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Open digital educational resources for training the chemistry lab safety and security rules

Valérie Camel,^{*1} Marie-Noëlle Maillard,¹ Nicolas Descharles,¹ Even Le Roux,¹ Mathieu Cladière,¹ Isabelle Billault²

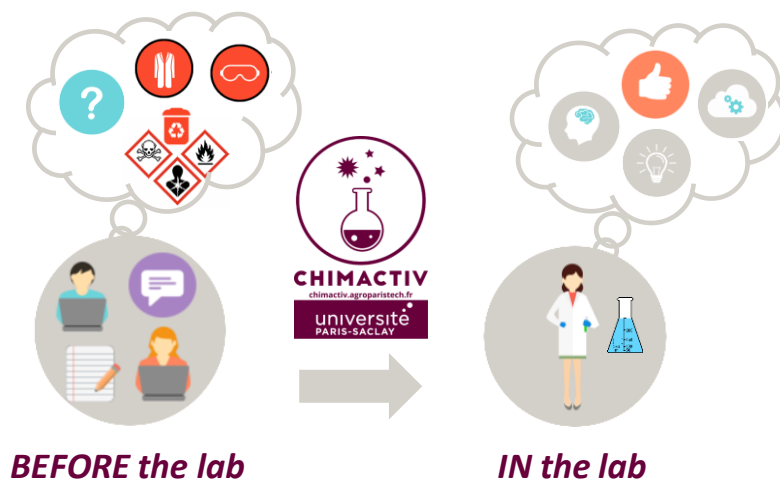
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ABSTRACT

Educational resources that cover essential knowledge related to chemical safety and security rules are
10 openly accessible on the CHIMACTIV website (<http://chimactiv.agroparistech.fr/>). Organized within
two digital sheets, the content covered range from personal and collective protection, from first aid to
handling hazardous chemicals. Being interactive and abundantly illustrated by photos and videos,
these resources may be used by teachers to encourage (or even oblige) their students to self-train
before the lab sessions. Our user experience clearly shows that students improve their chemical safety
15 knowledge and culture upon consulting these resources. Thanks to their digital responsive character,
these open resources may also be accessible during the lab sessions, enabling the students to get the
information “just-in-time”. Also, decision trees for liquid and solid waste management options are
available, helping the students to gain in reflexivity as well as to acquire the right moves during the lab
sessions.

20 GRAPHICAL ABSTRACT



KEYWORDS

General public, Safety / Hazards, Distance Learning / Self Instruction, Internet / Web-Based Learning,
25 Student-Centered Learning

INTRODUCTION

Security and safety rules should be a prerequisite for students and trainers before chemistry lab sessions. However, in our graduated programs we have experienced that a part of our students arrive
30 in lab sessions without deep knowledge of proper behavior to adopt in a chemistry lab. Indeed, they may have different backgrounds, with several degrees of lab experience. They also mostly originate from biological undergraduate programs, with little specific experience of chemistry lab.

Teaching safety rules in classroom before the lab might be boring and uninteresting for students. Besides, the time devoted to such course is lacking in our programs. On the other hand, teaching
35 these rules at the beginning of lab sessions is uncomfortable, with subsequent reduced time for the practical experiments. Besides some safety aspects should be trained before arriving in the lab, such as the appropriate dress code for a chemistry lab. In such a context, we have developed digital interactive resources with a view of enabling the students for self-training before the lab sessions. These open educational resources are easily accessible on any digital consultation device, and
40 attractive due to graphic design and browsing tested previously with students.

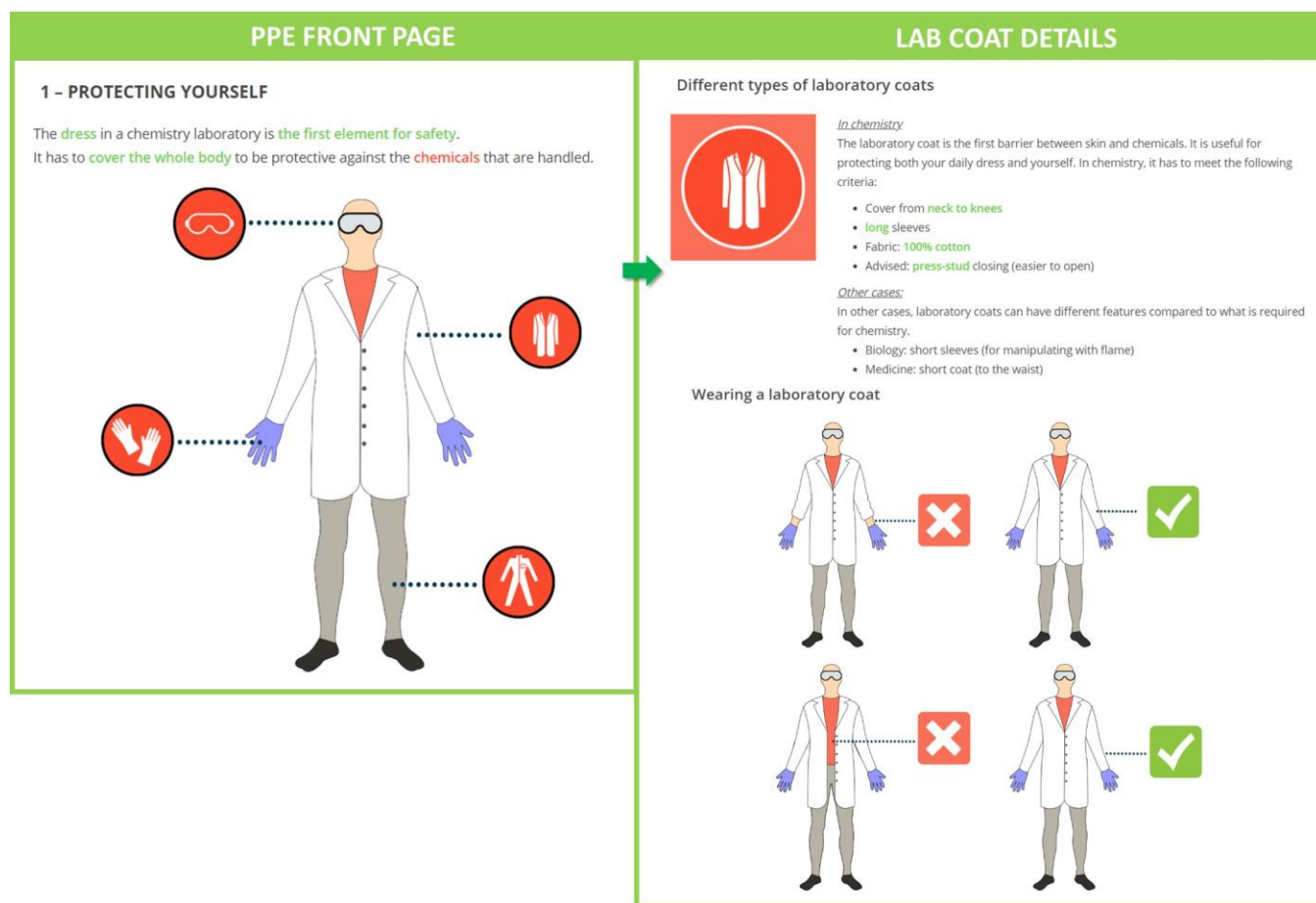
Directly accessible from the website CHIMACTIV (<http://chimactiv.agroparistech.fr/>),¹⁻² two digital sheets are dedicated for training the chemistry lab safety and security rules. The first one is dedicated to protection of persons in the lab. The second one is concerned with the chemical hazards possibly present in the lab, including options for managing wastes. A short survey of teachers of different
45 degrees (from high school to university), carried out during a workshop aimed to get them familiar with the CHIMACTIV website,³ clearly showed their great interest in using these two safety sheets with their students. These first returns prompted us to disseminate the use of these digital resources.

After a presentation of the content of these open interactive resources, their alignment with the RAMP approach proposed by the American Chemical Society⁴⁻⁵ is discussed. Then, consultation data
50 and examples of teaching scenarios for integrating these educational resources are presented, with observed benefits mentioned.

TRAINING BASIC RULES FOR PROTECTING THE OPERATORS

Personal protection

One major point for students lies in adopting adequate behavior when entering the lab. In
55 particular, even though students in graduated programs are very familiar with the lab coat wearing, they sometimes do not have the reflex of closing it properly or removing it when leaving the lab. As illustrated in **figure 1**, the front page related to personal protective equipment (PPE) clearly shows the proper lab coat dressing. Several icons are interactive, to get more details about face protection, protection gloves, lab coat and proper dress.



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Figure 1. The PPE front page, with details shown relative to the lab coat.

Face protection is frequently unfamiliar for the students, or neglected. In particular, we have observed that frequently graduate students do not have a positive attitude regarding eye protection, since they are convinced that the operations they will have to do are safe and/or they will operate safely so that there is no risk for their eyes. They must be trained to understand that safety glasses are mandatory in the lab for any person present, even if he/she wears eyeglasses. Protection glasses are presented, with also recalling prohibition of wearing contact lenses in the lab since this is generally unknown by our students. Hair protection is also presented. Using masks in appropriate cases is also detailed.

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For protection gloves, very few students know the different types that do exist, and which one they should use depending on the experiment and reagents or solvents they will have to deal with in the

lab. So, we detail the main types of gloves they may find in a lab, with their possible applications. In that way, students are more aware of this critical part of their protection.

75 Adapted dress is also detailed, since we have experienced students coming in the lab sessions with shorts or open shoes, especially during the summer time. Preventing such at risk dress is essential to protect them from possible skin contact with splashes or spills, and this starts with proper education before the lab sessions.

Collective protection

80 Since safe individual behaviors are mandatory to protect all the group present in the lab, important knowledge is also given relative to collective protection means. As shown in **figure 2**, we have divided this section in three parts: bench, room and hood.

The room section is useful to remind the students to take care of their bags and personal belongings with appropriate storage. This is sometimes tricky to achieve in practice due to the lack of
85 dedicated spaces in the chemistry laboratories. Yet, this is highly important to prevent incidents or even accidents and injuries given the number of students handling at the same time in the laboratory. The ban of eating and drinking is also recalled, as well as the ban of running or smoking in the lab.

In the bench part, students are warned of the importance of well organizing the space on the laboratory bench to prevent any spilling or other incident due to lack of space. They are also advised to
90 indicate on any glass container the nature of the filling as well as its concentration to prevent from improper mixing and risk of exothermic reaction.

To complete the collective protection part, indications about fume hood are also presented. Firstly, the simple operation to switch the aspiration on is illustrated. Then, the good laboratory practice (GLP) relative to the correct position of the window pane is also shown thanks to illustrative photographs
95 and short recommendations.

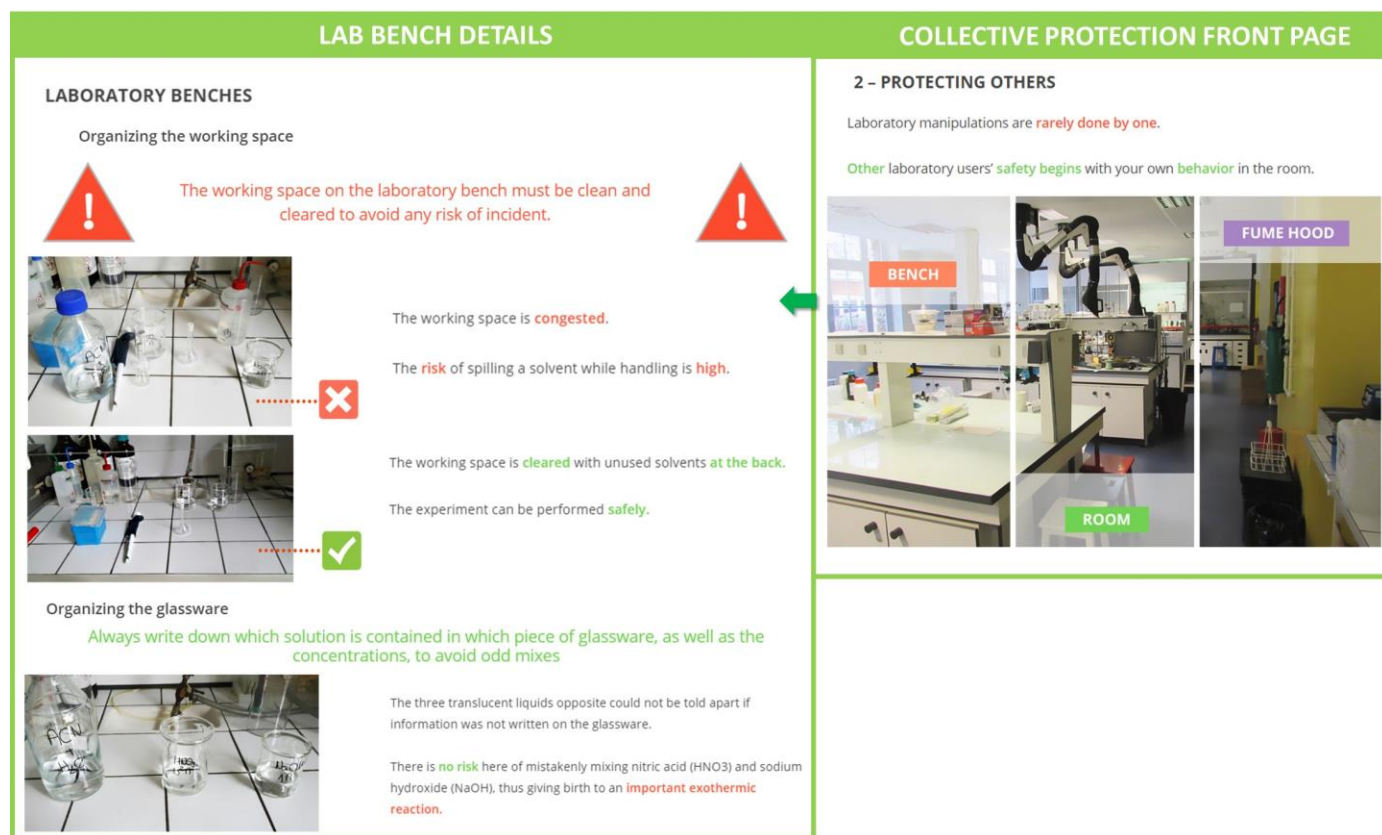


Figure 2. The collective protection front page, with details shown relative to the bench safety recommendations.

First aid

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In case of incident or accident occurring in the chemistry lab, some emergency actions should be taken. First aid actions to assist the possible victim are listed on one hand (see **figure 3**), such as rinsing the injured eye opened under a cold or warm trickle of water, while on the other hand rescue devices are presented (fire extinguishers, emergency shower, eye wash and fire blanket). The purpose is rather to get the students knowing the different devices that exist than to detail the operating

105 instructions for each item. Being trained to the particular environment of a chemistry lab is a prerequisite for adopting safe and secure behavior.


EMERGENCY TECHNIQUES DETAILS

Incidents	Emergency Techniques
Swallowed products	<ul style="list-style-type: none"> Rinse the mouth Do not drink Do not encourage to throw up
Projections in the eyes	<ul style="list-style-type: none"> Rinse the opened eye under a cold or warm trickle of water, while leaning the head and keeping the contaminated eye below the wholesome eye
Thermal burns	<ul style="list-style-type: none"> Rinse immediately under a trickle of cold water for 15 minutes Keep the clothes that are stuck to the skin
Chemical burns	<ul style="list-style-type: none"> Rinse immediately under a trickle of cold water Remove the contaminated clothes without touching the face
Cuts	<ul style="list-style-type: none"> Compress locally to stop the hemorrhage Have the victim sit and reassure the victim
Fire	<ul style="list-style-type: none"> Smoulder the fire On somebody: lay the person down and cover the person with a fire blanket
Irritating or toxic gas inhalations	<ul style="list-style-type: none"> Get the victim out and breathe fresh air


FIRST AID FRONT PAGE

If an accident could not be avoided first aid techniques must be applied. There are two types of techniques:

- The techniques to dispense to the victim
- The use of the rescue devices



First Aid



Rescue devices

Click on the different elements to get more information

During the experimental sessions, it is a priority to alert as fast as possible the teacher who will take care of the victim and dispense the first aid techniques.

Figure 3. The first aid front page, with details shown relative to emergency techniques in case of incidents.

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Illustrative videos

To help the students integrating the different recommendations and advices presented previously so as to adopt a safe and secure behavior in the lab and during the experiments, two short videos are proposed. They both show one operator entering the lab, and starting some basic manipulations. The video “A bad day of experimental works” shows unsafe behavior or actions to ban, while the video “A good day of experimental works” shows the safe and secure behaviors and actions to adopt in the lab. We believe that showing the unsafe behavior is complementary and as important as presenting the proper behavior. Videos are supposed to be humoristic, in order to better mark the memory of the viewers.

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HANDLING DANGEROUS CHEMICALS

Recognizing the types of chemicals

Obviously, having knowledge about the chemicals is essential to prevent the students to make errors that might result in incident like damage or injury. We have distinguished three essential parts that merge in the front page of this section as shown in **figure 4**: the hazard pictograms according to the global harmonized system (GHS) of classification and labelling of chemicals,⁶ the chemicals categories, and their storage conditions.

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Training students to get familiar with the hazard pictograms is crucial. In addition to ensuring adapted managing options in the lab, it also contributes to help them having similar safe behavior in

other contexts such as at home when they use biocides for example. As illustrated in **figure 4**,
130 pictograms are gathered in three groups, depending on the damages: physical hazards (such as
explosion, corrosion, etc.), human health damage (such as reprotoxicity) and chemicals that are toxic
for the environment (for example toxic for aquatic life). Whenever adequate, some pictograms merge in
two groups. All the pictograms are interactive, so that the lecturer can get into some details about the
meaning of the pictogram as well as the hazard statement according to the international labeling
135 regulation (see the example of corrosive substances in **figure 4**). Information relative to health toxicity
is further detailed with all the hazard statements listed and some caution for safe handling given.

CHEMICALS FRONT PAGE

HAZARD PICTOGRAMS (CLP)

CHEMICALS

CHEMICALS STORAGE

HAZARD PICTOGRAMS DETAILS

Hazard pictograms

Since 2008, on a European scale, the "Classification, Labelling and Packaging of substances and mixtures" regulation (EC 1272/2008, also known as the CLP regulation) have standardised the existing hazard pictograms and also changed the hazard and precautionary statements. In this way, with those new rules, the hazard pictograms come systematically with numbers that refer to hazard statements (e. g. H200, H315). Those hazard statements allow to identify more precisely what the substance may cause, whereas the hazard pictograms allow to identify the hazard category. Thus, it is important to know and to be able to find rapidly the meaning of the pictograms and the statements.

In this regulation, the hazards are divided in three categories: the physical hazards, the health hazards and the environmental hazards.

Always read the label before using a chemical

Health hazards

Environmental hazards

Physical hazards

Pictogram	Meaning	Ex. Hazard statements
	Corrosive substances	H290 May be corrosive to metals

Figure 4. The chemicals front page, with details relative to hazard pictograms and focus on the corrosive substances pictogram.

140 From the front page the visitor can also access to knowledge of the different types of chemicals (i.e. organic solvents, reagents, toxic products, acids and bases). Each type is further detailed in specific pages. Briefly, most common organic solvents are listed as their categories (e.g. alcohols, esters), and the need of caution for handling them under a fume hood due to their properties (such as volatility) and toxicities is also clearly exposed. Then essential information relative to acids and bases is given on

145 a separated page, especially that they may be either organic or mineral, present different physical states, and exert strong or weak proton affinity. The need for wearing PPE and manipulating under fume hood is also clearly claimed here.

Caution about the reactivity of some chemicals is detailed in another page of this safety sheet, with examples of chemical reactions concerned as well as details about the relative hazards labelling and
150 statements.

Finally, proper storage conditions are recalled in the last part of this sub-section of the safety sheet. Besides elementary storage conditions in a chemical hold, details are also given for storage conditions in the laboratory (i.e. in the fridge or under the fume hood). A table of chemical compatibility for storage is also given, depending on their labelling pictograms.

155 **Managing liquid wastes**

Proper management of liquid wastes is mandatory in the lab. Yet, students are not very familiar with this side of the safety rules. Besides, management actions depend on the type of liquid or mixture, being thus quite uneasy for them.

On the CHIMACTIV website, we alert students to the requirement for being very careful when they
160 throw away a chemical liquid in order to avoid any hazardous reaction upon mixing chemicals (thereby avoiding incident or accident in the lab) as well as prevent environmental contamination. Then we give simple and practical advices or recommendations (“What I must throw in”/ “What I can throw in”/ “What I must not throw in”) for the main categories of liquid wastes encountered in chemistry labs as illustrated in **figure 5**: non-halogenated organic solvents, halogenated organic solvents, toxic liquids,
165 organic and mineral acidic liquids, organic and mineral basic liquids. Finally, practical advices and recommendations relative to the ways of properly and safely throwing the liquid wastes in the adapted containers are detailed.

To help the students getting familiar with the proper waste option depending on the liquid waste considered, an interactive decision tree is proposed as shown in **figure 5**. It is entirely extractable in a
170 pdf format, enabling the students and their professors to keep this decision tree on their own digital devices or to print it, thereby favoring them to well manage liquid wastes whenever they are in the lab.

LIQUID WASTES FRONT PAGE (extract) INTERACTIVE DECISION TREE FOR LIQUIDS (extract)

Liquid wastes

All of the solutions used in a laboratory **must be sorted and thrown away in an adequate collecting container**. The sorting of liquid wastes is very important because **depending on the type of chemicals collected in the container, the elimination treatments will be different (just like the price!)**.

Just like the storage, it is important **not to mix incompatible chemicals to avoid any reaction**.

Decision tree to sort your liquid waste

The liquid wastes containers that are encountered are the following:

NON-HALOGENATED ORGANIC SOLVENTS

What I must throw in:
Solvents that does not contain chlorine, fluorine, bromine
E. g. alkanes, alkenes, alcohol, nitrile, ester, ether, glycol ether, ketone

What I can throw in:
Toxic organic solutions concentrated less than 0.1% w/w

What I must not throw in:
Organic and mineral acids and bases
Halogenated organic solvents
Toxic organic solutions concentrated more than 0.1% w/w
Aqueous solutions

HALOGENATED ORGANIC SOLVENTS

What I must throw in:
Solvents that contain chlorine, fluorine, bromine
E. g. dichloromethane, chlorobenzene, bromopropane

What I can throw in:
Toxic organic solutions concentrated less than 0.1% w/w
Non-halogenated organic solvents

What I must not throw in:
Organic and mineral acids and bases
Toxic organic solutions concentrated more than 0.1% w/w
Aqueous solutions

175 Figure 5. The liquid waste front page, with some details of the interactive decision tree for choosing the best options for sorting liquid wastes.

Managing solid wastes

This sub-section is organized in a similar way as the previous one related to liquid wastes as depicted in **figure 6**. From the front page an interactive decision tree is accessible to help finding the best management option, which is readily extractable and printable for a convenient use.

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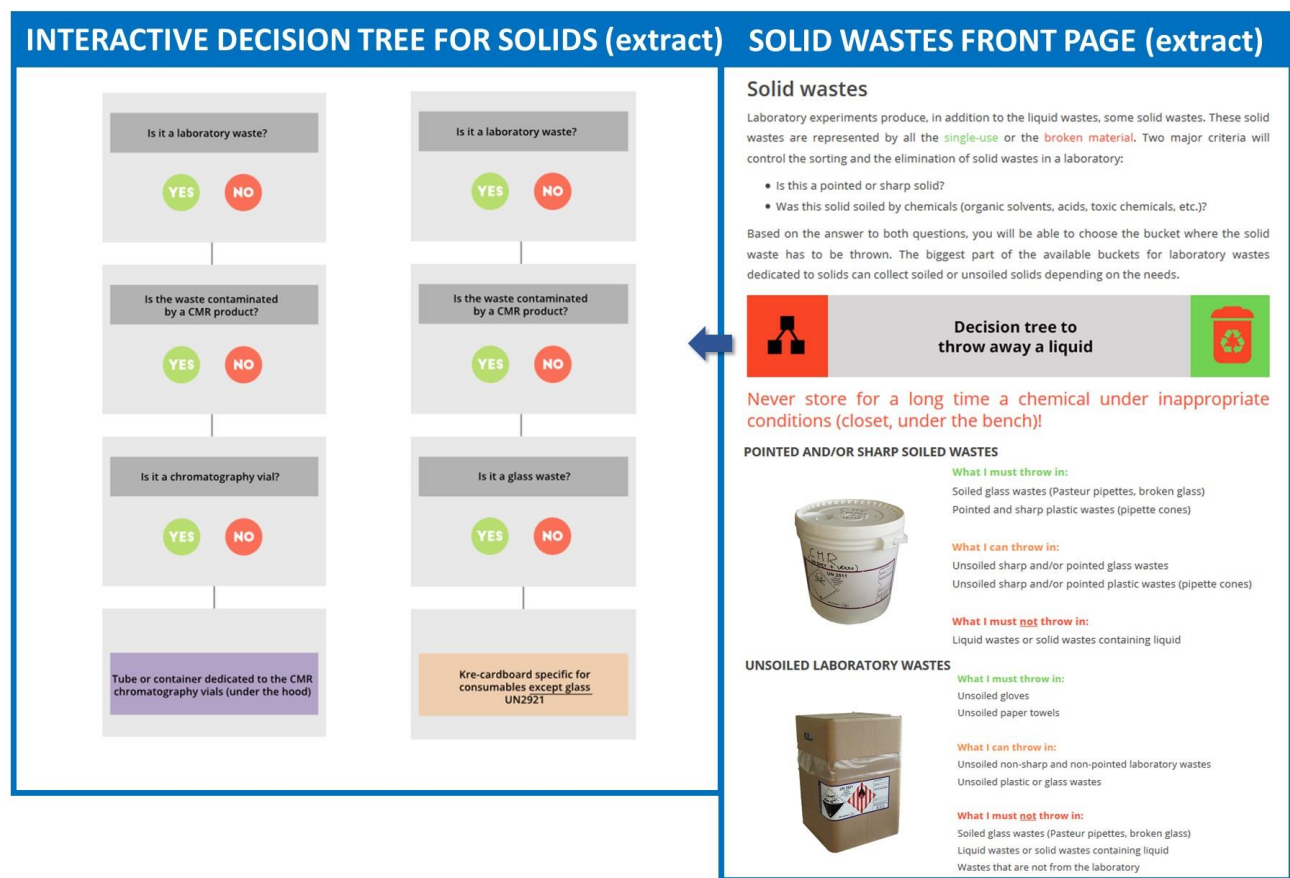


Figure 6. The solid waste front page, with some details of the interactive decision tree for choosing the best options for sorting solid wastes.

In practice, we have observed that students have little knowledge about solid wastes, resulting in
 185 unsecure behavior or actions (such as to throw their gloves in conventional trash for example). So, we
 detail the main types of solid wastes they might encounter in a chemistry lab: pointed and/or sharp
 soiled wastes, non-pointed and/or non-sharp soiled wastes, unsoiled laboratory wastes,
 chromatography vials, other unsoiled wastes. Here again, simple and practical advices or
 recommendations are sorted according to “What I must throw in”/ “What I can throw in”/ “What I
 190 must not throw in” as illustrated in **figure 6**. They are implemented by short recommendations for
 properly and safely throwing the solid wastes in the adapted containers.

Exercising

Two interactive exercises are proposed, to help the students memorizing previous delivered
 knowledge in this digital sheet. In each one, four different liquid wastes are proposed, and students
 195 have to drag-and-drop each of them in the properly labelled container among five that are proposed.

OUR RESOURCES ALIGNMENT WITH THE RAMP APPROACH

This point is considered here relative to the pre-lab instructions only, since this is the major learning objective of our resources as already mentioned. The accessibility of our digital resources enable the students to go back to the information “just-in-time” in the lab whenever they want.

200 Recognize the hazards

This part of the RAMP approach is the most covered since this is “the key first step to safety”.⁷ Our digital resources enable the students to get familiar with the GHS and its pictograms before entering in the lab, as well as the different classes of toxic chemicals. They are also introduced to acute and chronic toxicity. Synthetic information is delivered so that they should be able to rapidly understand
205 the labelling of chemical containers, thereby recognizing these chemical hazards.

Assess the risks of the hazards

Along with the GHS pictograms, the CHIMACTIV website introduces the students to the hazard statements. That way, they are aware of the fact that a similar pictogram could reflect different health effects and severity (death, cancer, irritation, allergies, etc.). This knowledge is useful for students to
210 rapidly assess what are the risks with the manipulation of the different chemicals during their lab session.

Minimize the risks of the hazards

Our resources enable students to get knowledge about the protective measures (PPE and collective protection) that should avoid their exposure to the chemical products under inappropriate operating
215 conditions. They also find recommendations for proper use of PPE, especially using gloves adapted to the considered chemicals. In addition, they are also warned about basic rules related to bench preparation before starting the experiment, as well as putting their personal belongings in appropriate place in the room to avoid any incident.

Prepare for emergencies from uncontrolled hazards

220 The first aid section of the CHIMACTIV website provides the minimal knowledge regarding emergency procedures in case of chemical or thermal burns, or in case of accidental contact with a chemical hazard. In addition, a rapid description of the different emergency devices enables the students to identify them in the lab avoiding to seek for them in emergency case. This is not to replace

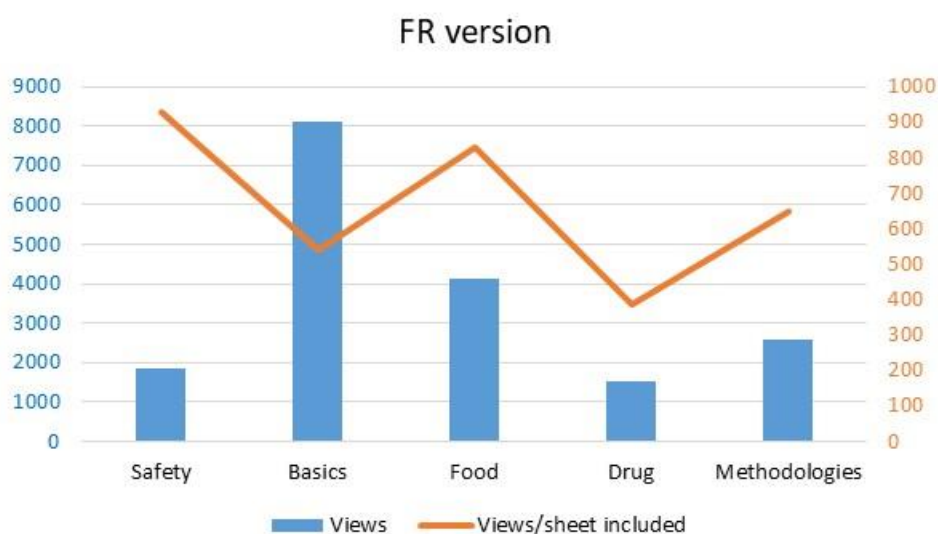
a complete formation for laboratory first aid, but instead to give everyone the minimum knowledge to
225 ensure safety for everybody.

USING THESE RESOURCES IN PRACTICE

Consultation statistics

Statistics data relative to the CHIMACTIV website consultation are available monthly including all
visitors, not only our students.² Based from responding to our survey available on the website, our
230 visitors profile is around 54% students (from high school to master degrees), 15% teachers and 7%
professional outside teaching (unfortunately, the information is missing for 24% of responders).

Over the sole period 1-20 January 2020, there were 6,711 visits on the website, resulting in a total
of 21,346 views on the French version and 3,110 on the English version (see **figure 7**). Looking deeper
on the data, the Safety section faces around 2,000 views. Since it offers only two digital sheets while
235 other CHIMACTIV sections gather from 4 to 15 sheets, it is more valuable to assess the view numbers
per digital sheet for each section of the website to draw the comparison. Interestingly, **figure 7** shows
that the Safety section has the highest rank for the French version of the website. It also ranks pretty
well for the English version, but due to the lower number of views in this language until now, new data
in the next future should comfort this statement.



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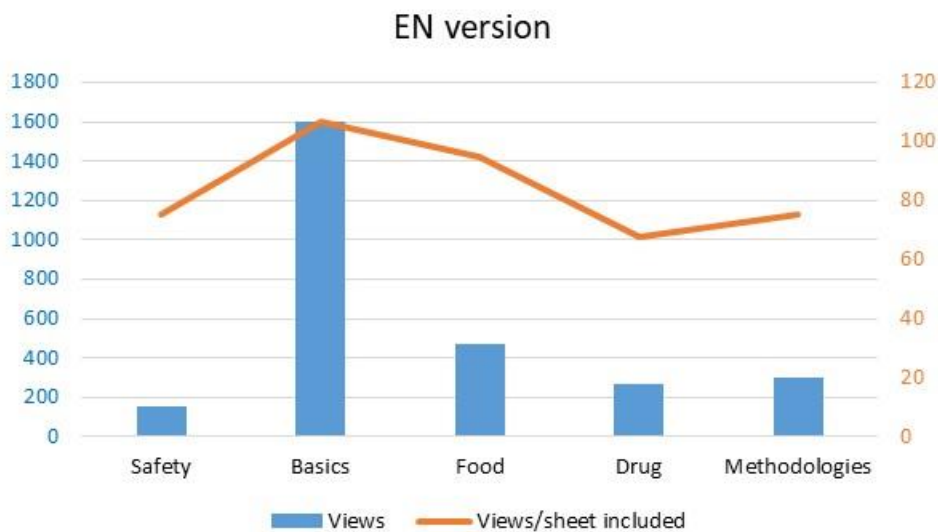


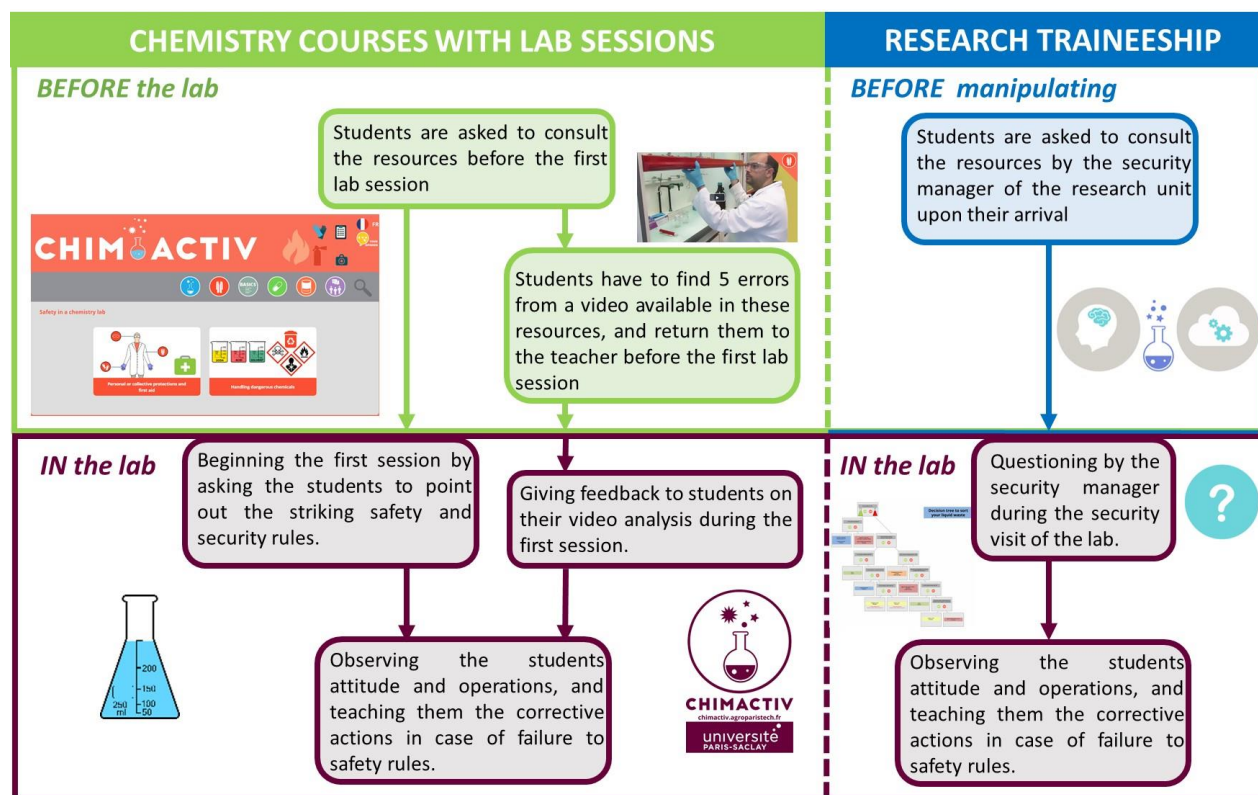
Figure 7. Consultation data of the open resources of the website CHIMACTIV (categorized by their section) over the period 1-20 January 2020: French (FR) version; English (EN) version.

245 Interestingly, whatever the language (French or English), the CHIMACTIV safety resources are consulted at 60% relative for hazard chemicals and 40% for protection. This is probably linked to the prior knowledge of our graduate students, more familiar with protection equipment.

Back from our teaching experience

250 We have been using the digital resources with our graduated students from around three years now. Interestingly, several academic programs have been concerned with diverse profiles of students. In particular, their knowledge and interest in chemistry vary greatly, ranging from biologists with a short experience in chemistry lab up to chemists who are quite familiar with basic safety and security rules. By way of consequence, the time devoted to chemistry lab sessions differ between these academic programs.

255 Fortunately, the open education resources of the CHIMACTIV website authorize a wide range of teaching and learning experiences. In our case, two major teaching scenarios have been conceived for integrating these resources in chemistry courses that include lab sessions, both for self-training of students before entering in the lab as schematized in **figure 8**.



260 Figure 8. Different scenarios tested to train our students with these open educational resources.

The simplest scenario lies in advising the students to consult these safety resources: this implies a brief presentation (either oral or written) of the CHIMACTIV website and its browsing tools,¹ as well as an explicitness that they need to have acquired minimal knowledge for their safety in the lab. This concerned rather generalist academic programs. Satisfaction surveys filled by the students at the end of the courses do suggest that they guide their consultation depending on their prior knowledge, spending more time on the resources that are not acquired or brand new for them. Upon their arrival in the lab for the first session, students were asked about main safety and security issues, to make them remember the key messages.

270 A more thorough integration of these safety open resources has been also experienced in a chemistry academic program, by adding a clear request for each student to watch the video “A bad day of experimental works” and to send the teacher at least five unsafe behaviors or actions that he/she has identified in this video. The students were all capable of identifying at least five mistakes, and this exercise was aimed to focus their attention on safety rules before entering the lab.

275 In addition, these safety resources have been also included in the welcome package for traineeship students in our research lab. They are kindly asked by the security manager to consult these open resources prior their first manipulations in the lab. This allows the trainee in particular to be able to review, at his/her own pace, safety information which have been mentioned during the lab safety visit and which could seem to him/her to be more complex (e.g. management of chemical waste).

280 **Observed benefits for students**

We have experienced our students to be more attentive to their protection when arriving in the lab, especially with regards to safety glasses and gloves. In particular, they do care about the different types of gloves that are present, and the most adapted to the experiments they will have to perform. Videos and photos available in our resources are probably key elements of this effective safety training as already mentioned.⁸

285 We also have observed students arriving in the lab more familiar with the lab environment and thus more confident. Engaging the discussion with them at the beginning of the lab sessions revealed them to be more aware of safety rules, and having a deeper related knowledge of chemicals than before thanks to the use of the CHIMACTIV website. Our students did confirm their feeling of being trained to safety aspects partly thanks to the website.

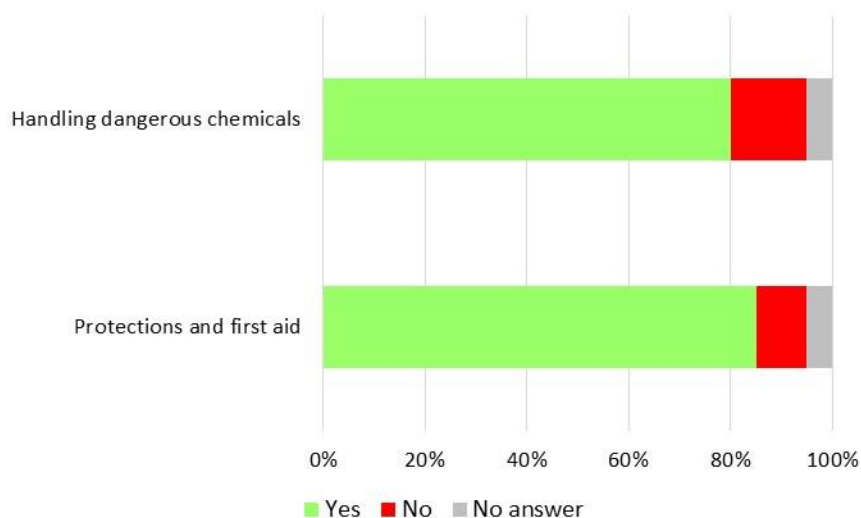
290 During the lab sessions they were much more aware of the waste management options. On that latter point, having printed in large format both decision trees and posted them in the chemistry lab (see **figure 9**) is very convenient in practice. Students can refer to these posters at any time during their lab sessions, to make sure they face the correct and safe management option. This is also very helpful for them to understand the principles underlying these decision trees. We also noted that a large proportion of the students prefer to consult the decision tree on their own smartphone during the session in order to ensure that the chemical waste from their experience is emptied into the appropriate container.



300 Figure 9. View of our chemistry lab with both decision trees (liquid and solid wastes) displayed, and details of both trees (credit photos: Even Le Roux).

Students were also surveyed for their satisfaction related to these resources (using individual anonymous questionnaires), and their feeling about their usefulness for being prepared for the lab sessions. Results related to two cohorts of graduated chemistry students are displayed in **figure 10**. In spite of some discrepancy between both cohorts, a great majority of the students perceived these resources as being useful for them to being prepared for the lab sessions. This feeling is even higher when non-chemistry students are surveyed (near 100%), due to their reduced prior knowledge related to safety.

Cohort 2017-2018 (20 students)



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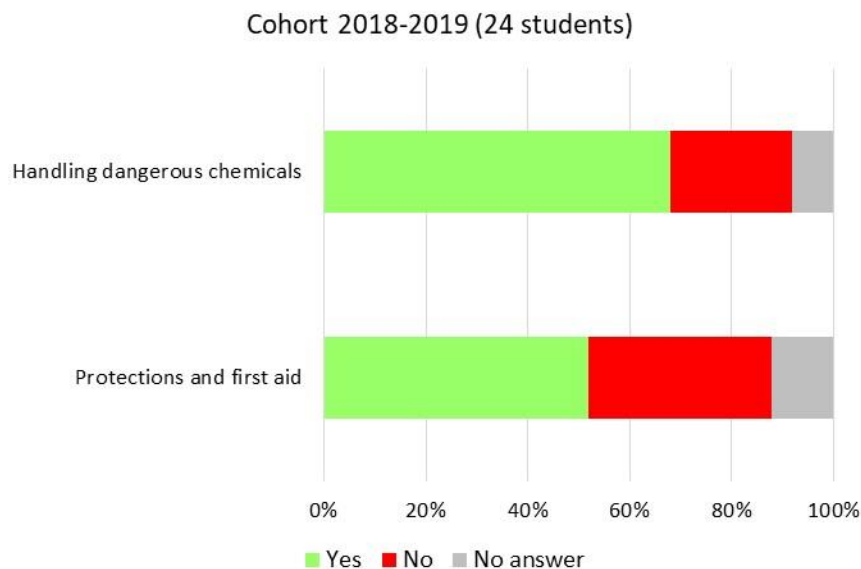


Figure 10. Perception of graduate chemistry students with regards to the usefulness of these safety digital resources for lab sessions.

CONCLUSION

315 Open educational resources related to chemical safety are available on the CHIMACTIV website. Being interactive and responsive, they are attractive for students to train before entering in the lab, or during the lab sessions. Different scenarios have been already implemented for using these resources that can be reproduced by other teachers whenever interested. Our data relative to the students' perception of usefulness of these resources are promising. Teachers' observations in the lab do confirm
 320 the valuable aspect of these resources, since students arrive in the lab more familiar with the lab environment (e.g. safety devices) and more aware of safety rules.

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