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Chemical and biological risk assessment in university teaching laboratories: an open question

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Abstract

Background and aim. According to Legislative Decree 81/08, any university student performing any activity in a laboratory, including teaching laboratories, is considered a worker and therefore subject to current legislation. This study aimed to assess the chemical and biological risk in university teaching laboratories of Urbino.

Methods. The chemical and biological risk assessment was carried out in 6 teaching laboratories of Urbino University using the ISPRA method and INAIL questionnaires (one for intentional use and one for potential exposure), respectively.

Results. Overall, the activities carried out in the examined teaching laboratories resulted in chemical level lower than 1, except one activity (1.304). In total, 192 hazardous reagents were identified; 16, classified as carcinogens/mutagens, are handled exclusively by the technical assistants. As regards the biological risk, the activities with potential exposure resulted in an acceptable risk level (83%) and only one in a medium risk level (17%). In the case of the intentional use, all the examined activities showed a medium risk level, ranging from 2.29 to 3.43.

Discussion. These results highlight the importance of the safety training provided to students attending the laboratories, as well as the awareness of teachers regarding safety. The risk assessment here presented was referred to technical assistants and course instructors, rather than the students themselves. Even if this approach is certainly more conservative, the question of the true extent of the chemical and biological risks to which students are exposed during their laboratory activities remains open.

Conclusions. The development of a standardized tool for this purpose, beside the standard risk assessments used in research laboratories, would provide more information on risk exposure and risk perceptions by the students.

1. Introduction

The main regulation of worker safety in Italian legislation is represented by the Legislative Decree 81/08 [1] indicating the safety representatives responsible for implementing the rules laid down in the workplace, including at the university level. In addition, Law 363/1998 [2] is specific for all the school environments in Italy and each University also has an internal Regulation containing, among others, particular rules relating to the safety of workers.

Indeed, Article 2 of Legislative Decree 81/08 also defines worker as "students at educational institutions and universities and participants in professional training courses that use laboratories, work equipment in general, chemical, physical, and biological agents, including video display terminals, limited to the periods in which the student is actually working with the equipment or laboratories in question." Accordingly, any university student who performs any activity in a laboratory, including teaching laboratories, is considered a worker and therefore subject to current legislation regarding health and safety in the workplace. Teaching laboratories represent a great opportunity for university education, especially in technical-scientific disciplines, as they allow students to acquire manual skills and become familiar with analytical techniques and basic experimental procedures. The access to these specific workplaces is limited to students who have attended and completed specific safety training, as required by current legislation and our University policy, which added to the obligatory courses, other three specific courses (for chemical agents, biological agents, exposure to electromagnetic fields). Indeed, continuous education is crucial for educators to establish and maintain a safe laboratory environment and promote good attitudes towards rational risk assessment and safe habits among students. The importance of this task lies not only in safety but also in preparing our students for future work in college, professional school, and the workplace. Effective safety education, also following the Good Laboratory Practice (GLP) [3], can minimize instructor liability in the event of an accident [4-5].

As regards the chemical risk assessment, the use of qualitative/semi-quantitative modelling approaches (index or numerical algorithms for risk estimation) is widespread [6,7], including tools such as MoVaRisCh, LaboRisCh, the ARPA/ISPRA algorithm or Datarisch, inspired by the Control Banding [8]. In the case of teaching laboratory activities, this approach is the most adequate considering the low quantities of the chemical agents used and the short time of exposure in the different laboratory activities.

Regarding biological risk, the extent present in teaching laboratory activities and the resulting implementation of preventive measures depend primarily on the use of hazardous biological agents. The intentional use of microorganisms refers to an important, and often fundamental, element of work activities, where exposure is therefore predictable; in this case, specific safety measures are planned for the specific source of risk. On the contrary, potential exposure is defined as possible but unpredictable exposure; this occurs whenever biological material from a potentially infectious sample is treated or manipulated, and accidental contact with such material is therefore possible. In these cases, so-called "universal" preventive measures are adopted. The teaching laboratories involve exposure to microrganisms, in most cases with low level of pathogenicity (Group 1 and 2), intentionally used according to the aim of the teaching activity. These kinds of laboratories have a high staff turnover, namely, students following practical activities required by the academic curricula. These activities are conducted by the course instructor and one or more technical assistants, which, since they are implicitly identified as supervisors by current regulations, are responsible for safety.

At our University, the teaching laboratories, like all other workplaces, have been subject to a risk assessment and a dedicated Risk Assessment Document (DVR) and related annexes have been developed. Indeed, the increased activity in university laboratories makes students more likely to be exposed to risks, such as toxic, corrosive, oxidising, flammable, radioactive, biological, or environmentally harmful substances [9-11].

In this direction, the present investigation aimed to assess the chemical and biological risk in six university teaching laboratories of Urbino using numerical algorithms methods for risk estimation to provide more detailed information on specific risks to staff working in our university laboratories.

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2. Materials and Methods

2.1. Study design

The chemical and biological risk assessment was carried out in 6 teaching laboratories of Urbino University (Table 1) in the period January 2023-June 2024. Before starting the data collection, preliminary inspections were conducted in the different workplaces to observe and analyse the tasks performed by each laboratory staff. The modality of data collection was also presented and described to each Laboratory Responsible.

Table 1. Examined teaching laboratories of Urbino University and related information about the carried-out activities, quantity of used chemical agents and type of biological agent.

Teaching Laboratory (ID)	Activity	Chemical agents (n)	Biological agents
Lab 1	Drug Formulation	47	NA
Lab 2	Drug Analysis and Analytical Chemistry	26	NA
Lab 3	Drug Analysis and Analytical Chemistry	63	NA
Lab 4	Drug Extractive Preparations and Synthesis	18	NA
Lab 5	Biochemistry, Biology, Hygiene, Microbiology	13	Group 1 and 2
Lab 6	Biochemistry, Biology, Microbiology	25	Group 1 and 2

2.2. Chemical risk assessment

For this purpose, the ISPRA method [12] was applied and a specific table for chemical risk assessment was elaborated and used to collect data from the different laboratories according to the following items:

1. The chemical agent name and the hazard class (H statements) according to information available on SDSs collected as PDF files.
2. Type of exposure considering inhalation, direct skin contact, accidental skin contact.
3. Physical state of the chemical agents.
4. Operating temperature and, for liquid, the boiling temperature.
5. Frequency including the duration of handling according to the number of minutes or hours daily, weekly, monthly, or annual periodicity.
6. The volume of substances/preparations considering the quantity consumed according to grams or ml used daily, weekly, or annually.
7. Method of use considering closed system, closed system with possible openings, closed system with sporadic openings, open system (little dispersive), dispersive use.
8. The stored quantity (if there is a warehouse or reagentarium in the laboratory).
9. Type of activity considering maintenance, normal working activity, waste management, cleaning.

Each Laboratory Responsible collected data on chemical risk by filling in the tables for the items mentioned above. All data was then sent to the Prevention and Protection Service for the subsequent processing phase.

2.3. ISPRA data analysis

In order to determine the level of exposure to hazardous chemical agents, all the elements characterising the exposure must be taken into consideration according to the following algorithm:

$$L = \sum_{i=1}^{n} \frac{Hi \cdot Ti \cdot Si \cdot Ei \cdot Qi \cdot Ui \cdot Di \cdot Ai}{Ki \cdot VLi}$$

where:

L: is the level of exposure of the individual worker to the ith hazardous chemical agents;

H_i: is the sum of the corresponding hazard factors characterising the risky properties R of the ith hazardous chemical agents, indicated by the specific risk phrases;

T_i: is the sum of the corresponding exposure factors T characterising the type of exposure to the ith hazardous chemical agents;

S_i: is the physical state factor S corresponding to the physical state of the ith hazardous chemical agents;

E_i: is given by the value of the duration factor E corresponding to the exposure time to the ith hazardous chemical agents in the reference week weighted with respect to the time factor;

Q_i: is given by the value of the quantity factor used Q corresponding to the quantity of the ith hazardous chemical agents used in the reference week;

D_i: is given by the value of the stored quantity factor D corresponding to the quantity of the ith hazardous chemical agents held in the reference week;

U_i: is the mode of use factor U corresponds to the mode of use of the ith hazardous chemical agents and the possibility of dispersion in the air;

A_i: is given by the value of the work factor A corresponding to the working circumstances in which the ith hazardous chemical agents is used;

K_i: is the worker's prevention and protection factor K, corresponding to the safety and hygiene elements present and effective against risks;

VL_i: is the limit value of the reference hazardous chemical agent where detectable (ppm).

Each value is then associated with a numerical coefficient based on the tables provided in the mentioned guidelines. For each ith hazardous chemical agents used by each operator, a Li value is obtained; the Li values obtained for each substance are added together to express the total exposure L of that given operator, assuming as a precaution, that all the substances declared used in a week were used in a single day. The level of exposure (L) was summarized in Table 2. Overall, the proposed method provides two distinct results: one for safety and the other for health. If L is less than 1, there is an irrelevant risk for health and if there is a low risk for safety too, the provisions of articles 225, 226, 229, and 230 of Legislative Decree 81/2008 are not applied (there is no obligation to carry out a more in-depth assessment). The data were expressed as a function of the Homogeneous Group, i.e. groups of workers who carry out the same activities in the same work environment. The data relating to the chemical risk assessment of each laboratory were illustrated to the workers in a series of in-person training meetings.

Table 2. Total exposure levels L for individual worker and Exposure levels per substance Li and for individual worker.

Overall Exposure Levels L for individual worker	
$L \geq 1$	Non-negligible risk to workers' health
$L<1$	Irrelevant risk to workers' health
Exposure Levels for each substance L_i and for each individual worker	
$L_i \geq 1$	Very High Health Risk
$0.1 \leq L_i < 1$	High Health Risk
$0.01 \leq L_i < 0.1$	Medium Health Risk
$0.001 \leq L_i < 0.01$	Low Health Risk

The collected data allowed to assess the carcinogens and mutagens risk. In this case, to determine the level of exposure to carcinogens and mutagens, all the elements characterising the exposure must be taken into consideration according to the following algorithm:

$$L_{canc} = \sum_{i=1}^{n} \frac{Pi \cdot Si \cdot Ti \cdot Qi \cdot Ei \cdot Fi}{6.25}$$

where:

L_{canc}: is the level of effectiveness of protection measures;

P_i: is the efficiency and effectiveness factor of collective protection devices during the use of ith carcinogenic/mutagenic agent;

S_i: is the factor depending on the process temperature of the ith substance;

E_i: is the duration factor corresponding to the exposure time of the ith carcinogen/mutagen expressed in minutes/day;

Q_i: is the quantity factor used corresponding to the quantity of the ith carcinogenic/mutagenic agent used in the single manipulation;

F_i: is the frequency factor of use for the ith substance expressed in days/year.

Each value is then associated with a numerical coefficient based on the tables provided in the mentioned guidelines. For each used hazardous substance, a Lcanc i value is obtained; each Lcanc i are added together to express the total exposure Lcanc of that given operator. In the case of carcinogens and mutagens there are no threshold values as for hazardous chemical agents, but workers are considered exposed or not exposed (all-or-nothing theory) (Table 3). If a Lcanc value lower than 1 is obtained, it can be stated that the prevention and protection interventions in place (art. 237 of Legislative Decree 81/2008) are effective (not exposed worker). Otherwise, if the Lcanc value is greater than or equal to 1 (exposed or, as precautional route, potentially exposed worker), it is necessary to intervene with additional protection measures (included the Health Surveillance, art. 242 and 243 of Legislative Decree 81/2008), followed by a new evaluation of the effectiveness using the proposed algorithm.

Table 3. Classification as exposed or not exposed based on the level of exposure to the substance.

Overall exposure levels $L_{canc\,i}$ for individual worker	
$L_{canc} \geq 1$	Exposed
$L_{canc} < 1$	Not exposed/potentially exposed
Exposure levels for each substance $L_{canc\,i}$ and for each individual worker	
$L_{canc\,i} \geq 1$	Exposed
$L_{canc\,i} < 1$	Not exposed/potentially exposed

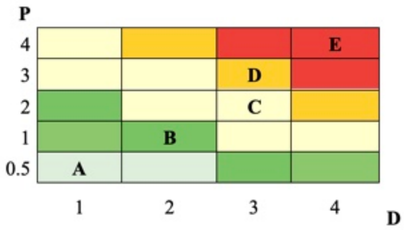
All the data (chemical, carcinogens and mutagens) were expressed as a function of the Homogeneous Group, i.e. groups of workers who carry out the same activities in the same work environment. The data relating to the chemical risk assessment of each laboratory were illustrated to the workers in a series of in-person training meetings.

2.4. Biological risk assessment

The biological risk assessment must consider all available information relating to the characteristics of the biological agent (classification based on Annexe XLVI of Legislative

Decree 81/08) and the operating methods (handling time, presence of PPE, etc.). In our workplaces, the risk assessment followed the method proposed by INAIL [13], based on an algorithm that receives information from two distinct questionnaires: one for intentional use (Questionnaire A) and one for potential exposure (Questionnaire B). After identifying the tasks that operate in the work context under examination, we proceed to collect the information necessary to assign numerical values to the coefficients that compose the algorithm, for the calculation of Probability (P, defined as the possibility that an individual exposed to biological agents becomes contaminated) and Damage (D, identified by the dangerousness of the biological agent) (Figure 1):

Figure 1. Risk calculation matrix and related risk levels



Risk level	Classification
A	Acceptable
B	Low
C	Medium
D	High
E	Unacceptable

The algorithm works with the following coefficients:

$$P = C\ x\ \left[\sum_{1}^{6} Fi + 1\right]/7$$

where:

C: is the presumed degree of contamination of the risk sources (from 1 considered very low, to 4 considered high as for the intentional use);

F: from 1 to 6 identify the characteristics that, according to the adopted model, influence the biological risk.:

F1 Quantity;

F2 Frequency;

F3 Structural features;

F4 Operating procedures;

F5 PPE;

F6 Safety training.

The final output gives the Risk value (R) following the formula:

$$R = P\ x\ D = \left\{C\ x\ \left[\sum_{1}^{6} Fi + 1\right]/7\right\}\ x\ D$$

Also, in this case, the data were expressed as a function of the Homogeneous Group, i.e. groups of workers who carry out the same activities in the same work environment. The data relating to the biological risk assessment of each laboratory were illustrated to the workers in a series of in-person training meetings.

3. Results and Discussion

The safety of the environment, campus, students, staff, and laboratory workers is the responsibility of scientific institutions, including universities. The risks and hazards of the handled materials and technical or scientific devices used must be fully understood by all laboratory personnel [14]. Over the past decade, laboratory safety in academic settings has been receiving a lot of attention because of several serious incidents [15]. A significant portion of this focus has been on developing methods for educating and training new investigators in chemical safety science [16]. A positive culture of safety is recognised as essential for promoting safer behaviour in a laboratory environment [17-19] as well as an effort of integration of this item into the academic and research experience [20].

3.1. Chemical risk

The teaching laboratories in university environments are characterised by the extreme variability of the chemical compounds, even at low concentrations. However, also when chemical agents are used for a short time and in diluted form, university teaching laboratories can present several safety problems, often linked to a combination of inexperience and procedural issues. Inexperienced students may underestimate the dangers of substances diluted or used briefly; for example, a pipetting error or accidental spill can still provoke corrosion/irritation burns. In addition, we must consider inhalation exposure because volatile compounds can evaporate even when diluted. If the activity is not conducted under a fume hood or if ventilation is insufficient, there is a risk of acute or chronic exposure. Many common organic solvents (such as ethanol and acetone) are flammable, even when diluted. If procedures are not strictly monitored (e.g., heating over an open flame instead of an electric hotplate or instrument malfunction), the risk of ignition remains. Moreover, accidental splashes of even diluted solutions can irritate the eyes and skin, especially if Personal Protective Equipment (PPE), such as safety goggles or gloves, is absent or misused. Finally, improper disposal of liquid residues (even at low concentrations) can cause environmental problems or hazardous reactions with other residues.

In the literature, chemical hazards have been investigated in laboratory and hospitals settings [21-23], as well as in research university laboratories [24-26], with different methodologies [7]. However, poor attention was dedicated to teaching laboratory involving students considered as workers [27]. There is no standard or specific method applicable to chemical risk assessment, and each Responsible for Health and Safety can use the most useful and adequate one for the examined setting. Obviously, each method has advantages and disadvantages, and only the role and the experience of the Responsible for Health and Safety can be decisive. In this investigation, involving teaching laboratory settings, we have decided to utilise the ISPRA model. The data collected from the examined teaching laboratories at Urbino, identified 192 substances and reagents that could have an effect on the health of workers. Among these, 16 are classified as carcinogens/mutagens, most of which (9/16) used in biological laboratories activities (Lab 5 and Lab 6) (Figure 2). Regarding the carcinogenic/mutagenic agents present in the various teaching laboratories, it has been verified with the supervisors that they are handled only by the technical assistants and not directly by the students.

Figure 2. Distribution of chemical agents and carcinogens/mutagens among the teaching laboratories of Urbino University.

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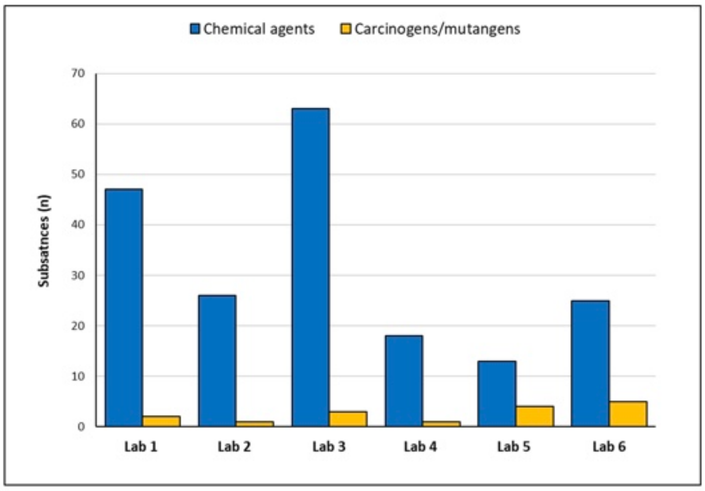

Data related to chemical risk assessment in teaching laboratories of Urbino University are summarized in Table 4.

Table 4. Chemical risk assessment in teaching laboratories of Urbino University. Data are subdivided based on the different activities performed in each laboratory.

Teaching laboratory	Activity	L chim	Risk level	L canc	Risk level
Lab 1	Drug Formulation	0.4042	Irrelevant	0.0533	Present; adequate protective measures
Lab 2	Drug Analysis	0.0105	Irrelevant	0.0067	Present; adequate protective measures
Lab 3	Analytical Chemistry	0.0431	Irrelevant	/	/
Lab 3	Quantitative Drug Analysis	111	Irrelevant	0.1000	Present; adequate protective measures
Lab 4	Drug Extractive Preparations	0.0076	Irrelevant	0.0167	Present; adequate protective measures
Lab 5	Biochemistry	1.304	Not irrelevant	0.1333	Present; adequate protective measures
Lab 5	Microbiology	0.0707	Irrelevant	0.2000	Present; adequate protective measures
Lab 5	Biochemistry	0.0022	Irrelevant	0.2000	Present; adequate protective measures
Lab 5	Biology	0.0022	Irrelevant	/	/
Lab 6	Biology	0.5676	Irrelevant	312	Present; adequate protective measures

As shown, all the activities carried out in the examined teaching laboratories resulted in L chim values lower than 1, with the only exception of one activity in Lab 5 (1.333); in this case, the chemical agent responsible of the high L value was identified in 1-imidazole, used during a biochemistry activity but handled, as reported above, by a technical assistant to guarantee the safety of the students. Regarding the carcinogens/mutagens, the L canc values were always lower than 1 and, in any case, the protective measure applied in these laboratories are considered adequate for the activities carried out. The obtained results allow us to define the corrective measures for a risk reduction action plan related to the identified chemical hazards, the most important of which is the substitution of the hazardous agent with one that is non-hazardous or less hazardous. In teaching laboratories, this measure is easily put into practice because the work protocols present a wide margin of variability compared to a protocol used in research activities (reproducibility of experiments, standardisation of methods, cost and availability of reagents, etc.). From data analysis, we can stress that the role of educational training programs is fundamental to improve the students' risk perception before starting laboratory activities, as also demonstrated by the experience of other authors [28-30].

3.2. Biological risk

Regarding biological risk, the use of Group 2 microorganisms (e.g., Staphylococcus aureus, Salmonella spp.) in teaching laboratories can be associated with numerous problems linked to inexperienced students. One is represented by aerosol formation created in common lab operations like shaking, centrifugation, pipetting (especially without a pipetting aid), or opening containers, activities that generate microscopic droplets containing microorganisms that can be inhaled (inhalation risk). The use of sharp objects (needles, loops, broken glassware) can cause accidental parenteral inoculation, transferring the biological agent into the bloodstream while indirect ingestion occurs through hand contamination followed by contact with the mouth/food/cigarettes (often by violating basic rules such as eating or drinking in the lab). Moreover, spills or splashes can contaminate work surfaces and equipment. creating a risk for subsequent users if not properly decontaminated. In this context, the figure of supervisors and the presence of formalised security procedures should guarantee the correct execution of these procedures.

Data related to biological risk assessment in teaching laboratories of Urbino University are reported in Table 5 and refer to each activity carried out in the considered laboratories. Risk values are between 0.29 (for biotechnology activity in Lab 5) and 3.43 (for microbiology activity in Lab 5 and Lab 6). In detail, among the examined activities with potential exposure, 5 resulted in an acceptable risk level (83%) and only one resulted in a medium risk level (17%). In the case of the intentional use, all the examined activities showed a medium risk level, ranging from 2.29 to 3.43, indicating that the activities are carried out following the supervisor's instructions in compliance with current legislation on health and safety in the workplace. These results highlight the importance of the training provided to students attending the laboratories, as well as the training and awareness of teachers regarding safety [11,29].

Table 5. Biological risk assessment in teaching laboratories of Urbino University. Data are subdivided based on the different activities performed in each laboratory as well as on the intentional use or potential exposure.

Teaching laboratory	Activity	Use	Risk values	Risk level
Lab 5	Nutritional Hygiene	Intentional use	2.29	Medium
Lab 5	Nutritional Hygiene	Potential exposure	0.43	Acceptable
Lab 5	Diagnostic Hygiene	Intentional use	2.29	Medium
Lab 5	Applied Microbiology	Intentional use	2.86	Medium
Lab 5	Food Microbiology	Intentional use	3.43	Medium
Lab 5	Food Microbiology	Potential exposure	0.86	Acceptable
Lab 5	Biochemistry	Potential exposure	0.57	Acceptable
Lab 5	Biology	Intentional use	2.29	Medium
Lab 5	Biotechnology	Potential exposure	0.29	Acceptable
Lab 6	Food Microbiology	Intentional use	3.43	Medium
Lab 6	Food Microbiology	Potential exposure	3.43	Medium
Lab 6	Biotechnology	Potential exposure	0.43	Acceptable

Conclusions

On the basis of the obtained results, residual risk mitigation measures have been developed and implemented for existing activities: for example, the handling of certain hazardous substances that are not easily replaceable, is assigned, on a rotating basis, to technical assistants. Moreover, if necessary, environmental monitoring can be scheduled under specific working conditions. Indeed, it should be noted that teaching activities with dozens of students cannot always afford the continuous use of existing fume hoods or microbiological safety hoods, both due to their limited number in teaching laboratories and logistical scheduling constraints. For this, the time of exposure to chemicals or handling of microorganisms must be reduced to the minimum strictly necessary and always with the adoption of adequate DPI.

The risk assessment presented here was conducted considering technical assistants and course instructors, rather than the students themselves; this approach is certainly more conservative, given that the quantities of chemical agents handled and the duration of student exposure are lower than those analyzed for the university staff during the laboratory activities. The fundamental criticality in this type of risk assessment lies in the paradox of legal equivalence: although Legislative Decree 81/08 equates students with workers, classical algorithmic tools (such as those herein used) are designed for industrial or healthcare settings, calibrated for chronic and professional exposure profiles. Applying these algorithms to university academic staff or teaching assistants to infer student risk overlooks the stochastic and transient nature of educational activities. While permanent staff exhibit repetitive but conscious exposure, students are characterized by acute and sporadic exposure, compounded by a high coefficient of procedural inexperience. Deterministic models based on fixed exposure are unable to parameterize the "crowding effect" or the dynamic environmental variables of a packed laboratory, where a single individual's human error can collectively compromise the safety layout. Consequently, risk assessment in this field remains an "open question," as it currently measures the supervisor's ability to protect themselves rather than mapping the specific vulnerability of the learner during the educational process. It would be desirable to develop a standardized tool for this purpose, alongside the standard risk assessment methods used in research laboratories, that would provide more information on risk exposure as well as on the risk perceptions by the students.

Authors' contribution

R. Campana: Conceptualization, Writing – original draft, Data curation, Writing – review & editing. F. Acero: Methodology, Formal analysis. S. Cangiotti: Review & editing. V. Musumeci: Review & editing. A. Gambarara: Project administration, Review & editing.

Declaration of competing interest

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