be risk-free

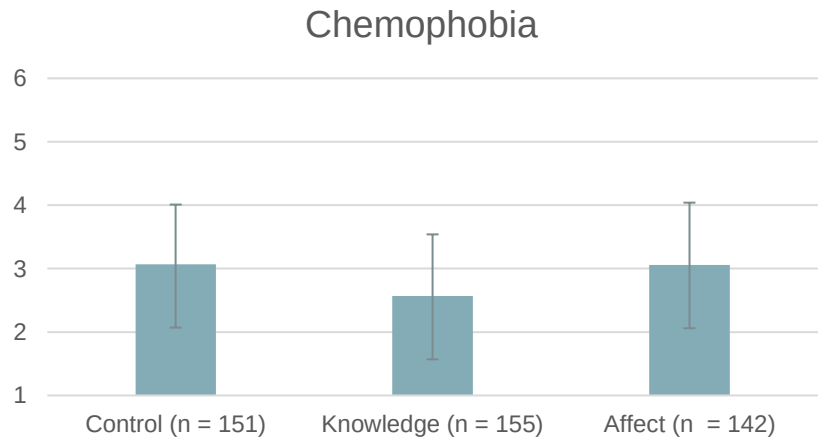

Figure 8 *Means of chemophobia by groups (adapted)[34].*

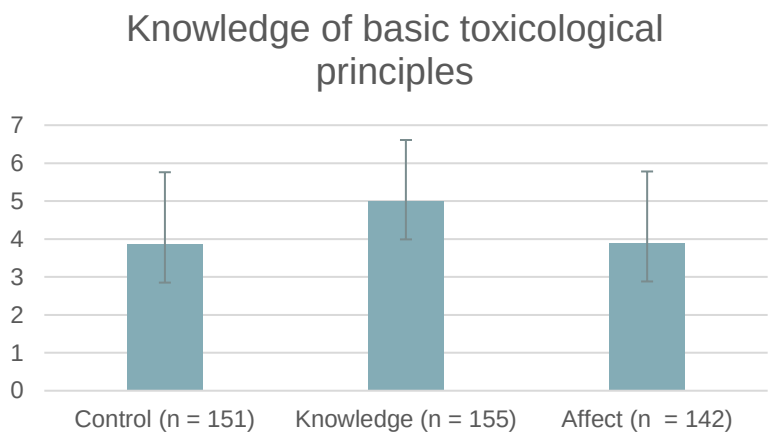

Figure 9 *Means of knowledge of basic toxicological principles by groups (adapted)[34].*

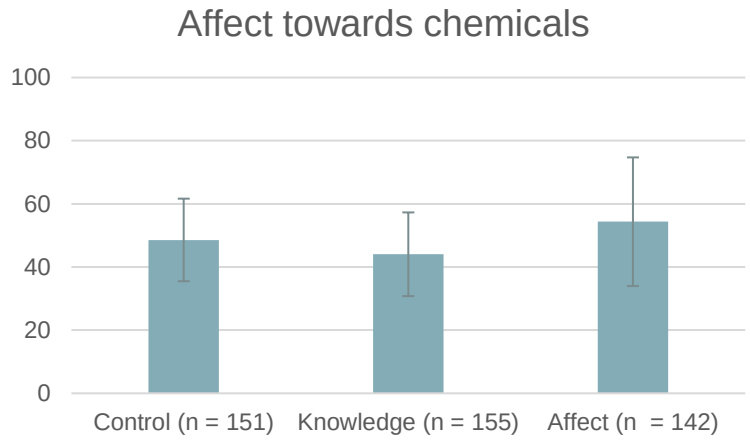

Figure 10 *Means of affect towards chemicals by groups (0 = negative; 100 = positive) (adapted)[34].*

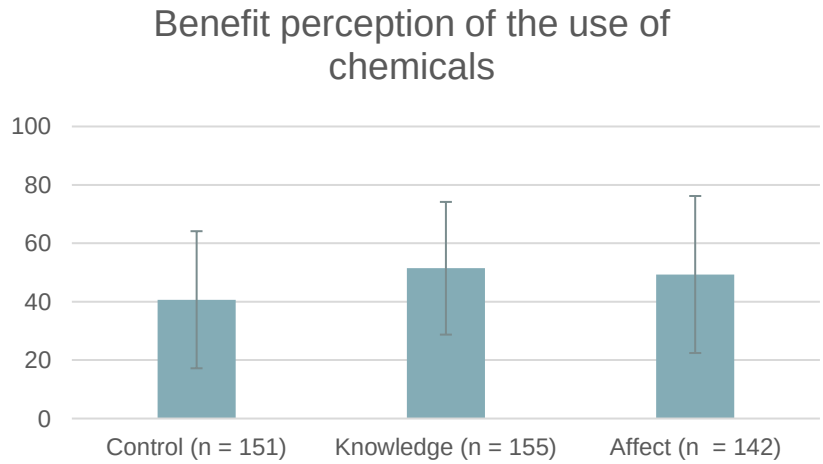

Figure 11 *Means of benefit perception of the use of chemicals by groups (adapted)[34]*

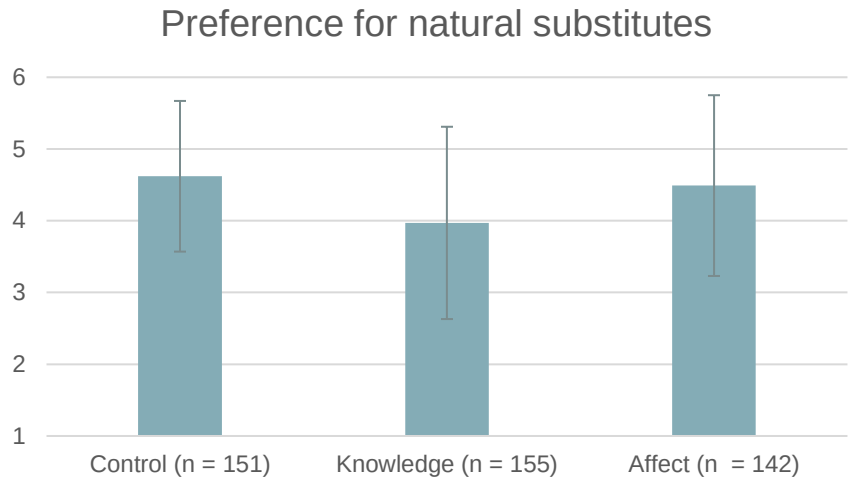

Figure 12 *Means of preference for natural substitutes (adapted)*[34]

What emerges is that the informational approach decreased chemophobia, increased people's knowledge of basic toxicological principles, increased benefit perception of the use of chemicals and lowered preference for natural substitutes in consumer products. The affect-based approach increased benefit perception of the use of chemicals and the positive affect toward chemicals. The authors acknowledge that literature shows that knowledge about a technology does not usually lead to a lower risk perception or a greater acceptance, but also show that this does not seem to be the case for chemicals[34]. The study shows how the provision of basic toxicological principles should be included when trying to assess chemophobia and how an informational approach should be preferred to a purely affect-based one[34].

CONCLUSION

Addressing chemophobia is not an easy endeavor and requires the collaboration of many fields and entities: from chemistry itself to sociology, from psychology to anthropology, from history of science to epistemology. The literature on the topic is scarce, and mainly composed of anecdotal opinions rather than fact-based argumentations (although it must be said that in the last ten years some remarkably interesting research has been carried out on this topic).

At the moment we can say that chemophobia exists and that it is a phenomenon probably born out of rational basis during the First World War or during the second half of the 20th century with the undeniable impact of the chemical industry on human health and the environment – and with a pivotal point in 1962 with the publication of Silent Spring by Rachel Carson. Chemophobia is then thought to be fostered by misrepresentation and underrepresentation by the media and by the absence of an honest *mea culpa* by the chemical industry in the aftermath of accidents. Chemophobia does not seem to affect the public perception of chemistry as a discipline, which is seen quite positively (or, at least, with neutrality) and of chemists that - even considering the existing confusion in Britain with pharmacists - are considered good, intelligent people. Chemophobia can therefore be defined as «the irrational fear of chemicals», but – in doing so – it must be remembered that laypeople have a narrow definition of «chemical», as a man-made substance, usually dangerous or harmful to health[35]. This assumes even more significance in light of the fact people believe that the chemical industry puts profit before societal good and look at it with skepticism.

The only possible solution to chemophobia comes through education and communication. On one side chemists must actively work on communicating their research in ways that are approachable to non-specialists[16], and on this there is an evolving and rich literature on effective strategies to communicate science which chemist and science communicators should be – at least – aware of[1,16].

> If we consider chemistry as a culture developed by specific people, a threefold interconnection characterizes the identity of chemistry: the connection within the chemical community, its language, and public perception of the discipline. Therefore, we should also understand chemistry as a form of communication and eradicate the distinction between the creating and communicating of knowledge[38].

To use a chemist-friendly metaphor, chemical communication should be approached like a retrosynthesis. One should start from the target, forgetting the idea of the existence of a general public and thinking about the presence of many publics with their own values, knowledge beliefs and motivations, and then work backwards to design the most appropriate communication strategy[16]. When communicating chemistry, one must engage in a two-way process with the audience in a co-construction of common significance. The audience should therefore become part of the communication process. The chemist should talk in a simple way of tangible things, maybe talking about his/her job or about themselves as individuals – and not only as scientists – trying to find points in common and shared values. In doing so, an informational approach should be preferred to a purely affect-based one and great attention should be put in discussing green chemistry and its contribution to the production of safer and sustainable chemicals.

On the other side, chemistry education in schools should be reshaped, remembering that many people said that they were put off chemistry at school. Chemistry should be taught through simple concepts and with the use of concrete practical examples, that are relevant to the student's everyday lives. It could be helpful to include in the curricula basic notions of toxicology, sustainability, and the human aspect of chemistry. The existence of the other kind of chemophobia, the anxiety generated by chemistry courses, should also be kept in mind, and further studied.

Our knowledge of chemophobia is far from comprehensive, further studies are needed to better understand its extent, origins, and possible solutions.

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APPENDIX

The results found in Web of Science (W), Scopus (S) and PubMed (P) are reported here. The 'x' marks their presence in the database. Results are also color coded. White ones are included in the review; red ones have being excluded after the abstract reading because they were not considered relevant; yellow ones have been excluded after abstract reading because relative to chemophobia as the anxiety related to chemistry courses; grey ones are duplicates; orange ones were not found or written in Czech.

W	S	P	Authors	Year	Title
x			Hoover, J. M.; Lee, J.; Hamrick, T	**2020**	Community Engagement In Science Through Art (Cesta) Summer Program
x	x		Guerris, M; Cuadros, J; Gonzalez-Sabate, L; Serrano, V	2020	Describing The Public Perception Of Chemistry On Twitter
x	x	x	Chalupa, R; Nesmerak, K	2020	Chemophobia Versus The Identity Of Chemists: Heroes Of Chemistry As An Effective Communication Strategy
x	x	x	Saleh, R; Bearth, A; Siegrist, M	2020	Addressing Chemophobia: Informational Versus Affect-Based Approaches
x	x	x	Shelomi, M	2020	Who's Afraid Of Deet? Fearmongering In Papers On Botanical Repellents
x	x		Tarasova, Np; Makarova, As	2020	Green Chemistry And Chemophobia
x	x	x	Kwon, Sa; Yoo, Hj; Song, E	2020	Korean Consumers' Recognition Of Risks Depending On The Provision Of Safety Information For Chemical Products
x	x		Eisberg, N	2020	Chemophobia
x	x	x	Saleh, R; Bearth, A; Siegrist, M	2019	Chemophobia Today: Consumers' Knowledge And Perceptions Of Chemicals
x	x	x	Siegrist, M; Bearth, A	2019	Chemophobia In Europe And Reasons For Biased Risk Perceptions
x			Webster, R; Hardy, Mc	2019	Finding The Central Science
x	x		Chalupa, R; Nesmerak, K	2019	Chelation As A Metaphor For The Effective Fight Against Chemophobia
x	x	x	Bearth, A; Saleh, R; Siegrist, M	2019	Lay-People's Knowledge About Toxicology And Its Principles In Eight European Countries
	x		Why Communicating Chemistry Can Be Complicated	2019	Acs Symposium Series
x	x		Hrudey, Se; Hrudey, Ej	2019	Common Themes Contributing To Recent Drinking Water Disease Outbreaks In Affluent Nations
x	x	x	Lee, Bm; Kwon, S; Cho, Ym; Kim, Kb; Seo, K; Min, Cs; Kim, K	2019	Perspectives On Trace Chemical Safety And Chemophobia: Risk Communication And Risk Management

x	x	x	Lee, Bm; Kwon, S; Cho, Ym; Kim, Kb; Seo, K; Min, Cs; Kim, K	2019	Perspectives On Trace Chemical Safety And Chemophobia: Risk Communication And Risk Management
x	x	x	Lee, Bm; Kwon, S; Cho, Ym; Kim, Kb; Seo, K; Min, Cs; Kim, K	2019	Perspectives On Trace Chemical Safety And Chemophobia: Risk Communication And Risk Management
x	x		Chalupa, R; Nesmerak, K	2018	Analytical Chemistry As A Tool For Suppressing Chemophobia: An Introduction To The 5e-Principle
			Koch, D	2018	Chemophobia - Simply Semantics Or Something Deeper?: How To Have A Discussion With A Non-Scientist
x			Serban, Bc; Buiu, O; Bumbac, M; Nicolescu, Cm; Cobianu, C	2018	Chemistry - The Journey From Central Science To Chemofobia; How Should We Address This?
x	x		Chalupa, R; Nesmerak, K	2017	Johann Wolfgang Von Goethe And Chemistry
x			Gagnon, Nl; Komor, Aj	2017	Addressing An Overlooked Science Outreach Audience: Development Of A Science Mentorship Program Focusing On Critical Thinking Skills For Adults Working Toward A High School Equivalency Degree
x	x	x	Connett, P	2017	Water Fluoridation Is Fluoride Chemophobia?
x			Kurbanoglu, Ni; Takunyaci, M	2017	Development And Evaluation Of An Instrument Measuring Anxiety Toward Physics Laboratory Classes Among University Students
x			Chlumova, K; Tomas, K	2017	What Is Added Into Our Food?
x			Hester, K	2016	Nanotort Liability At Common Law
x			Morrissey, S	2015	Chemistry Reacts To Chemophobia: A Problem Of Public Perception And/Or Communication?
x			Kurbanoglu, Ni; Akin, A	2015	Development Of A Scale To Measure Organic Chemistry Anxiety Level Of University Students
x	x		Morais, C	2015	Storytelling With Chemistry And Related Hands-On Activities: Informal Learning Experiences To Prevent Chemophobia And Promote Young Children's Scientific Literacy
x	x		Chalupa, R; Nesmerak, K	2014	Chemophobia, Public Image Of Chemistry And What Is To Be Done
x	x		Smith, Dk	2014	Itube, You Tube, We Tube: Social Media Videos In Chemistry Education And Outreach
x			Boerner, Lk; Burks, R; Hartings, M; Jones, C; Shanks, K; Stemwedel, Jd; Vanalphen, B	2014	Combatting Chemophobia: Speaking Science To Distrust And Engaging With Empathy, Online, And Face-To-Face
x			Senocak, E; Baloglu, M	2014	The Adaptation And Preliminary Psychometric Properties Of The Derived Chemistry Anxiety Rating Scale
x	x	x	Francl, M	2013	How To Counteract Chemophobia
x	x		Gribble, Gw	2013	Food Chemistry And Chemophobia
	x		Marteel-Parrish A.E., Abraham M.A.	2013	Understanding The Issues
	x		Hill J., Kumar D.D.	2013	Challenges For Chemical Education: Implementing The 'Chemistry For All' Vision

x			Farias, L	2012	Combating Chemophobia
x			Rouhi, Am	2012	Chemophobia And Fire Safety
x			Nelson, Gl	2012	Joe Chemical Plays To Chemophobia
x			Kurbanoglu, Ni; Akin, A	2012	The Relationships Between University Students' Organic Chemistry Anxiety, Chemistry Attitudes, And Self-Efficacy: A Structural Equation Model
		x	Hartings Mr, Fahy D.	2011	Communicating Chemistry For Public Engagement
x			Reisch, Ms	2011	Chemistry Kit Chemophobia, Goof-Proof Golf Balls
x			Mccarthy, Wc; Widanski, Bb	2009	Assessment Of Chemistry Anxiety In A Two-Year College
x	x	x	Edwards, Kt; Goddard, J; Varnado, W	2009	Survey Of Mosquito Control Knowledge, Attitudes, And Practices Among County And Municipal Programs In Mississippi
x			Gephart, Ja; O'donnell, M; Bretz, Sl	2009	From Chemophobia To Green Chemistry: An Analysis Of Marketing Claims In National Geographic Green Guide
x			Fivizzani, Kp	2008	Chas 11-Chemophobia In The Chemistry Curriculum
x			Meloan, Ce	2008	Chemophobia Addressed
x	x		Billington, S; Smith, Rb; Karousos, Ng; Cowham, E; Davis, J	2008	Covert Approaches To Countering Adult Chemophobia
	x		Dini J.W.	2007	Food And Chemical Priorities
x	x		Duffus, Jh; Worth, Hgj	2006	Toxicology And The Environment: An Iupac Teaching Program For Chemists
x	x		Duffus, Jh; Worth, Hgj	2006	Toxicology And The Environment - An Iupac Teaching Programme For Chemists
x	x		Bhanumati, S; Deep, H	2006	Within The Portals Of Green Chemistry: Green Strategies To Manage Curriculum Induced Hazards In Chemistry Laboratories
x	x	x	Ali, A; Rautemaa, R; Hietanen, J; Jarvensivu, A; Richardson, M; Konttinen, Yt	2006	Expression Of Interleukin-8 And Its Receptor Il-8ra In Chronic Hyperplastic Candidosis
x	x		Laszlo, P	2006	On The Self-Image Of Chemists, 1950-2000
	x		Korsten L.	2006	Advances In Control Of Postharvest Diseases In Tropical Fresh Produce
	x	x	Simpson W.M., Brock C.D.	2005	Chemophobia, Family Medicine, And The Doctor-Patient Relationship
	x	x	Simpson W.M., Brock C.D.	2005	Chemophobia, Family Medicine, And The Doctor-Patient Relationship
	x		Degregori T.R., Rogers J.R.	2004	Statistical And Economic Data Analyses For The Impact Of Ddt, Chlorine, Fluoride And Other "Chemicals" On Public Health
x			Reese K.M.	2003	Chemophobia Foe Versus Vanilla Fans
	x		Reed D.	2003	Countering 'Chemophobia'
	x		Wragg P.J.	2003	Approaches To Assessing Risk
			Sanger, Mj; Brincks, El; Phelps, Aj; Pak, Ms; Lyovkin, An	2001	A Comparison Of Secondary Chemistry Courses And Chemistry Teacher Preparation Programs In Iowa And Saint Petersburg, Russia
x	x		Eddy, Rm	2000	Chemophobia In The College Classroom: Extent, Sources, And Student Characteristics

x	x		Maschewsky, W	1999	Mcs - Chemophobia Or Chemical Trauma?
x	x		Berdonosov, Ss; Kuzmenko, Ne; Kharisov, Bi	1999	Experience In Chemical Education In Russia: How To Attract The Young Generation To Chemistry Under Conditions Of Chemophobia
x			Levy, Gb	1999	Chemophobia And Bibliophobia
x	x		Dini, Jw	1999	Chemophobia - Part 2
x	x		Dini, Jw	1998	Chemophobia - Part 1
x			[Anonymous]	1998	'Chemophobia' Offers Lesson To Biotech Industry
x			Romeo, Ga	1998	Chemophobia Concerns
x			Blumberg, Aa	1997	Some Tactics In Controlling Chemophobia.
x	x		Eddy, Rm	1997	Chemophobia In The College Classroom: Extent, Sources, And Student Characteristics.
			Clauchek, Sv; Delaru, Vv	1997	Devising Of The Screening Technique For The Diagnostics Of Inclination To Development Of Induced States
	x	x	Lees-Haley P.R.	1997	Neurobehavioral Assessment In Toxic Injury Evaluations
x	x		Michaelis, Ar	1996	Stop - Chemophobia
x			Worman, Jj	1996	Dispelling Chemophobia Inside And Outside Of The Classroom.
x			Eddy, Rm; Wood, Jt	1996	Preparing Chemistry Teachers And Remediating Chemophobia Through Demonstrations And Experiments.
x	x	x	Leeshaley, Pr	1995	Neurobehavioral Assessment In Toxic Injury Evaluations
x	x		Baggett, G	1993	Causes Of Chemophobia
x	x		Breslow, R	1993	Lets Put An End To Chemophobia
x	x		Zingaro, Ra	1993	Arsenic - A Classic Example Of Chemophobia
	x	x	Marks T.A.	1993	Birth Defects, Cancer, Chemicals And Public Hysteria
	x		Lucke W.E.	1992	Toxicity Of Metalworking Fluids: Myths And Reality - A Chemist's Perspective
x			Fawcett, Hh	1992	Why Chemophobia
x			Susag, Rh	1992	Superfund Site Chemophobia
			Gribble, G	1991	The Chemophobia Conundrum
x	x		Kauffman, Gb	1991	Chemophobia
			Rogers, Lb	1991	Abating Chemophobia - A New Role For Analytical Chemists In The Environmental, Food, Pharmaceutical And Clinical Areas
x	x	x	Infante, Pf	1991	Prevention Versus Chemophobia - A Defense Of Rodent Carcinogenicity Tests
			Heckman, Jh	1991	Packaging Industries And The Food-Additives Amendment - A Reprise
x	x		Silbergeld, Ek	1991	Beyond Chemophobia - A Reasonably Apprehensive View Of Chemical Industrialization And Agriculture
x			Aldridge, S	1990	Curing Chemophobia

x			Saxen, R	1990	A New Phenomenon, Chemophobia
x			Szmant, Hh	1989	An Overview Of Chemophobia
x			Kauffman, Gb	1989	The Origins And History Of Chemophobia
x			Mcclelland, Al	1989	Economic Consequences Of Chemophobia
x			Luberoff, Bj	1989	Is Chemophobia Curable
x			Ware, Sa	1989	Yes Virginia - There Is A Cure For Chemophobia
x			Wahl, Gh; Shaw, Gj	1989	Chemophobia - Problem Or Opportunity
x	x		Cleary, T	1989	Combatting Chemophobia
x	x		Kay, M	1989	Overcoming Chemophobia - A Key Factor In Solving The Missouri Dioxin Problem
x			Sweeting, Lm	1988	Whos Responsible For Chemophobia
x			Taunton, Lr	1987	Fighting Chemophobia
x			Jueneman, Fb	1986	Chemophobia
	x	x	Caruba A.	1985	Chemophobia Complicates Pest Control.
x			George, B	1985	Chemophobia - The Hidden Causes
x			Zitter, Ta	1984	Effect Of Citizen Chemophobia On Plant Pathology
x			Mackinnon, Am	1983	Chemophobia - An Industry Under Attack
x			Jackson, Em	1982	Chemophobia
	x		Scott Pattison E.	1981	Rampant Chemophobia
	x		Szmant H.H.	1981	For Erradicating Chemophobia
	x		Mackinnon D.	1981	Chemophobia
x			[Anonymous]	1978	Chemophobia - New Disease