Perception of Chemistry and Chemistry Education: a Case Study and Some Reflections

Giulia Chiocca [1] and Valentina Domenici [2,*]

1 Downlands Community School, Dale Avenue Hassocks, West Sussex BN6 8LP, (UK);
E-mail: Chioccagiulia@hotmail.it
2 Dipartimento di Chimica e Chimica Industriale, via Moruzzi 13, 56124, Pisa (Italy);
E-mail: valentina.domenici@unipi.it
* Correspondence: valentina.domenici@unipi.it; Tel.: +39-050-2219215.

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Abstract:
Perception of chemistry in the general public has been object of several investigations in the past, putting in evidence the diffusion of neutral or negative attitudes, which can be summarized in the so-called 'chemophobic' behaviour. In the present study we analysed the results obtained from a structured survey aimed to intercept Italian young people and to investigate the relationships among their chemistry perception, school experiences and chemistry background. The complete questionnaire was made of 29 questions (25 multiple choice questions and 4 open questions) and the analysis of results was performed on 431 participants, which were selected among initial 627 ones to exclude chemists or students in chemistry. The investigated sample gives a snapshot of Italian young people of medium-high school education, and it reveals a general not-negative perception of chemistry, but a relatively low engagement toward chemistry-related subjects. Interestingly, most people are aware of the role of chemistry teachers and school experiences in their attitude toward

chemistry and, at the same time, the participants to the survey demonstrated to have a relatively poor knowledge of the main concepts of chemical science. These aspects may be helpful for chemistry educators at different levels, from primary schools to the universities.

Keywords: image of chemistry; image of science; perception of chemistry; chemistry knowledge; communication of chemistry; chemistry education.

1. Introduction

Chemistry is one of the most important branches of science since the knowledge of basic concepts of chemistry is as essential for further studies in chemistry-related fields as well as for approaching other sciences, such as natural science, biology, biochemistry, physics, environmental sciences and geology.[1] Most importantly, it enables learners to understand what is happening in the World around them and to use a scientifically critical approach to evaluate and assess the information about different topics related to chemistry that they may encounter every day in newspapers, television programs or in the context of a conversation. Moreover, a good knowledge of chemistry can help people to debunk conspiracy theories and other counterproductive scaremongering attitudes, as those referred as 'fake news'.[2] Despite its importance in daily life, chemistry is often considered a difficult subject by those ones who approach this science as beginners.[3,4] Is this merely a prejudice or is there a reason behind this mistrust towards chemistry? Why is it considered such a challenging field of study? Nowadays, the bulk of the population has a fairly sceptical attitude towards science in general.[2,3] This does not refer to the scientific kind of scepticism, which is based on enquiry, empirical research and reproducibility of results, but a general mistrust of the solutions offered by science, giving chemicals a reputation as 'unnatural', 'artificial' or 'poisonous'.[2,5,6] In the marketing world this tendency is exploited to improve the sales of so-called 'natural' products.[6] Another term which is often used by organic companies is 'chemical-free', an extremely misleading claim which rings absurd for any professional scientist, if not for others. The word 'natural' is often used to imply 'healthier' and 'safer'. This is misleading because many natural substances are neither healthy nor safe (e.g. nicotine or arsenic). Chemical scientists use 'natural' to describe substances that are derived from Nature. The word 'synthetic' is sometimes used to mean 'unpleasant' or 'dangerous', however, it simply means 'man-made'. A similar word, 'artificial', implies, in addition, that a chemical does not occur naturally, whereas 'synthetic' may refer to naturally occurring chemicals that are copied by humans with industrial or laboratorial processes.[2,7] Another misused word is 'contamination', which is frequently used to imply harmful effects.[8] However, just because a substance is found somewhere it does not normally occur, this does not necessarily mean it is having a detrimental effect. Making the public aware of how words are misused by the media is a very powerful tool in the fight against scientific misinformation and it is necessary to improve the way chemistry is seen by the public.[9]

In their article, "Communicating Chemistry for Public Engagement", Matthew Hartings and Declan Fahy[10] affirm that chemistry's bad reputation is due to 'chemophobia', a word invented by Pierre Laszlo, who is both a chemist and a populariser of science, to describe the evident trend in the words that people associate with chemistry, such as "poisons, toxins, chemical warfare, alchemy, sorcery, pollution, and mad scientists".[11] One of the consequences of chemophobia is that people working in creative fields, such as television, cinema or publishing, avoid associating the word 'chemistry' with the title of their products, fearing that consumers will keep their distance due to bad hangovers from school days or a fear of chemicals.[2,7]

Chemophobia has several definitions, such as: "an irrational aversion to or prejudice against chemicals or chemistry", "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".[2,7,12-15] This social phenomenon has been linked both to a "well-founded concern over the potential adverse effects of synthetic chemicals", and to "an irrational fear of these substances because of misconceptions about their potential for harm".[16] Different organizations define the word chemophobia in different ways. The IUPAC (International Union of Pure and Applied Chemistry) describes chemophobia as an "irrational fear of chemicals".[17] For the American Council on Science and Health, chemophobia is a fear of synthetic substances arising from "scare stories" and exaggerating claims about their dangers prevalent in the media.[17] Chemistry professor Pierre Laszlo, who is famous for his work on scientific popularization, writes that historically, chemists have experienced chemophobia from the majority of the population, and he "considers it to be rooted both in irrational notions and in genuine concerns (such as those over chemical warfare and industrial disasters)".[11] Chemists made a great deal of effort to counteract chemophobia,[18,19] particularly with regard to educating consumers on the safety of food additives and prepackaged foods.[15] Other counteractions, such as improved communication of science[10,14] or strategies for tackling adult chemophobia, are described in the literature. Many different organisations also tried to fight this attitude and restore a positive image to chemistry. In the United Kingdom, several associations, such as the Royal Society of Chemistry (RSC),[20] and in Italy, the *Società Chimica Italiana*,[21] are working to debunk misconceptions and other counterproductive attitudes towards chemical issues. A very significant action was carried on by the Royal Society of Chemistry in 2015, when a deep investigation about the perception of chemistry in UK[22] was performed. This was the first national, in-depth study on how the UK public thinks and feels about chemistry, chemists and chemicals. The aim of this study for the chemists of RSC was to achieve a better understanding of how chemistry is perceived by the general public. A result that came as quite the surprise to professional chemists is that, on the whole, the public has a much better opinion of chemistry, chemists and chemicals than was expected. People also recognize the positive contributions of chemistry both to their daily life and to economic growth and are fairly certain that the benefits of chemistry far outweigh any harmful effects.[22] Based on this study, the Royal Society of Chemistry released a communication toolkit.[23] Taking the key findings of the study as a springboard, the guidelines of this toolkit were written to help professional chemists to communicate more efficiently in various contexts with their public. The study showed a fairly widespread feeling of ambivalence towards chemistry that causes a lack of both engagement and understanding of chemistry. Although people recognize its positive role in the betterment of society, chemistry is still considered a difficult and, frankly, dry subject to study.

The guidelines suggested by the RSC[23] were designed to cover the weak spot of the public attitude towards chemistry, especially the lack of emotional connection and the lack of confidence found in the public. To establish a personal link with chemistry, professional chemists should let their passion for chemistry shine through when they discuss it. According to these documents,[22,23] the enthusiasm perceived by the public could help them to relate more positively to chemistry, viewing chemists as individuals with passions and interests rather than the cold, detached image of a scientist, thereby helping to build a feeling of familiarity.

An interesting work concerning the public perception of chemistry in the general public was published by Guerris *et al.* in 2020.[9] This study was based on the analysis of more than 200 thousand tweets on the social network 'Twitter', containing the words "chemistry", "chemical" or "chem". From this study[9] the authors reported a prevalence of topics related to the learning environment, activities and tasks in chemistry courses, and human activities related to chemical industry. Interestingly these short messages contained more positive than negative perceptions of chemistry. However, chemophobia-related terms were present in large amount.

In the Italian context, the image of chemistry was first investigated in 2005-2006 on a selected sample in the context of science museums and, in particular, of museums of chemistry,[24,25] revealing a relatively low impact of these contexts in the general public, mainly due to several limitations of these non-formal contexts (i.e. low number of visitors, lack of funding, …). On the other hand, the strong relationship among these science museums and schools, from primary schools to the universities, has been often demonstrated to be effective in rising the engagement of people toward chemistry, to change the visitors' perception, and to get better the learning and teaching of chemistry.[25-29]

In the present paper, we report the complete results of the analysis of an on-line survey which was designed to investigate the perception of chemistry among young Italian people and to explore the relationship of the image of chemistry with previous school experiences and chemistry knowledge.

Preliminary and partial results were published in the Italian journal '*La Chimica nella Scuola*'.[30] The results of this survey are interesting since they indicate a correlation between the image of chemistry of the participants and their previous school experiences, as well as to their knowledge about basic principles of Chemistry.

2. Materials and Methods

2.1 The structure of the survey

The survey was structured into three parts: the first is concerned with the personal details of the subject (6 questions); the second is about the perception and image of chemistry (15 questions); the third is about the subject's chemical knowledge and awareness (8 questions). The complete questionnaire made of 29 questions (25 multiple choice questions and 4 open questions) can be found in the Appendix A.

First part. The personal information and requested details are age, gender, educational history and current occupation. The study specifically targeted young people (for our purposes, 18-40 years of age). Also, the questions about the subject's chosen educational field help to characterize the survey population, giving a full and rounded picture of the target audience at hand. Of particular interest is secondary education specialization, that is to say which type of school the subject chose, be it an academic secondary school (scientific or humanistic high school), or a technical / professional school, as well as the prevalent subjects taught, such as sciences, art, humanities, economics, technology etc. Further on, the test subjects are asked to specify their choice of university course. Finally, the survey asks about their current occupational status (student, employed, unemployed). These pieces of information are essential to create a faithful image of the test population and to analyse the data collected coherently.

Second part. The second part of the test focuses on the perception and image of chemistry. It seeks to investigate specifically what people associate with chemistry, how they feel about it and how important they consider its role in daily life. Further questions deal with their relationship with chemistry as a school subject, the problems encountered when they studied it and the role of the teachers. People are asked to state how confident they feel about discussing a chemistry-related topic, which applications of chemistry interest them and where they normally encounter chemistry-related topics. A few of these questions were inspired by those in the study released in early June 2015 in the UK by the Royal Society of Chemistry.[22]

Third part. In the third part of the test, knowledge of chemistry is assessed. The questions are about simple general chemistry topics and are related to their applications in daily life. People are asked to assess their own scientific knowledge, e.g. the definition of a scientific theory, the differentiation of physical from chemical changes, identifying the right molecular representation of a simple reaction, separating substances from mixtures of substances and finally, calculating the concentration of a solution. The final section examines popular attitudes towards the presence of chemicals in everyday life.

2.2 The participants

The survey was published on-line, and it was spread through social networks, such as Facebook, Twitter and YouTube.[30,31] In about two months, 627 people answered to the survey. For the analysis of data, people who was studying or studied chemistry or chemistry-related subjects (such as pharmacology or pharmaceutical chemistry) have been excluded from the survey population in order not to skew the results of the study. After removing those test subjects, the overall sample size is 431 participants.

2.3 The analysis of the survey

The survey was built on a google form so that the statistical analysis could be performed simply by using Excel. Further elaborations of the collected information were performed with free visualization tools, such as Voyant tools.

3. Results

3.1 An overview of the personal information data

The personal information data collected conveys the image of a very young population (Figure 1a): around 82% are under 30 years old and 50% are between 18 and 24 years old. Therefore, the age range that we wanted to target specifically has responded satisfactorily and we are able to draw conclusions applicable to the Italian youth.

As far as the highest level of education completed goes, about half the subjects (51%) only finished their secondary education and 27% finished their undergraduate studies. The rest of the population sample obtained a postgraduate degree or a PhD (Figure 1b). However, this suggests that our sample cannot be considered representative of the average Italians, as other statistics show that in Italy a not insignificant number of students leave the high school before completion. The majority of people who took the test were still studying during the survey (Figure 1c): 68% are students, working students or PhD students, revealing a population which is still largely in education, thereby providing us with a fairly representative picture of the Italian school system.

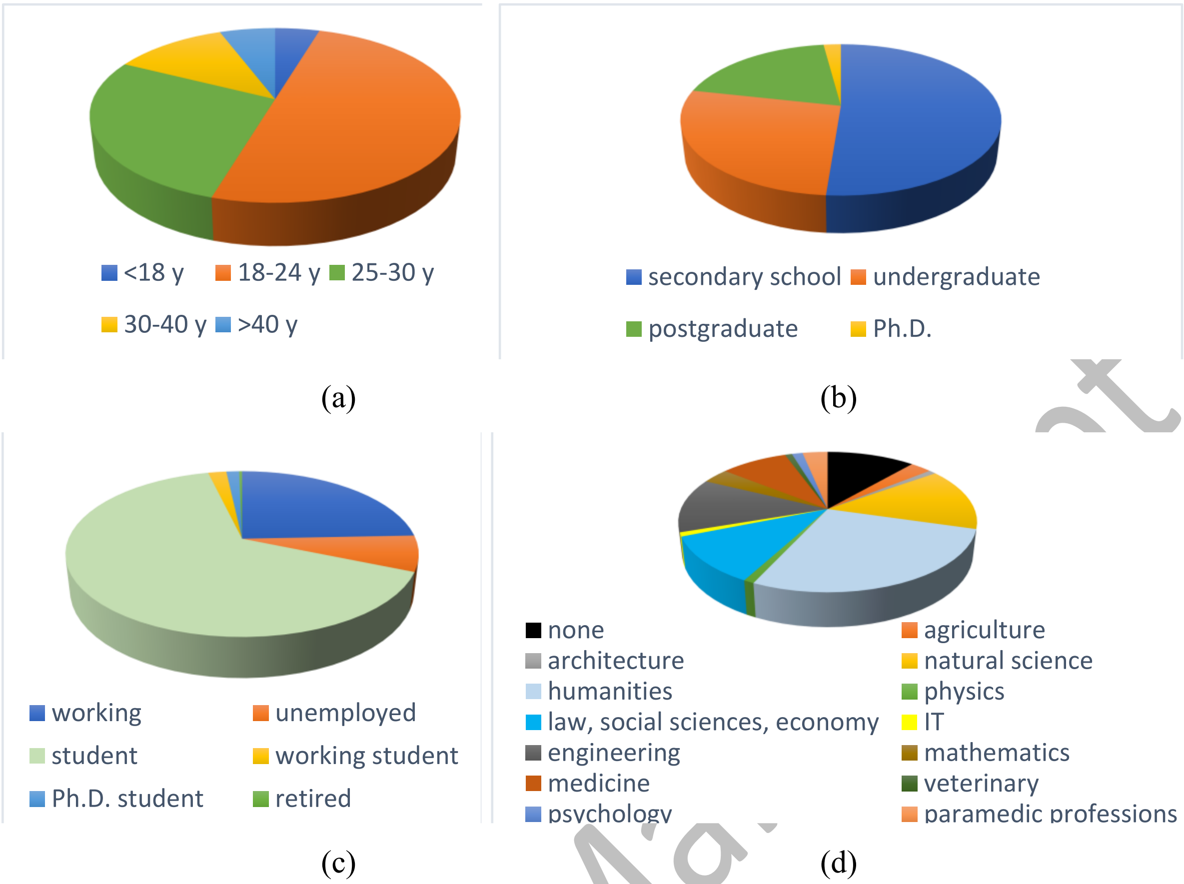


Figure 1. (a) Age distribution of the population sample; (b) Highest level of education completed at the moment of the survey; (c) Current occupation; (d) Area of University study. Note that 'IT' stays for 'Information Technology'.

Moreover, 58% of the population attended a scientific lyceum or scientific technical school at secondary level. About 36% had a humanistic education (classic, linguistic or socio-pedagogic ones). Other areas of educational paths, such as economy, hospitality and professional ones, are underrepresented.

A relatively low percentage of 11% never attended the University, suggesting a broadly well-educated sample compared to the national average. Around 48% of the sample studied or is studying a science-related subject, indicating that they (most probably) studied chemistry up to university level and therefore should have an in-depth knowledge of the relatively elementary topics tested later in the study (Figure 1d).

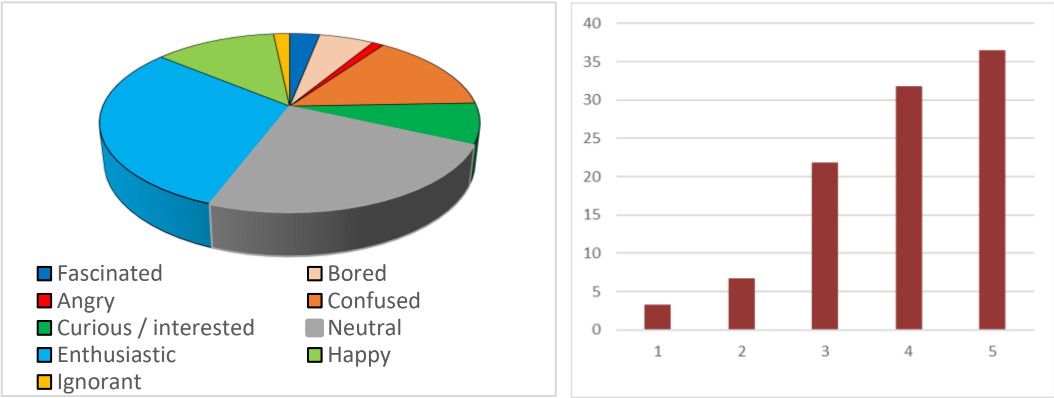
The last question of this first part of the test concerned the gender distribution of the population: it emerged that 67% of the people participating in the study were female, indicating a distinct gender bias.

3.2 An overview of the public attitude towards chemistry

The second part of the test is about the public attitude towards chemistry of the population sample. The first question was an open question asking what people associate with the word 'chemistry'. This question was intended to collect ideas, impressions and thoughts as in a brainstorming activity. By using the Voyant tool a "word cloud" was generated from the text provided, giving more importance and therefore more space to the words that appear more often in the text.[30] Recurrent words include 'chemical', 'periodic table', 'elements', 'matter', 'laboratory', 'school' and 'life'. This trend denotes that most people relate chemistry to memories of the subject as taught at school and it may have trouble shaking off its scholarly image to graduate into real-life. Maybe surprisingly for some chemists, one of the most commonly used words is not 'poisonous', 'harmful' or 'artificial', but 'life', a very positive term which connects chemistry with the vital experience and recognizes chemistry as essential for life. Other words which frequently recur reinforce this idea: 'everything', 'world', 'food', 'interesting', 'good', and so on. One collocation with a moderate recurrence rate is "Breaking Bad", a clear reference to the American television series, which is quite popular among young people in Italy, too. This fact indicates how the media can deeply affect the public's perceptions and way of thinking. Other recurring words include 'biology', 'medicine', 'organic', 'inorganic', 'cosmetics', 'physics', 'research', 'complex' and 'science': this choice indicates that people are aware of the centrality of chemistry in relation to other sciences and its importance in the process of reaching the modern standard of living we are used to.

Afterwards, the subjects were asked how they feel about chemistry. Positively, over 30% feel enthusiastic about it (see Figure 2a). Another key result is that 24% of the population feel neutral about chemistry. A similar trend (but even more emphasized) of neutrality was found in the UK study.[22] Almost 15% of the population assert that they feel confused about it, revealing that chemistry is still regarded as a difficult and puzzling subject to study by a significant part of the population, and this may contribute to and even perpetuate the image of chemistry and chemists as fairly insular.

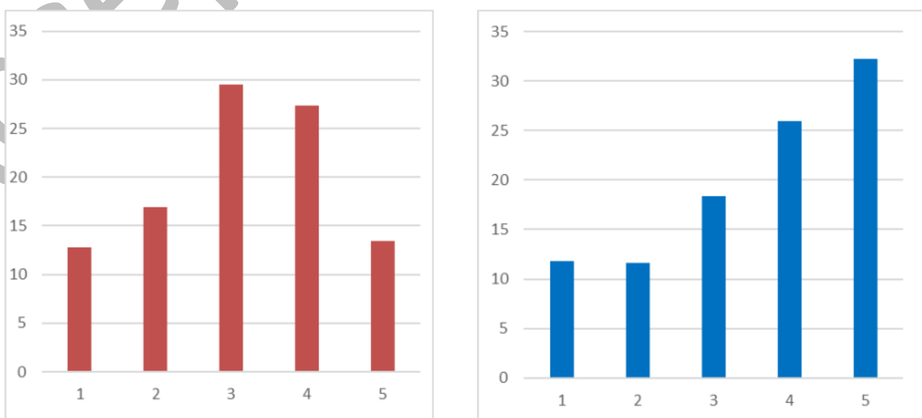
As shown in Figure 2b, another important result is that people consider chemistry essential to our modern way of life: over 68% of the population deem chemistry to be necessary in daily life. Many chemists often feel that the subject to which they dedicated their life is underappreciated or underestimated by the general public,[2,5,7] but this result reveals that the public has a better perception of chemistry than most professional chemists would have guessed. This disparity may represent a generational gap. Those who grew up with a fear of the unknown and the possibilities of chemical warfare may reflect such insecurities onto a younger generation who, in reality, are much better informed and more comfortable with the role of chemistry in daily life, aware that the chemist no longer represents the warmonger, but rather a key part of the production of everything around them.



(a) (b)

Figure 2. (a) Answers to the question 'How do you feel about chemistry?' (b) Distribution of answers, expressed as percentage values, to the question 'How important is chemistry in daily life?' 1 is for 'Unnecessary' and 5 is for 'Necessary'.

In this section we are reporting the results of the survey concerning the participants' previous school experiences with the subject of 'chemistry'. This aspect is important to understand what the role of school is, and, in particular, the influence of chemistry teachers in the perception of chemistry. From the survey, we see that around 30% of the sample had an awful experience with chemistry at school, another 29% had a neutral one and 41% had a good or very good one (see Figure 3a). Another relevant, yet unsurprising, result is that 58% of the population consider the role of the teacher important or very important in learning and studying chemistry (see Figure 3b). This attitude shows the importance of the teacher's education and training as well as his/her teaching skills. To enhance the perception and the knowledge of chemistry among the public, it is essential to keep the teachers up to date with the progress made both in chemistry and in the educational sciences. These results are in line with previous findings based on chemistry teacher training experiences.[24-28]



(a) (b)

Figure 3. (a) Distribution of answers, expressed as percentage values, to the question 'How would you describe your relationship with the study of chemistry?' 1 is for 'awful' and 5 is for 'very good'. (b) Distribution of

answers, expressed as percentage values, the question 'How important has been the role of the teacher in learning and studying chemistry?' 1 is for 'Not important' and 5 is for 'Very important'.

When asked about the problems they encountered while studying chemistry at school, people gave results which provided an interesting insight into the priorities of the Italian educational system (see Figure 4).

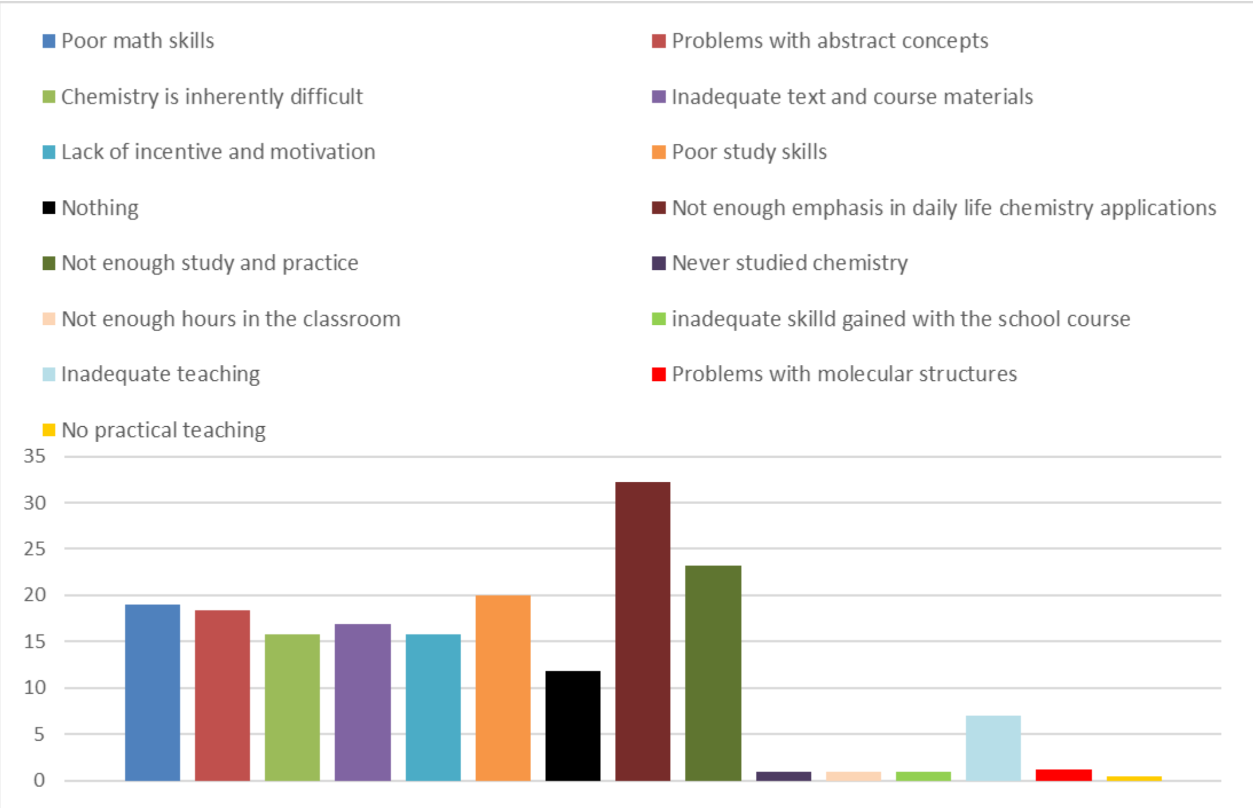
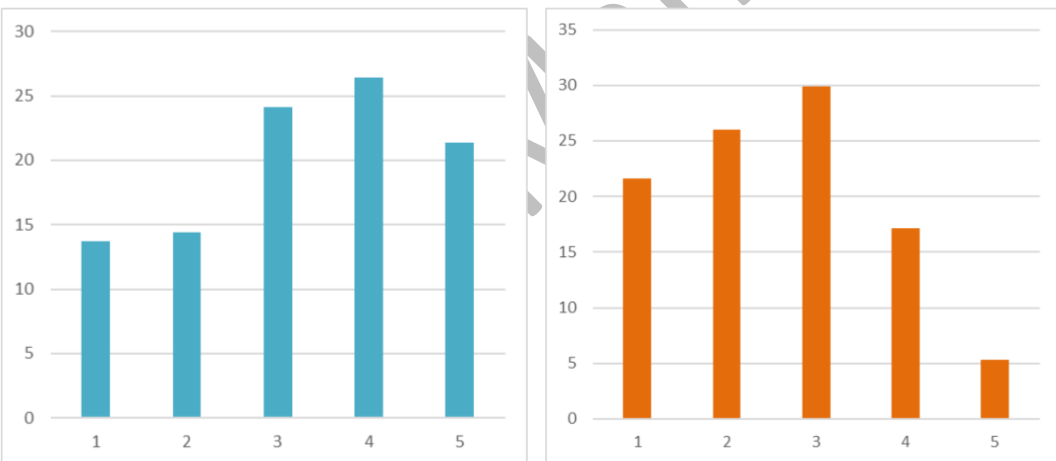


Figure 4. Distribution of answers, expressed as percentage values, to the question 'What kinds of problems have you encountered when studying?' People could select among a series of answers and they could select more than one choice.

Almost a third (32%) agree that there is not enough emphasis on the applications of chemistry in day-to-day life. This finding is particularly relevant for educators, because it suggests to them which path can be followed in order to improve their students' engagement with chemistry as it is taught at school, which, as we have seen, is vital in shaping their lifelong relationship with the science. About 24% selected the answer 'Not enough study and practice', putting in evidence the few hours dedicated to the subject of chemistry, especially in some high schools, and the lack of laboratorial activities and practice. Another result to be taken into consideration for a overall approach to education is that 19% consider their mathematical skill too poor to facilitate a good understanding of chemistry (see Figure 4). This result suggests that educators should make it a priority to verify that the mathematical skills of their students are adequate for the topics they want to cover in chemistry lessons: for example, a poor knowledge of the meaning and implications of the logarithmic function can greatly affect the understanding of pH in chemistry. The problem with abstract concepts, reported by 18% of the public, is well documented in the literature and confirms that the difficulty (confirmed by 16% of the public) of chemistry lies in its highly conceptual nature.[4] A significant 43% of the population relate the problems they encountered with the study of chemistry with more general failings in their approach to their studies, such as poor study skills or not enough practice and study. Also, a lack of interest and motivation, reported by 16% of the public, gravely affects the learning of this school subject.

When questioned about the preparation of chemistry teachers, around 48% consider the teachers well or very well prepared, 24% neither well nor poorly prepared and 28% of the population think that their teachers are not knowledgeable enough (Figure 5a). Some constantly recurring comments written in the free comment area bemoaned the lack of adequate funding dedicated to laboratory work, school syllabi which seem out of date and the large presence of chemistry teachers in secondary schools who trained at the University mainly in biology or natural sciences, rendering them unprepared for the broad range of enquiries that a curious student mind can bring to the table.

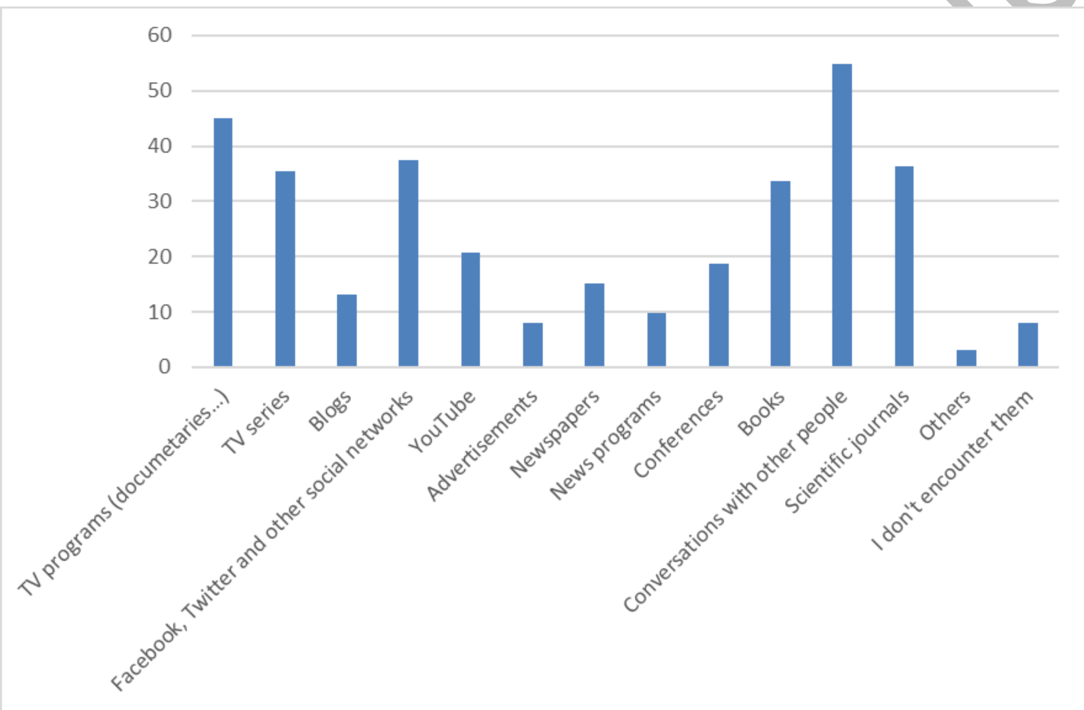


(a) (b)

Figure 5. (a) Distribution of answers, expressed as percentage values, to the question 'How prepared were your chemistry teachers?' 1 is for 'very poorly' and 5 is for 'very well'. (b) Distribution of answers, expressed as percentage values, to the question 'I feel confident to talk about chemistry' 1 is for 'strong disagree' and 5 is for 'totally agree'.

The question summarized in Figure 5b deals with the confidence that people have when discussing chemistry-related topics. The unsurprising result is that only 23% feel confident enough, while 48% don't feel up to confidently talking about a chemistry-related topic and the remaining 30% neither agree nor disagree. This could suggest that whilst a superficial knowledge of some other topics tends to suffice for the purposes of a casual conversation, chemistry is viewed as a more technically in-depth subject which requires comprehension of various aspects for even a low-level discussion.

When questioned about where people encounter chemistry-related topics (see Figure 6a), a surprising 54% talk about it with other people, including friends, family members and colleagues. Social networks and television programs were confirmed to be the most widely used media in modern society, garnering a frequency of 37% and 45% respectively. As previously mentioned, a very important role is also played by television series: 35% of the population encounter topics connected with chemistry thanks to TV series such as "Breaking Bad". 20% find topics connected with chemistry on YouTube, 34% in books and 36% in scientific journals.



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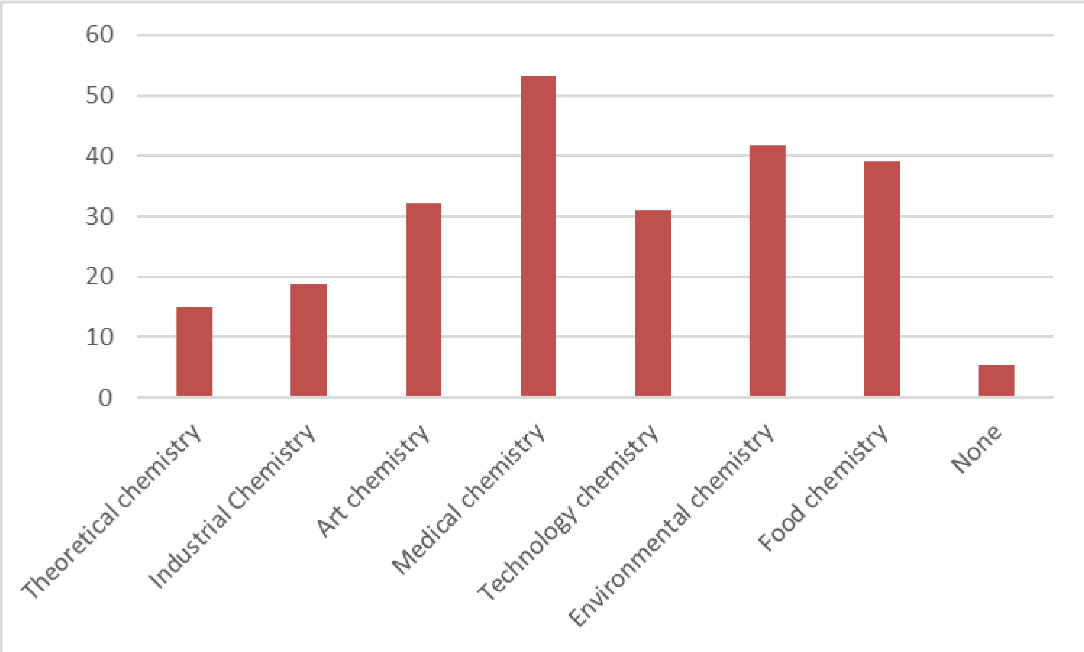


(b)

Figure 6. (a) Distribution of answers, expressed as percentage values, to the question 'Where do you encounter topics connected with Chemistry?' People could select among a series of answers and they could select more than one choice. (b) Distribution of answers, expressed as percentage values, to the question 'Which application of Chemistry are you interested to study further?' People could select among a series of answers and they could select more than one choice.

One of the most important results of the whole study relates to the applications of chemistry that people are most interested in as reported in Figure 6b: 53% are interested in medical chemistry, 42% in environmental chemistry and 39% in food chemistry. These particularly encouraging results reveal that people do not fail to grasp the importance of chemistry for the progress of mankind and they do not only relate it to disasters of the past such as the thalidomide scandals in pharmacology or environmental disasters such as the Bhopal methyl isocyanate gas leak. This attitude shows that people are able to see both the positive side of science and its risks, whilst still believing in the importance of scientific process.

In the next question, people were asked what could be done to improve the image of chemistry (see Figure 7). One of the results was especially striking: 77% of those surveyed think that more lesson time should be devoted to the everyday applications of chemistry. The necessity for more emphasis on everyday applications came out in other test questions previously discussed here. This result should be taken into consideration by educators as it reveals that people would be more engaged with science if they were taught about the many essential and interesting applications it has in everyday life. Another 61% would like more effective collaboration on the part of scientists, both in exposing the general public to chemistry and in providing clearer explanations when discussing the subject, using layman's terms where possible. Chemists and science popularisers are asked to improve their communication skills in order to make chemistry more appealing to the public. This is an important feature underlined in the last two decades by chemists too.[3,10,14]

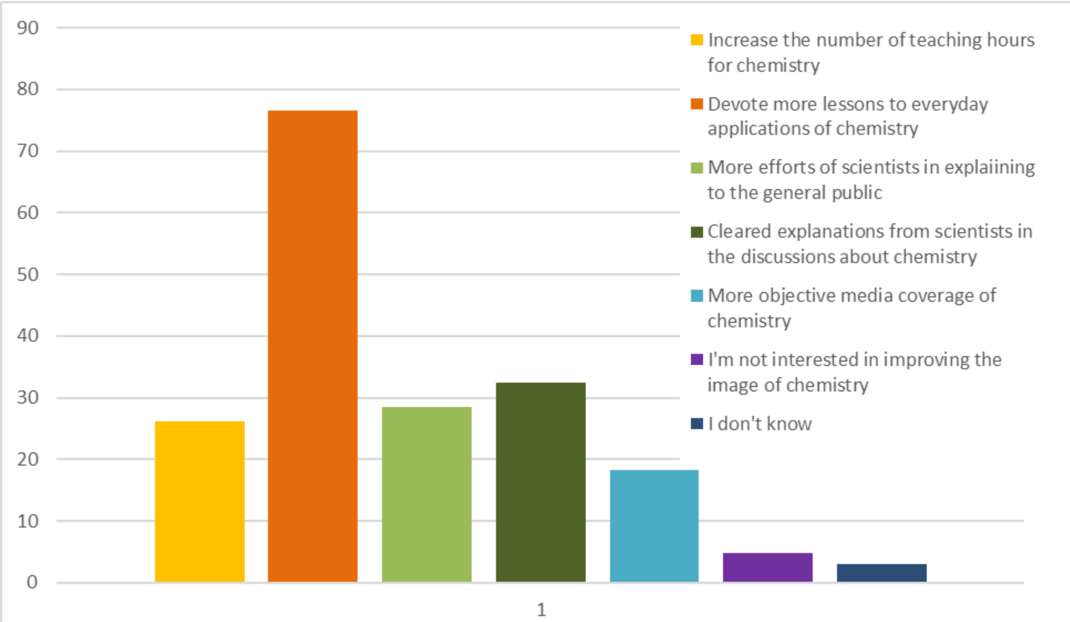


Figure 7. Distribution of answers, expressed as percentage values, to the question 'What could be done to improve the image of chemistry?' People could select among a series of answers and they could select more than one choice.

In the last question of this section, people were asked whether they ever visited a chemical-related factory (Figure 8). The fact that 72% had never visited one reaffirms the lack of experience of everyday applications of chemistry and shows how important it is that schools provide such a formative and informative experience for their students. The chance to see a chemical process with their own eyes can help people to address possible misconceptions that they might have and evaluate chemistry in a fairer way. Moreover, as reported in a recent work,[32] chemical industries have a role in the building of chemophobic attitudes and in the diffusion of erroneous ideas about chemistry. In this respect, the direct knowledge of industrial sites through open-days and other initiatives could be of help in counteracting the chemophobia.

Figure 8. Distribution of answers, expressed as percentage values, to the question ‘Have you ever visited a chemical-related factory?’ People could select among a series of answers and they could select more than one choice.

3.3 An overview of scientific-chemical knowledge

In the third part of the survey, the questions were more focused on the assessment of the chemical knowledge of the participants. Specifically, the first question was a self-assessment in which people had to evaluate their own knowledge of chemistry (Figure 9a). Around 50% of the sample deem their knowledge to be poor or very poor. Another 34% consider it neither good nor poor and only 16% think they have a good command of chemical knowledge.

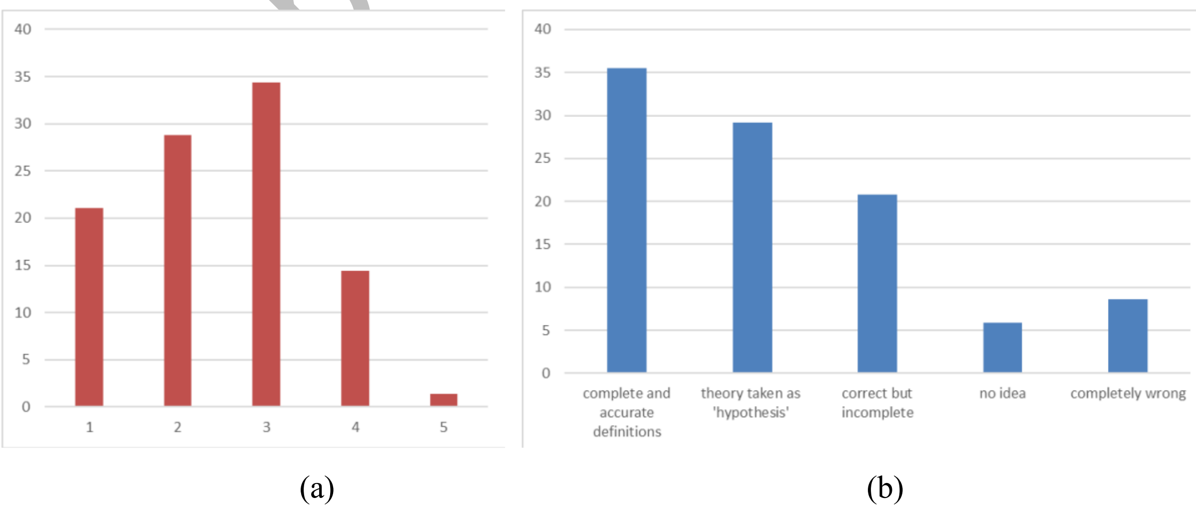
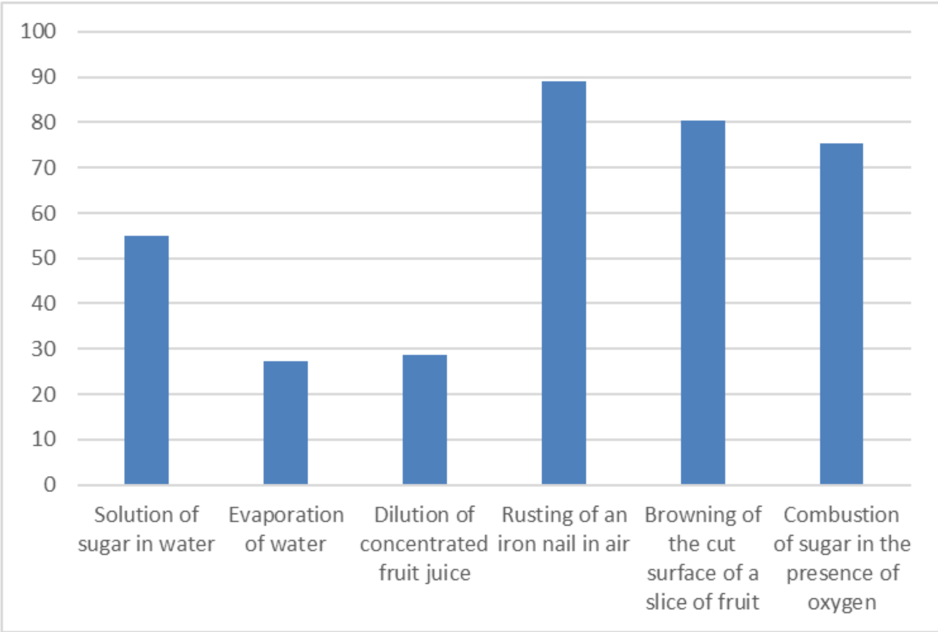


Figure 9. (a) Distribution of answers, expressed as percentage values, to the question ‘How do you perceive your knowledge of chemistry?’ 1 is for ‘completely inadequate’ and 5 is for ‘very good’. (b) Distribution of answers, expressed as percentage values, concerning the participants’ definition of what a scientific theory is’.

The following question asked people to give the definition of a scientific theory. The choice of introducing this open question is related to the diffusion of fake news and the spread practice to confuse scientific and pseudoscientific news.[2] A selection of representative definitions given by the participants is: [A scientific theory is] ‘an hypothesis that is confirmed by an experiment’, ‘a statement used to explain a phenomenon’, ‘an assessment that need to be demonstrated’, ‘an hypothesis about a phenomenon that is not yet falsified’, ‘an opinion on a phenomenon that is based on scientific data which confirm it’, ‘a product of a thinking process which is based on the scientific method’, ‘an hypothesis that can be validated by experiments and scientific evidences’. Overall, 55% gave an almost correct definition, but 21% were not precise enough in the explanation, leaving an incomplete or vague answer. As seen from this selection of definition, a large part of the sample (about 29%) took "theory" to mean "hypothesis" in the context of scientific method; this result is particularly relevant for two distinct reasons. Firstly, a significant part of the population lacks understanding of the scientific method, which is the foundation for any scientific subject. The second and most disconcerting reason is that they literally mistake a scientific theory, which is the most reliable, rigorous, and comprehensive form of scientific knowledge, for a mere "hypothesis". This misunderstanding may lead to a situation where many people say ‘‘evolution is just a theory’’ assuming that this means its basic principles are still debatable. They do not realize that gravity is also ‘‘just a theory,’’ and that, to a scientist, a theory is an explanation of what has been observed.

The following questions are related to fundamental concepts in chemistry. For instance, a question aims to assess the participants’ knowledge of what a chemical reaction is, and if they are able to identify chemical reactions among a series of processes. The results showed in Figure 10a indicate that a large part of the population has problems distinguishing a chemical reaction from a physical transformation: 55% considered the solution of sugar in water to be a chemical reaction when it is in fact a special kind of mixture between two substances. 27% and 29% respectively took evaporation of water and dilution of fruit juice concentrate to be chemical reactions. These results show that a fairly large proportion of the population lacks some basic knowledge of chemistry on topics that are normally explained within the first weeks of secondary school and that are necessary for further understanding of the subject. These results agree with several works reported in the literature showing the diffusion of misconceptions among first year undergraduate students.[33]



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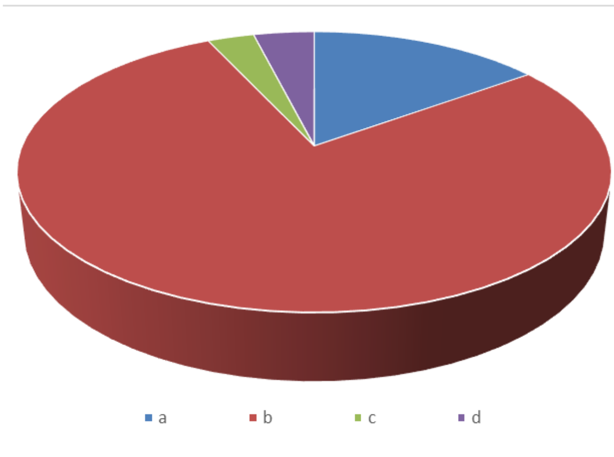

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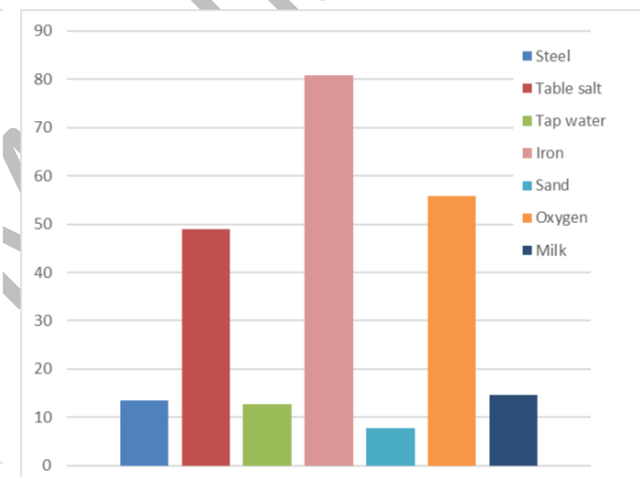


(c)

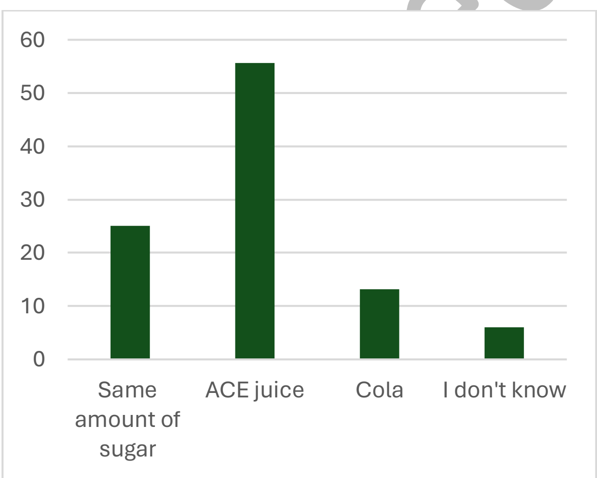
Figure 10. (a) Distribution of answers, expressed as percentage values, to the question ‘Which ones are chemical reactions?’ The right answers are the 4th, 5th and 6th, while the 1st, 2nd and 3rd were wrong answer. (b) Distribution of answer, expressed as percentage values, related to the correct graphic representation of the chemical reaction of hydrogen and nitrogen to give ammonia (see question 24 in the Appendix A). The correct answer is ‘b’. (c) Distribution of answer, expressed as percentage values, concerning the question: ‘Which are substances and not mixtures of substances?’ People could select more than one option.

Another important ability to assess is related to the understanding of the correct link between a chemical formula (with its element symbols) and its graphical representation (referring to a simple particulate model of matter). Given a specific chemical equation which was already balanced, in our case the formation of ammonia (see question n. 24 in Appendix A), people had to identify the molecular representation that most accurately portrays the chemical reaction. This question was also designed to evaluate the ability to pass from a symbolic level to a representational one. Overall, 78% gave the correct answer ('b'), proving that they were able to link symbolism with representation, often considered a particularly difficult skill to acquire for novices (Figure 10b).

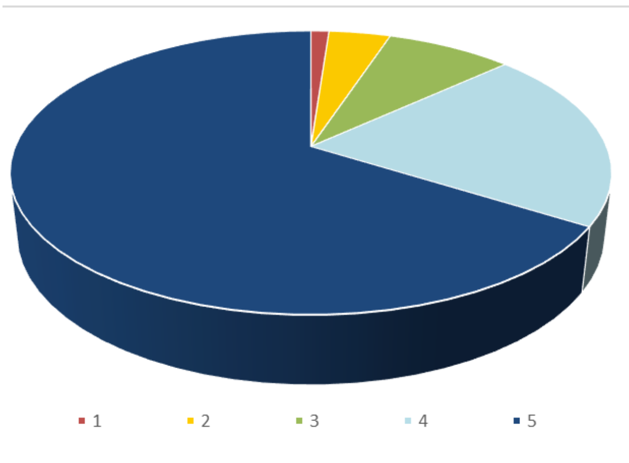
Another key concept in chemistry is that of 'chemical substance'. When asked to determine which are substances and which are mixtures of substances among a series of options, more doubtful results arose, as people often failed to distinguish one from another. As shown in Figure 10c, 81% consider iron a substance (correct answer), but only 56% gave the same answer for oxygen and only 49% for common table salt. A surprising 15% consider milk to be a substance and not a mixture. Sand and tap water are mixtures, too.

In the next question, participants were asked to solve the following problem about dilution: "A 330 mL can of Coca-Cola contains 36.3g of sugar while 100 mL of ACE juice contains 12.1 g of sugar. Millilitre per millilitre, which one contains more sugar?". As seen in Figure 11a, only 56% gave the right answer to this question, yet the solution required only simple mathematical skill, normally acquired around age 11.

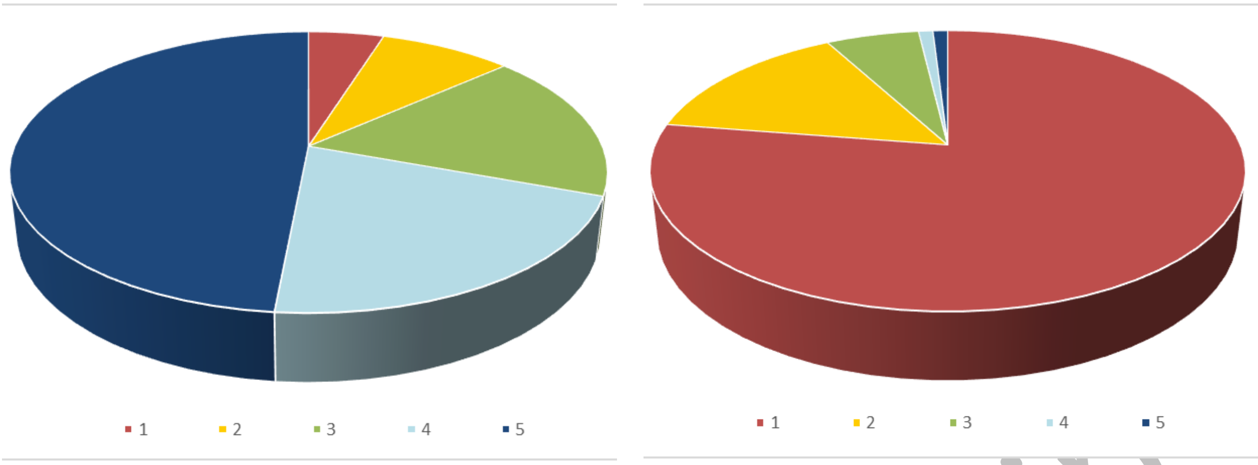
After posing the sorts of questions that participants may have encountered at school, the attitude of the public towards chemicals was investigated. Three different statements about chemicals were presented and people had to agree or disagree with what was said on a scale of 1 to 5 (see Figure 11b). These results are quite encouraging as far as questions about the negative image of chemistry and of chemicals: 89% of the population agreed that everything is made of chemicals.



(a)



(b)



(c) (d)

Figure 11. (a) Distribution of answer, expressed as percentage values, related to the correct calculation of the amount of sugar in the two cans. The correct answer is 'b'. The others are wrong. (b) Distribution of answer, expressed as percentage values, concerning the statement: 'Everything is made of chemicals.' People could select between 1 (strongly disagree) and 5 (strongly agree). (c) Distribution of answer, expressed as percentage values, to the statement: 'Everything, including water and oxygen, can be toxic at a certain dose'. People could select between 1 (strongly disagree) and 5 (strongly agree). (d) Distribution of answer, expressed as percentage values, to the statement: 'All chemicals are man-made'. People could select between 1 (strongly disagree) and 5 (strongly agree).

The final two questions are related to some diffuse misconceptions: the fact that natural substances are all not-toxic and in general safe, and that chemicals are a product of man activities. As seen in Figure 11c, 69% of the population agreed that everything, including water and oxygen, can be toxic at a certain dose, and 92% of the total sample disagreed that all chemicals are 'man-made', as shown in Figure 11d.

These findings relating to the perception of chemicals prove that "when talking about chemicals, most people are not referring to what scientists mean by the same word. The word 'chemicals' is used in everyday language as a shorthand to refer to harmful or potentially dangerous substances. Changing the way people use the word is arguably almost impossible. We should acknowledge that these two different meanings exist, and not worry that people are "getting it wrong". Explaining that 'everything is made of chemicals' will not necessarily change people's views; in fact, the majority of people already know this, and people can hold both meanings of the word as true at the same time.

4. Conclusions

From the results of the study described in the previous paragraphs different conclusions of large-scale effort can be drawn. The young population represented in this study, mainly composed of Italian people under 30 years old with a 67% of female, is not representative of the Italian average population, but it offers a good image of the young Italian generations with medium-high education and so it can also be representative of the state of the Italian educational system.

Although there is a part of the population that feels neutral towards chemistry, the majority have a positive approach towards it, in contrast with a condition of neutrality reported in the UK by the RSC's study.[22] It shows that people with a higher level of education are more passionate about theoretical subjects such as chemistry and that education is the key to winning out over the misconceptions and preconceptions linked with the image of chemistry. A large chunk of the public recognizes the importance of chemistry in daily life, and it judges chemicals in a fair manner, contrary to what was expected due to the frequent misuses of the word "chemicals" in the media. Again, this finding shows that a better-educated public understands the value of science – in this case chemistry – and that it is more prone both to recognize that the benefits of chemistry outweigh any harmful effects and to think critically and rationally about chemistry and its potential, rather than letting the media and other sources influence their opinion about it. Since the majority of people registered an interest in the applications of chemistry that can have a positive impact for mankind's problems, such as those related to the environment, technology, energy supply and medical/pharmaceutical advancements, science educators and popularisers should give more relevance to these subjects when engaging with their public because people feel more passionate about things when they can understand a practical use for them.

The results emerging from this study show an evident lack of confidence in talking about chemistry-related topics (48%), comparable with the UK study (58% for women and 45% for men).[22] This feeling of inferiority can justify the observed lack of emotional engagement, that may also be due both to a lack of exposure to the broad range of possibilities of applied chemistry or to inadequate education. Indeed, a large proportion of the public has issues of some kind when approaching the study of chemistry.

In the public unconscious, the idea of chemistry is primarily linked with memories of school days. Similarly to the British study[22] and to the study of perception of chemistry done through the analysis of tweets,[9] the words most frequently associated with chemistry are: 'molecules', 'laboratory', 'matter', 'elements', 'periodic table', 'atoms', 'reactions' and 'teachers'. Thus, teachers play an important role in shaping a young mind's ability to learn, and the fact that a minor but significant proportion of the public considers the teachers they had to be insufficiently prepared negatively affects the awareness and the interest of their students in the field. Though important, this is not the only cause of a tepid relationship with chemistry – a combination of different contributing factors affects the learning process: from inadequate mathematical skills and problems with abstract concepts to a lack of interest and motivation for the subject, inadequate emphasis on day-to-day life applications of chemistry and the fact that a large majority of the public have never seen a chemical-related factory in real life.

The results from the questions investigating the general public's knowledge of chemistry reveal a few gaps in their cultural formation. Although a large majority of the population (58%) had chosen a secondary educational path in which most of the teaching hours were dedicated to Mathematics and Sciences in general, a lot of the sample failed to provide correct answers to very elementary chemistry questions, such as the identification of a chemical reaction, the differentiation of substances from mixtures and the definition of a scientific theory. This trend did not recur for every topic presented: for example, a good understanding of the relation between the symbolic level of chemistry and the representation of the microscopic level was evident. Overall, the patchy competence shown by the participants when asked to provide answers to simple chemical questions bolsters the premise for the lack of confidence already reported and confirms the public's self-perception of being poorly armed with chemical knowledge. Since a not inconsiderable minority of the public reported problems with the subject caused by a lack of mathematical skills, this finding suggests that certain chemistry topics should be taught only after certain specific goals are achieved in the other complementary scientific subjects, such as mathematics and physics, from which chemistry is ultimately derived.

Since most of the people who took part in this study was still in the educational and professional training system, the picture here represented can give an accurate portrayal of the current situation of the Italian school system and the quality of the education offered to its students, and considering that the population of this study achieved a level of education which is higher than the national average, the results relating to the knowledge of the subject are discouraging, indicating that the quality of teaching needs to be improved and that even the section of the population that has proceeded further in their studies fail to achieve an adequate level of knowledge of chemistry.

Conflicts of Interest: The authors declare no conflict of interest.

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Appendix A

Questions of the survey *(Note that the original questions were in Italian)*

1) How old are you? o <18 years old o 18-24 years old o 25-30 years old o 30-40 years old o >40 years old
2) What is the highest level of education you have completed? o Secondary school o Undergraduate degree o Postgraduate degree o PhD o Other
3) Which type of educational path did you take at secondary level? o Scientific lyceum o Classical lyceum o Linguistic lyceum o Artistic/musical lyceum o Sociopsychological/educational lyceum o Technical institute (economic) o Technical institute (technical/scientific) o Vocational institute (hospitality) o Vocational institute (production and construction) o Other
4) What did you study at university? o I didn't go to university o Engineering o Architecture o Medicine o Veterinary science o Paramedical professions (dietician, nurse, obstetrician, physiotherapist etc.) o Law, Social sciences, Economics o Humanities (Literature, Foreign Languages, History, Philosophy, Communication, Education, Music etc.) o Mathematics o Physics o Natural sciences (including Biology, Biotechnology, Geology etc.) o Pharmacology o Chemistry/Industrial Chemistry o Other
5) What is your current occupational status? o Student o Working o Unemployed o Other
6) What is your gender? o Male

○ Female ○ Other
7) What do you mentally associate with chemistry? (minimum 100 characters) This is a very open question and the reply is purely subjective. Brainstorming is encouraged. (***Open question***)
8) How do you feel about chemistry? ○ Neutral ○ Enthusiastic ○ Happy ○ Confused ○ Bored ○ Sad ○ Angry ○ Shocked ○ Other
9) How important is chemistry in daily life? 1. Unnecessary 2. 3. 4. 5. Necessary
10) How would you describe your relationship with the study of chemistry? 1. Awful 2. 3. 4. 5. Very good
11) What kinds of problems have you encountered when studying chemistry? ○ Problems with abstract concepts ○ Chemistry is inherently difficult ○ Lack of incentive and motivation ○ Inadequate textbooks and course materials ○ Poor mathematical skills ○ Not enough study and practice ○ Poor study skills ○ Not enough emphasis on the day-to-day life applications of chemistry ○ None ○ Other
12) How important has the role of the teacher been in learning and studying chemistry? 1. Unimportant 2. 3. 4. 5. Very important
13) How well-prepared were your chemistry teachers? 1. Very poorly

2.
3.
4.
5. Very well

14) In your opinion, what are the negative aspects of Italian schools? And what would you do to improve them?

(*Optional open question*)

15) "I feel confident enough to talk about chemistry." To what extent do you agree with this statement?

1. Strongly disagree
2.
3.
4.
5. Totally agree

16) Where do you encounter topics connected with chemistry?

- TV programmes (eg documentaries)
- TV series
- Blogs
- Facebook, Twitter and other social networks
- Youtube
- Advertisements
- Newspapers
- News programmes
- Conferences
- Books
- Conversations with other people
- Scientific journals
- I don't encounter them
- Other

17) Which application of chemistry would you be interested in studying further?

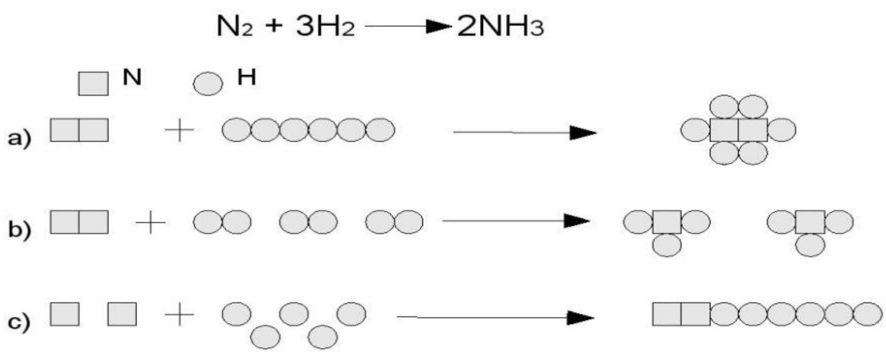
- Theoretical chemistry
- Industrial chemistry (e.g. development of new, environmentally-friendly technology and processes)
- Chemistry of art (e.g. conservation and restoration of artworks)
- Medical chemistry (e.g. development of new drugs)
- Technological chemistry (e.g. development of biodegradable polymers)
- Environmental chemistry (e.g. energy solutions, water purification etc.)
- Food chemistry (e.g. development of agricultural technology to increase production, molecular cuisine)
- None
- Other

18) What could be done to improve the image of chemistry?

- Increase the number of teaching hours for chemistry
- Devote more lesson time to everyday applications of chemistry
- More effort on the part of scientists to expose the masses to chemistry
- Clearer explanations from scientists in the discussion of chemistry
- I'm not interested in improving the image of chemistry
- I don't know
- Other

19) Have you ever visited a chemical-related factory? o I have never visited one o Paper o Glass o Colourants and paints o Fertilisers o Inorganic compounds o Petrol and fuel o Soaps, detergents and cosmetics o Plastic and synthetic fibres o Pharmaceutical products o Explosives o Other
20) Do you have any comments to add about the image of chemistry? (*Optional open question*)
21) How would you rate your knowledge of chemistry? 1. Completely inadequate 2. 3. 4. 5. Very good
22) In scientific terms, what is a theory? Explain in your own words – you need not give a formal or overly elaborate definition. (Open question)
23) Which of the following are chemical reactions? You can give more than one reply. o Solution of sugar in water o Evaporation of water o Dilution of fruit juice concentrate o Rusting of an iron nail in air o Browning of the cut surface of a slice of fruit o Combustion of sugar in the presence of oxygen

24) The equation for the reaction which produces ammonia is written at the top, and the images below show a few possible molecular representations of the reaction…



… which of these is correct?

a)

b)

c)

None of these

25) Which of these are substances and not mixtures of substances?

- Milk
- Iron
- Tap water
- Steel
- Sand
- Table salt
- Oxygen

26) A 330ml can of Coca-Cola contains 36.3g of sugar whilst an ACE juice contains 12.1g of sugar per 100ml. In the same quantity, which of the two drinks contains more sugar?

- Cola
- ACE juice
- Same amount of sugar
- I don't know

27) "Everything is made of chemicals"

Do you agree with this statement?

1. Strongly disagree
2.
3.
4.
5. Totally agree

28) "Everything, including water and oxygen, can be toxic at a certain dose."

Do you agree with this statement?

1. Strongly disagree
2.
3.
4.
5. Totally agree

29) "All chemicals are man-made."

Do you agree with this statement?

1. Strongly disagree
2.
3.
4.
5. Totally agree