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A Field Survey on Promotion of Safety in School Laboratories

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Keywords

chemistry education;
laboratory;
secondary/high school;
risk perception

Abstract

A training activity was conducted in a technical high school aimed at promoting the health and safety culture in chemistry laboratories. 84 students were involved. Three seminar meetings and three laboratory workshops were held. At the beginning of the activity (T0) and at the end (T1) the following tools were given to the students: a questionnaire on the topics covered by the training activity; a questionnaire containing the general risk propensity scale and some additional questions relating to the perception of risk. A comparison of the data between T0 and T1 revealed an overall improvement in students' ability to identify specific hazards, but it also highlighted the need to improve the good laboratory practices. Students tend to attribute a greater awareness to themselves than they are willing to acknowledge in their peers. It emerged a more effective promotion of risk-awareness rather than risk-management, as predictable, considering the short intervention time.

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INTRODUCTION

From the most recent European report on working conditions (Parent Thirion et al, 2017), dated 2017, 17% of workers in the European Union reported to being exposed to potentially hazardous products for at least a quarter of their working time, which has practically remained unchanged compared to 2000. These data, unfortunately, show how progress in reducing worker exposure very often clash with production cycles, whose characteristics are such as to considerably affect the real conditions and exposure times.

When considering the number of chemical substances marketed in Europe, currently around 23,800 (ECHA, 2020), and in particular the presence of about 8,000 chemicals with hazardous properties, the need to protect workers is certainly not only appropriate, but also indispensable.

The European campaign launched by the European Occupational Safety and Health Agency - EU-OSHA for the two-year period 2018/19 was inserted within this framework with the aim of raising public awareness on the risks of hazardous substances at the workplace, as well as promoting a culture of prevention of such risks.

Students of educational institutions fully fall within the definition of ‘worker’, pursuant to the legislation on occupational health and safety, where (laboratory) activities that could potentially bring a student in contact with specific regulated risks, such as chemical risks, are conducted.

Even if, in different countries, were published guidelines and recommendations seeking to minimize chemical risks in academic laboratories, the idea that this type of laboratories can present non-negligible chemical risks is still not widespread (Álvarez-Chávez et al, 2019). While evidences of possible risks are confirmed by the statistics on accidents and their severity that have occurred in school laboratories, with documented 533 accidents over a period of three years (Stuart & Toreki, 2014, Olewski & Snakard, 2017), and more recent data showed that 45% of workers in university or school laboratories have had accidents and 73.7% of cases are accidents that were linked to chemical exposure (Nasrallah et al, 2022).

Training and information are core risk prevention tools for every worker, and even more so for a student who is approaching specific risks such as chemical ones for the first time. Knowledge on distinguishing a hazard from a risk and identifying individual risks is fundamental to the prevention actions to be implemented (Stuart & McEwen, 2016).

Occupational health and safety education is particularly effective when it places the person at the center of its concern, and, in particular, in the school context hence enabling students to develop the ability to understand what surrounds them, what they are manipulating and, consequently, making independent conscious decisions in relation to their own well-being and that of others. This goal can only be achieved through a correct perception of risks and the adoption of correct behaviors.

Awareness of exposure to a risk is related to the perceived probability of being harmed. The estimate of this probability does not always correspond to the real possibility that a harmful event could occur. Since in addition to being guided by objective factors relating to the specific risk, the probability is influenced by subjective evaluations (familiarity, experience and emotions) and by the subject’s social-cultural context (Burns & Slovic, 2012; Slovic et al, 2000). For example, according to the psychometric paradigm, the perception of risk is based on subjective variables and is influenced by various factors relating to the characteristics of the hazards and situations behind the risk. This paradigm focuses on individual responses and on personal psychological determinants and assumes that the individual propensity to expose themselves to risk derives from the action of mental strategies that can sometimes lead to ‘perceptual distortions’, or to underestimates or overestimates of the risk (Slovic et al, 2000; Taylor & Snyder,2017).

With respect to personal characteristics that influence the risk perception process: males may show a greater propensity to risk than females (Nicholson et al, 2005; Powell &Ansic, 1997). Adolescents, in general, show a greater propensity than other age groups of the population (Steinberg et al, 2008). Finally, certain personality traits, such as openness to experience and emotional instability, make people more heedless of risk and less prone to its careful evaluation (Nicholson et al, 2005; Lauriola &Levin, 2005; Finucane et al, 2000).

In any case, the debate on the existence of a general risk disposition (Zhang et al, 2019), as well as of other personological (Figner &Weber, 2011; Mata et al, 2018) and situational components (Kahneman &Tversky, 1979; Scholer et al, 2012; Tversky & Kahneman, 1986), is still open.

According to Álvarez-Chávez (2019), equipping students with the tools necessary for a correct identification and perception of risk is the key ingredient for the success of any safety education program in a chemistry laboratory.

Chemistry laboratories contain substances useful for carrying out simple experiments that support the learning in the educational programs of many types of high school. The emphasis in using a laboratory is generally placed on understanding the processes and learning the procedures necessary to obtain certain results. However, adequate attention is not always focused on the safe conduct of such experiments or on the variables that could cause risks to health and/or safety, hence the need to act in such contexts.

Therefore, starting from the objectives of the EU-OSHA European Campaign and considering what is documented and shown in scientific literature, the possibility of addressing a training plan to inexperienced ‘workers’, like students of upper secondary schools, seemed to be an excellent starting point for promoting the health and safety culture in the chemical sector.

The aim of the study was answered to the questions: how students perceive the risk from chemicals? How they are able to internalize good laboratory practices and what types of topics are less understandable? What initiatives would be useful to improve the assimilation of the principles of risk prevention in the laboratory?

METHODS

Study Design

The study was focused at raising awareness of the possible chemical risks in the laboratory of a technical and technological institute, at promoting awareness and identifying the risk. In particular the path was articulated in several steps: a first phase of awareness of their preparation and perception of risk, a second phase of information on the risks present, a third phase of practice and practical application and finally a final phase of verification. The emphasis was placed on both learning and adopting good practices for the prevention of possible risks, and on the impact of students’ behavior on their own health and safety and those of their peers.

A technical and technological institute specializing in environmental biotechnologies was involved. The training activity started with the participation of the third, fourth and fifth years in the specific course of study (6 classes in all); therefore, the totality of the students was 84 mixed students aged between 16 and 19; 54 males and 30 females.

In particular, 84 students took part in the first meeting (T0); of these, 74 (88%) also attended the third and last meeting (T1).

The lower number of participants in T1 is mainly due to the absence of the student on the specific day, no student has explicitly decided to leave the study or not to answer the questionnaires.

All questionnaires were conducted anonymously.

The study included an initial seminar meeting with the teachers to discuss the training course, the themes chosen for initial discussion and the methods of conducting the survey.

In agreement with the school, it was decided to focus the training on: notions of identifying the chemical risk from the labels and reading safety data sheets; knowledge and adoption of good laboratory practices; personal protective equipment (PPE), their description and choice based on the risk conditions both in daily handling and in the event of accidental spills; laboratory waste as a potential source of hazard, the need for differentiation and clear identification.

For each class, a course of three meetings was planned, divided into a first hour of seminar, with a classroom-taught lesson, together with the use of videos and dynamic presentations to illustrate the topics of the day, followed by a further hour of practice in the laboratory to illustrate the practical aspect as previously described. The time between the first meeting (T0) and the last meeting (T1) was of 7 to 10 days. The laboratory activity was dedicated to: reading the labels of products in the school laboratory to identify the potential hazards and preparation of diluted solutions of hazardous substances, with identification of the relative correct labelling to be affixed also to subsequent diluted solutions; in-depth study of the safety data sheets of the products present in the laboratory, responding to specific requests on the individual product, searching for information on the sheet and reference to good laboratory practice; the exercise on PPE, with the simulation of specific exposure scenarios and the request for identification of the correct PPE to be used.

Tools

During the first meeting (T0), two tools were given to the students:

- a questionnaire aimed to investigate the students' knowledge of the basic concepts useful to identify a hazard deriving from used chemicals. This questionnaire was divided into 10 closed, multiple choice questions (4 answers for each question), referred namely to: identification of the hazard symbols on the labels of hazardous chemicals (3 items); knowledge of the content of the safety data sheets (1 item); knowledge of good laboratory practice, especially in relation to the type of risk that can be identified in a laboratory (1 item), storage of incompatible substances (1 item) and the use of the fume extraction hood (2 items); waste management in the laboratory (2 items).

The same questions were proposed twice, at T0 to measure the student starting level in each of the areas of interest and at T1 (third and last meeting) to measure the possible changes following the student's participation in the training meetings.

This double administration was useful to understand the starting level of knowledge of these absolutely basic concepts for the chemical hazard management and, to a certain extent, to understand which elements, following a small training program, could be clarified or particularly difficult to understand.

- the General Risk Propensity Scale –GriPS (Zhang et al, 2019) is aimed at assessing the level of general risk propensity of the students involved. This scale is composed by a set of items that ask the person to evaluate their relationship with risk from different points of view. People with higher scores on this tool usually have a greater propensity to actively expose themselves to stressful situations and conditions. This propensity is believed to be dispositional in nature, being linked to the personality of the subjects.

Were added some questions related to the perception of each student's ability to adequately manage the hazards from chemical agents in the laboratory.

A last set of questions were proposed on the sense of responsibility perceived with respect to the value of engaging in a health-promoting behavior for both one's own safety and that of others.

This tool was given to students before and after the training activity. Form A of the questionnaire - the longest - included all the questions of form B as well as four general exploratory questions and 6 of the 8 questions of the General Risk Propensity Scale - GRiPS. The answers were defined using a 5-point Likert response scale (1 = strongly disagree; 5 = strongly agree, or 1 = 'not at all', 5 = 'very much').

Statistical processing of the results

The data obtained from the questionnaire, relating to the topics covered in the meetings, were illustrated with a descriptive analysis, reasoning with a view to an incorrect answer (0)/correct answer (1). The differences among the results of the questionnaires relating to basic knowledge, with respect to identifying the chemical hazards present in the laboratory and good practices at T0 and T1, were compared using the Fisher Yates test to quantitatively evaluate a statistical significance level.

Regarding the risk perception questionnaires, for items at T0, the chi-square test ($\chi 2$) was used to determine the existence of discrepancies between expected and observed frequencies. While where appropriate, Cramer's V coefficient was used to determine the size of any observed association and, finally, standardized residuals were used to determine in which cells of the contingency table the observed differences were concentrated.

Given the low sample size, the statistical significance of the comparison between T0 and T1 was verified by comparing the confidence intervals constructed around the mean estimates for T0 and T1 using the bootstrap method (Efron & Tibshirani, 1994). This resampling technique with replacement allows approximating the sample distribution (in terms of mean and variance) of a reference parameter (in this case, the standard error from which the confidence interval is derived). Following this approach, the averages obtained by the students on the various measures at T0 and T1 were considered different ($p < 0.05$) when the associated confidence intervals did not overlap each other.

RESULTS AND DISCUSSION

Basic knowledge questionnaire

With respect to the topics of the training activity, figures 1 and 2 show the results of the 10 answers of the questionnaire on basic knowledge, the one administered in T0 and the one administered in T1, expressed in percentage values of correct answer or not.

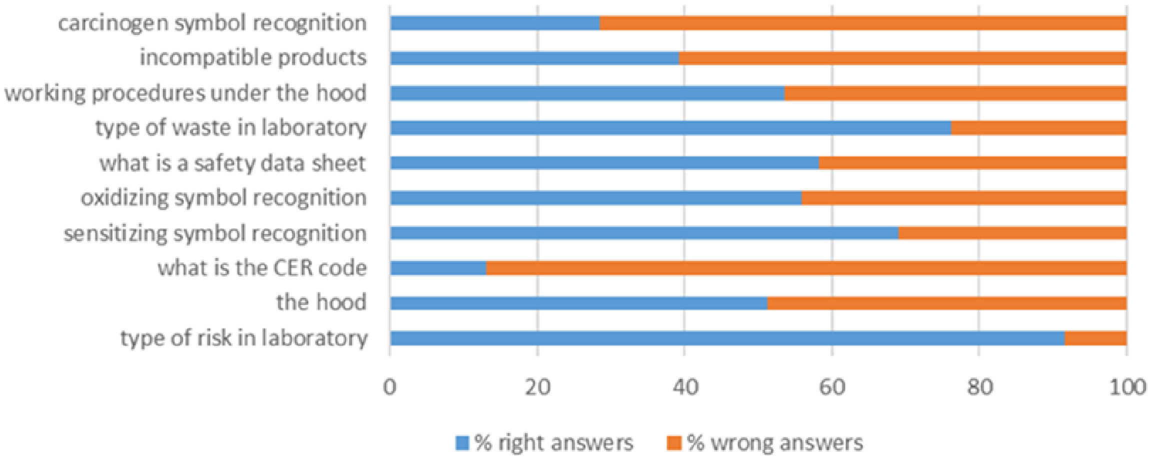

Figure 1. Basic knowledge test results (T0)

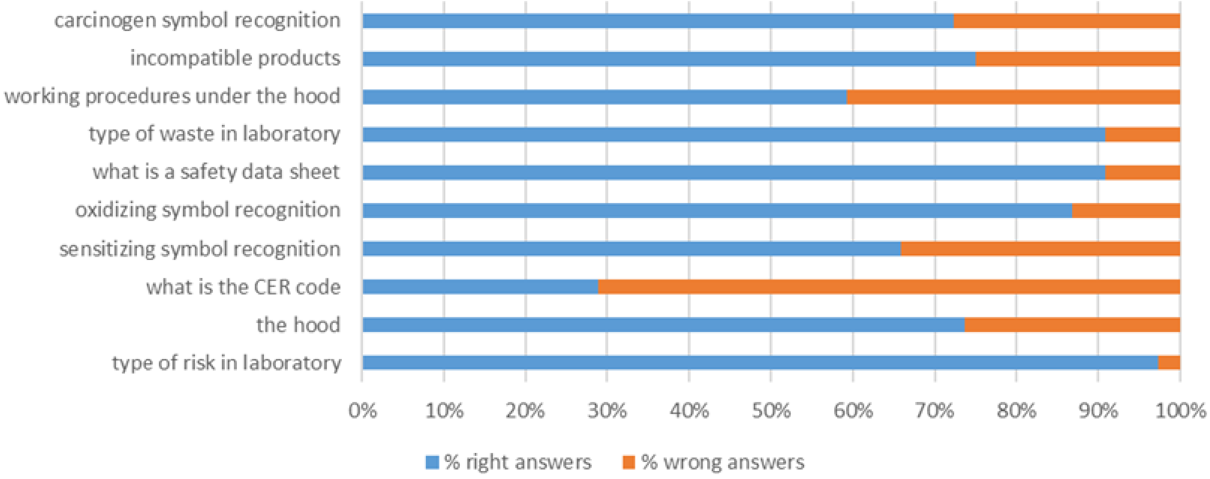

Figure 2. Basic knowledge test results (T1)

The comparison between the outcomes, with the relative statistical significance (Fisher Yates test), is presented in table no. 1.

Table 1. Statistical comparison of the results of the questionnaires on basic knowledge (Fisher Yates Test, before/after)

item	p-value	Percentage difference of correct answers
Carcinogen symbol recognition	<0.001	+43%
Incompatible products	<0.001	+37%
Working procedures under the hood	>0.40	+6%
Type of waste in laboratory	<0.01	+16%
What is a safety data sheet	<0.001	+34%
Recognition of oxidizing symbol	<0.001	+32%
Recognition of sensitizing symbol	>0.70	-2%
What is a CER code	<0.01	+17%
The hood and its use	<0.01	+23%
Types of risk in laboratory	0.01<p<0.05	+7%

With regard to the operational notions illustrated in the training activity, they clarified elements relating to identifying chemical hazards, with increases of up to 43% compared to the correctness of the answers (recognition of a carcinogen). For 8 items, there was a significant difference in the answer, which reiterates the effectiveness of the conducted training activity.

Two items emerge in which the training activity did not have a significant impact, which are recognition of a sensitizing substance and the correct way of working under the extraction hood.

Risk perception study

At T0 and T1, the ability to manage and perceive a specific risk was investigated and, in particular, the 'ability to manage specific risks', 'the skills of peers to control or avoid them', 'the probability of risk in the laboratory'. Each question was divided into six areas relating to specific risks (skin contact, inhalation, eye contact, ingestion, flammability and explosiveness) that the student had to evaluate. Each question had a reliability estimated with Cronbach's alpha which was found to be adequate: 'ability to manage specific risks' T0 = 0.77, T1 = 0.83; 'the skill of peers to control or avoid them' T0 = 0.86, T 1 = 0.84; 'The probability of risk in the laboratory' T0 = 0.73, T1 = 0.83.

The knowledge of the risk was assessed both with respect to oneself ('How much do you think you know about the risks from chemical agents') and with respect to one's peers ('In your opinion, how much do your peers know about the risks from chemical agents?').

Finally, the level of training in good practices and safety was assessed and the level of risk acceptance, with the question: 'A small accident in the laboratory is inevitable; these are the 'drawbacks of the trade''.

In the analysis of associations in T0, there was a significant association between the questions 'I can identify and manage chemical risk in the laboratory' and 'My peers can identify and manage chemical risk in the laboratory' ($\chi 2$ (4) = 25.4, $p < 0.01$; Cramer's V coefficient equal to 0.39, proving a moderately high association (table 2).

Table 2. Association (at T0) between the questions

	My peers and the chemical risk			
Me and chemical risk	They do not know to manage risk	They know how to identify it but not manage it	They know how to identify and manage it	Total
I don't know how to manage risk	2(2%)	0 (0%)	0(0%)	1(2%)
I know to identify it but not manage it	12(14%)	40(48%)	2(2%)	54(65%)
I know how to identify and manage it	2(2%)	15(18%)	10(12%)[a]	27(33%)
Total	16(19%)	55(66%)	12(14%)	83(100%)

[a]The values outside the brackets relate to the observed 'raw' frequency. The values inside the brackets are the observed 'percentage' frequencies. Values in bold represent significant differences between expected and observed frequencies

The standardized residuals showed that students have indicated more often than expected on a case-by-case basis (standardized residual = 3.09) both for themselves and their peers to be 'fully capable' of identifying and managing the risk from chemical agents in laboratory.

Students report that they strongly agree (mean = 4.14, standard deviation = 1.02) on the importance of telling their peers the potential danger of what they are doing in laboratory and being ready to correct themselves if someone pointed out that they were making a possible error (mean = 3.99, standard deviation = 0.99).

Considering the GriPS scale, the students showed a significantly lower risk propensity than the reference sample (29 vs 40 on T scale), declaring that they are not inclined to take risks. From this, it appears that they are probably more sensitive to risk given their 'work' context (i.e. school chemistry laboratory) and therefore are more careful than the general population.

The use of Cohen's (Cohen, 1992) coefficient d reveals that the variation in the perception of risk relating to the extent of learning is to be considered 'moderate' ('ability to manage specific risks', d = 0.37; 'skills of peers to control or avoid them', d = 0.34; 'probability of risk in the laboratory', d = 0.38).

Compared to the area of training in good practices and safety, there is a significant increase between T0 and T1 ($p < 0.05$) of moderate entity (d = 0.32).

In the area relating to knowledge of risk, statistically significant differences were found ($p < 0.05$) which showed an increase in both students' knowledge and those attributed to their peers. In the first case (chemical risk), the analysis of Cohen's d value shows a significant or 'large' increase (d = 0.94), whereas in the second case (classmates) the change is 'moderate' (d = 0.66).

Discussion

training methods involving practice activity and possible of free dialogue among teachers and students produced more effective results, these considerations emerge not only from common experience in the field, but also from studies conducted to assess the effectiveness of safety training programmes for young people (Burke et al., 2006; Zierold, 2015).

In a recent survey (Robson et al, 2012), considering 36 workplaces training programs, was observed that all programs showed positive, statistically significant results even if more than 63% were only with one session. Particularly the training's effectiveness on behaviours showed strong evidence.

Ricci et al (2016) carried out a meta-analysis on 28 selected studies to highlight the effectiveness of training programs in workplaces regarding attitudes, beliefs, knowledge, behaviour and health. Findings showed occupational and health safety training induced positive effects on workers' attitudes and beliefs toward health protection, less convincing evidence on behaviour and minor effect on health. Interesting data emerged: the most effective training in term of improving safety knowledge and attitudes seemed to be individual self-learning together with learning sessions no longer than 1 hour. This element support the present training program design, in term of time (lesson no longer than 1 hour) and organization (laboratory activity with single experiment and activity to do).

The process of teaching and learning science is greatly helped with the experimental activities in science laboratories, hence the laboratory safety is a matter of concern which must be given due consideration. Training students to recognize the common laboratory hazard symbols must be one of the first step of their science education. Some authors (Wangdi & Tshomo, 2016) carried out an investigation on 166 high school students to understand their knowledge of hazard symbols of chemicals and the findings indicated that the students were not able to recognize the common laboratory hazard symbols and they have revealed confusion in recognizing them, particularly for those used with lower frequency.

A recent study (Limboo et al, 2021) on 261 students showed that, even if the investigated high schools had good written safety practices with adequate laboratory facilities and safety skills, chemicals and waste materials were disposed of without treatment and further, there were shortages of safety gloves and goggles fume hood and pipette fillers. This underlines how the training activity about health and safety in laboratory need periodic updates but also real application. Similarly another study on 226 tertiary students aimed to investigate the chemical laboratory safety awareness, attitudes and practices showed that though awareness was high there were deficiencies in the areas of hazard identification and emergency response (Ayana et al, 2017).

The importance of academic preparation of future science teachers, in occupational safety and health is also a topic question underlined in literature (Feszterova, 2015). Focused on teacher requisites, Kadiyala & Kealeboga (2021), carried out an investigation on 84 preservice science teachers and they found that only about the half of the sample was formally trained on health and safety in laboratory.

In the present investigation, with regard to the topics covered in the training activity, the students less understood two elements: the recognition of the symbol relating to a sensitizing substance and the correct working methods under the extraction hood. Regarding the first question, it is believed that the students' attention, even during the classroom theoretical lesson, was captured more by those hazards that were known to them (see for example the difference in the carcinogen symbols), since the sensitizing risk is less known and understood, even socially, so it was probably less memorized.

Overall, the results relating to the identification of hazards from reading the labels show the need for this information to be reiterated on several occasions. In the school curriculum, lessons relating to the hazard symbols are given in the first two years, but the training herein presented was conducted on students in the last 3 years of the course, these concepts do not seem to have been internalized. This data could be use-full when assessing the need to reiterate the basic elements of hazard identification al-so in years that follow, so that they become a consolidated wealth of knowledge within the school curriculum.

In general, the present training study has raised the students' awareness on the hazards and risks from exposure to chemicals. Moreover, it seems to have produced changes in the perception of risk, it was possible to verify a significant, albeit partial, accentuation of the students' sensitivity/concern towards the risks associated with the presence of chemicals in daily life.

The results that emerged showed statistically significant increases both in the perception of risk and in the perception of one's skills in managing it. Probably the training received made the students more attentive to the nature of substances and hazards, promoting in them a more realistic view of the consequences associated with their incorrect use. This new awareness is likely to bring with it a more careful consideration of one's ability to literally follow the procedures learned as well as a possible reduction in 'light-hearted' behaviours that can lead to adverse effects on health and safety.

It is interesting to note that students tend to attribute to themselves a higher knowledge and awareness of risks than they are willing to recognize in their peers. Although not necessarily inaccurate, this evaluation reflects a certain basic tendency inherent in the judgement processes, which pushes individuals to feel above average (a sort of 'better than average effect') (Kim et al, 2017). (Alicke &Govorun, 2005) This trend emerges whenever people are asked to compare their skills with those of any member of their social group. This possible bias in the evaluation of learning is therefore always needs to be taken into account when evaluating skill development programs.

The careful analysis of the effects of the activity reveals how much this was more effective in promoting knowledge of the risk rather than its management, at least according to what the students reported. This result is not surprising: the development of management skills usually requires longer time and individual practice to promote the necessary skills.

Other interesting results of the study concern the data collected in the pre-activity phase (i.e., T0), students declare themselves and their peers as generally able to both identify and manage the risks deriving from chemical agents in the laboratory. They also say they are willing to report bad practices and to correct themselves if they realize that they have implemented an un-safe procedure. Although these data appear reassuring at a first reading, they should be critically recorded, since the same psychological processes that lead to the underestimation of risk in fact work in the overestimation of one's skills.

Finally, another interesting fact concerns the low risk propensity found in the sample through the GRiPS, irrespective of the adolescent age of the subjects involved. This data would seem to support the reliability of the data collected, suggesting that, overall, the extent of the bias present is reasonable.

CONCLUSIONS

The outcome of the survey herein presented achieves the objectives set at the biginning: the use of a practical approach, as well as theoretical, to the safety of chemical risk in the laboratory is a functional approach to the training of students.

Considering the stanting questions we can say that:

- how students perceive the risk from chemicals? the risk perception survey showed that students tend to perceive risk fairly correctly even if they tend to maximize their ability to manage it, skills they don't recognize from their peers
- How they are able to internalize good laboratory practices and what types of topics are less understandable? The training approach that combines frontal lessons and practical activities has been successful for the acquisition of new knowledge, some aspects and concepts, further away from the everyday life of students, require more time and repetition to be clearly acquired, such as the sensitizing risk.
- What initiatives would be useful to improve the assimilation of the principles of risk prevention in the laboratory? We believe that the knowledge acquisition phase directly in the laboratory has been central to obtaining the best results, a training plan that includes more "doing" concepts could lead to even better results.

Correct information is the first of the preventive measures to be adopted to ensure, even in schools, everyone's safety, including one's own. Information must be followed by adequate and periodically updated education, instruction and training initiatives, to prevent irresponsible and/or inadequate behaviour from persisting during laboratory exercises, which may lead to injuries and accidents. This activity, if carried out systematically, will be able to train future workers to protect themselves in very different professional contexts.

Promoting good practices in risk management within academic laboratories means protecting the health and safety of all those involved. For this reason, developing effective training programs in this regard is important above all in order to make safety training a routine process in the school environment as well.

The strengths of the study presented are a pre and post intervention research design, which allows a precise assessment of the changes produced by the activity; the broad-spectrum analysis of the areas affected by the training program, which permits a detailed overview of its effectiveness.

On the other hand, the limits to be recognized are in the numerically contained and unbalanced sample by gender (the classes tend to be predominantly male), in the exclusive use of self-assessment tools and in the lack of a follow-up evaluation, for the time being.

This experience should be considered as a stimulus initiative that aims at sharing languages and contents to build up critical awareness on the topic.

Knowing how to recognize the hazards factors to which one is exposed, perceiving the inherent risks in the environment and in the work process, working safely: this is the virtuous path desired for today's students and future workers.

Students learning in a technical institute have the duty/right to understand the risks they run during laboratory activities, and therefore to prevent them.

This contribution, albeit as a pilot survey, presents the evaluation of a structured training program to highlight the learning produced in the areas of interest, the basic notions that should be strengthened and any critical elements.

Of course, the brevity of the path could only affect some notions to a limited extent, but the structure of the training activity has highlighted the importance of the practical element directly in the laboratory and comparison with the students, reiterating how ‘learning by doing’ is certainly a principle to be pursued. The results strengthen the idea that effective communication of the risks present in laboratories must also take into account the indications deriving from studies on risk perception, in order to maximize their effectiveness.

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