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Safety issues in Polish chemistry textbooks

Aspectes de seguretat en els llibres de text de química polonesos

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abstract

In this article, we analyze textbooks in regard to safety within the chemistry laboratory. Successful laboratory work requires the fulfillment of safety conditions that protect students. Teachers rely on textbooks and so we looked at six upper secondary level textbooks. We examined the number and type of experiments included in the books and also to the degree safety instructions were refered to in school experiments. Teacher´s guidebooks and expert reviews were also evaluated.

keywords

Safety in chemical laboratory, textbook analysis, research, expert review.

resum

En aquest article s'analitzen llibres de text des del punt de vista de la seguretat al laboratori. Per dur a terme el treball experimental amb èxit, és necessari el compliment de les condicions de seguretat que protegeixen els estudiants. El professorat es basa en els llibres de text; per aquest motiu s'han analitzat sis llibres de text de química de batxillerat. S'han examinat sobre la base del nombre i tipus d'experiments i del nivell d'instruccions de seguretat en relació amb les pràctiques escolars. També s'han avaluat les guies del professor i informes d'experts.

paraules clau

Seguretat en el laboratori de química, anàlisis de llibres de text, informes d'experts.

Introduction

Investigations involving practical work are essential in thinking activities (Watson 1998): experimentation is the basis of chemistry teaching and learning. It is also obvious that the laboratory plays a major role in the education of scientists (Bound 1986). A crucial requirement of successful laboratory work is the fulfillment of safety conditions which protect students. To achieve this, teachers need support in the form of different kinds of curricular materials and training, for example, books and video clips. In Northern European countries, teachers have access to excellent safety guide-books and handouts (UK - ASE 1996, 2001*a*, 2001*b* Germany - Richtlinien 1995, Sweden – Helleberg 2002 etc.) which are provided by the government or teachers' associations. That kind of information is also included in the students' textbooks.

Background and aims

Since its accession to the European Union in 2004, Poland has ahered to the EU directives for safety in chemical laboratories.

Teachers had to introduce changes in laboratories and in the curricula, through the necessity of familiarizing the students with International Chemical Safety Cards. This was something new for teachers, because there had been no previous opportunity to learn about this during the teacher training. Nowadays, they have to acquire this knowledge on their.

Because of a lack of time, skills and research instruments, teachers often have problems to choosing the best textbook. Teachers need to be aware of the problems and limitations of their chosen textbook

The most easily available curricular materials for teachers are textbooks and teacher's books, many teachers rely on these books, especially when they are novices or are teaching outside their main area of study. There are collections of experiments which were published in the 1970s, and also some translated books, however, textbooks remain the principle source of information for teachers. We decided to analyze Polish textbooks and guides by focusing on safety within the laboratory.

Analysis of textbooks is a popular research area (Bakonis, 1998; Clément 2005, 2008, Koulaidis, 2004; Pingel, 1999; Weinbrenner, 1992), especially when they are teaching outside their area of expertise (Stern & Roseman, 2004). Macro and micro-analysis are applied, as well as qualitative and quantitative approaches. Conferences or seminars are devoted this research e.g. IOSTE International Meeting 'Critical Analysis of School Science textbooks', Tunisia, 7-10 February 2007 or 'The Past and Future of Chemistry textbooks' 9th ECRICE, Istanbul, 6-9 July 2008.

Existing textbook analyses focus on the evaluation of content in relation to scientific disciplines, and to educational goals i.e. whether it is correct, complete, comprehensible, etc. (Snyder & Broadway, 2004; Stern & Roseman, 2004). Besides this, the contents of textbooks are analysed using the KVP scheme: K –scientific knowledge, V –values as ideologies, philosophies or ethics, –the social practices of the authors and publishers of the textbooks as well as that of the teachers (Clément, 2006).

Research on chemistry textbooks is quite rare in Poland, although this kind of analysis could prove very useful for teachers, who have to choose from 16 textbooks for secondary level. Because of a lack of time, skills and research instruments, teachers often have problems to choosing the best textbook. Teachers need to be aware of the problems and limitations of their chosen textbook. As a large part of the textbook is taken up by illustrations, teachers need to be aware of the impact the images will have on students.(Cook, 2008).

As there are no Polish language journals, which publishes reuslts of research, any research would have to be published in English, which can be problematic for those teachers who can't understand English. In spite of the official reviewing process, textbooks still contain many misconceptions (Reizer & Stopa 2004). Therefore, the Polish Academy of Arts and Sciences (PAU) decided on a special commission to prepare the list of textbooks which are recommended to schools. This was followed by the publication of reviews done by members of PAU: usually 2 reviews for every investigated textbook (PAU 2006).

Methodology

Textbooks were analyzed in order to determine the chemical safety problems in school laboratories. Other types of documents were analyzed in order to reflect the authors' opinions about the importance of health and safety issues in chemistry learning.

Three types of documents were investigated:

- Basic/direct documents - chemistry textbooks published between 2004- 2007.
- Indirect documents - corresponding guides for teachers.
- Opinion forming /Consultative Documents - PAU reviews.

Descriptive and comparative studies were done according to the methodology described Lobocki 2006, Pilch 1995, and Skrzypczak 2003

- Both text and graphic material were investigated.
- Content analysis techniques were applied.
- Interpretation of documentation in consideration of the above mentioned research problems was carried out

A) Textbooks

In the first stage of research we chose six chemistry textbooks designed for upper secondary level students, which had been previously reviewed by PAU (see table 1, and fig.1).

Textbook	Authors	Level
1	A&B	basic
2	A&B	extended
3	C&D	basic and extended, part 1
4	C&D	basic and extended, part 2
5	C&D	extended, part 3
6	E&F	basic

Table 1. List of analyzed textbooks.

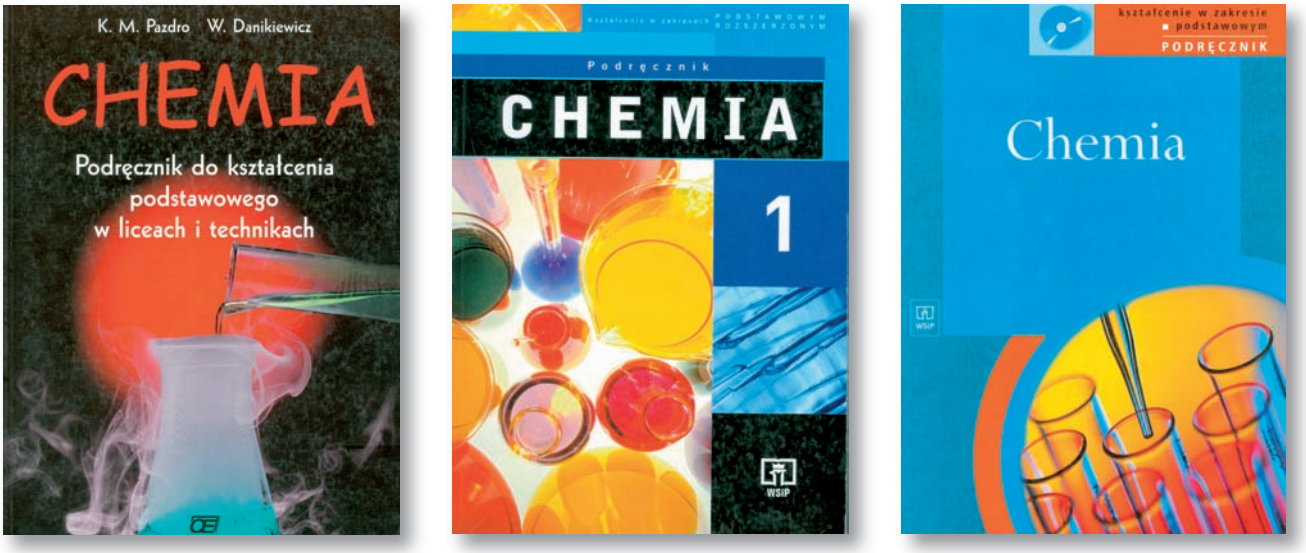


Fig. 1 Examples of textbook covers.

The following research questions were asked:

• How important is laboratory work in a didactic process from the author point of view? The answers were based on the number of experiments

• How important is students' laboratory work in a didactic process from the author point of view? The answers were based on a comparison of the number of the experiments proposed for teachers, demonstrations, and those for students

• How is laboratory work presented in the textbook:

- Which experiments were selected for presentation and how did it affect their description in the textbook.
- What is the scope of the chemical safety issue introduced in the textbook (labeling, pictograms, R and S phrases, International Chemical Safety Cards (MSDS), safety rules etc.)? – in the text and in the graphic material (pictures, drawings, photos)
- Was the description of the experiment presented in the book done properly? The answer was based on assessment of the condition of experiments, cautions/warnings - information about chemical hazards, personal protective equipment, disposal of chemical waste, safety of basic chemical operations etc.

B) Guidebooks for teachers

Six teachers guides were investigated. The following research question were asked: 'How important is laboratory work in a didactic process from the author's point of view?'. The answer was based on the number of experiments mentioned there, number of experiments described from a safety point of view, and the presence of general safety remarks.

How is laboratory work presented in the textbook:
Which experiments were selected for presentation and how did it affect their description in the textbook.
What is the scope of the chemical safety issue introduced in the textbook

C) Reviews of chemistry textbooks

PAU has published eleven reviews of the six textbooks of chemistry for students of upper secondary school. Those reviews were investigated.

The following research questions have been asked:

How important is laboratory work in a didactic process from the reviewer's point of view? – the answer was based on the number of remarks concerning laboratory work

Quality of reviews – the answer was based on the nature of criticism: both positive and negative comments

Results and conclusions

Results show that, generally speaking, there are two main approaches in the way of selection of experiments proposed for textbooks:

1. Only safe experiments are suggested, since their description does not require (in the authors' opinion) emphasis on potential hazards, as a negative image of chemistry could be created (textbook 1 and 2).

2. Potentially hazardous experiments are also suggested, however the descriptions contain very

detailed instructions to the way the experiments should be carried out (textbooks: 3, 4, 5 and the corresponding guidebooks), or with limited description (textbook 6). It is thought that 'dangerous' activities might generate the idea that chemistry, while having possible hazards, can be fascinating.

In our research we found that Polish researcher and teachers who are authors of chemistry textbooks, or their reviewers, don't have similar opinions.

A) Comparison of chemistry textbooks

Specific results are shown in Table 2. All of the investigated textbooks proposed a similar numbers of experiments. A percentage of the suggested experiments for independent student practice is also explained, and demonstrates a direct relation to their degree of complexity (simpler experiments are more often suggested for independent rendition) which appears to be an obvious fact. The following methodological aspects are linked to these issues:

- The more complicated the experiments, the more difficult they are for inexperienced students to do. Because of this, they can take up too much valuable classroom time**.** This can, in turn, increase the possibility of an accident. These experiments should be demonstrated by a teacher, though independent student activities are considered to be very valuable and the activities of students during experiment demonstrations are considerably decreased.
- More complicated experiments are much more interesting to student as they reflect more accurately real life possibilities.

Text analysis

There is no separate chapter in the majority of textbooks pertaining to the safety rules in the laboratory. Similarly, there is no information about MSDS nor about the labeling of chemical substances. The last issue can easily be explained: it transpires that textbooks have a considerably long production cycle, and as the requirement to use MSDS in the Polish pre-university education system was only introduced while these textbooks were in development. It also requires an "induction" period to allow to authors digest possible new ideas to be included in these textbooks (Fig. 2).

A considerable difference exists in the degree of complexity and perplexity of proposed experiments, and of the required equipment (in particular, between textbooks 2 and 3). The authors of the

	textbook 1	textbook 2	textbook 3	textbook 4	textbook 5	textbook 6
Total number of proposed experiments	102	113	99 (basic)	100	33	73
% of students experiments	88 %	66 %	44.5 % (basic)	44 %		99 %*
Chapter focused on laboratory work	–	–	6 first pages	–	–	2 pages inside the book
Information about labeling of chemical products and MSDS	–	–	Pictograms	–	–	–
Personal protective equipment presented on pictures	No elements of human body	No elements of human body	Laboratory coat, gloves	Gloves	Gloves	Some students but no protective equipment
Example of potential dangerous experiments: use of methanal	Used No warnings	Not used	Not used	Used, gloves and fume cupboard suggested	Not used	Used, caution regards to toxicity
Disposal of chemical waste	–	–	Only Cl_2 into $Na_2S_2O_3$ solution	–	Br_2 into $Na_2S_2O_3$ solution, HC_2Ag into HCl,	Only NO_2 into NaOH solution
Dangerous experiments proposed (example)	–	–	White phosphorus, CO			Br_2

*not clearly defined.

Table 2. Analysis of the textbooks' content.

Pierwsza pomoc w nagłych wypadkach

1. W razie oparzenia gorącym przedmiotem należy dane miejsce natychmiast ochłodzić zimną wodą. W wypadku silniejszego oparzenia niezbędna jest pomoc lekarska.
2. Miejsce oparzone zasadami (NaOH, KOH itp.) należy szybko i dokładnie spłukać wodą, a następnie przemyć 1% roztworem kwasu octowego i ponownie spłukać wodą.
3. W razie oparzenia kwasami należy dane miejsce obficie spłukać wodą, po czym przemyć 1% roztworem sody (węglanu sodu).

Na opakowaniach niektórych produktów są umieszczone znaki graficzne informujące o ich działaniu. Używając takich produktów, należy zachować szczególną ostrożność.

Fig.2. Short introduction of safety issues.

Fig. 3. Example on showing use of personal protection equipment

Fig.4. Example of incorrect representation

textbooks which contained descriptions of more difficult experiments placed much more emphasis on precise descriptions, and added full photographic documentation which enabled students to become acquainted with particular stages of the experiments and their results, even if there was no possibility to conduct those experiments at school.

Descriptions of chemical experiments are not always correct (see example with methanal-Table 2).

A lack of recommendations to use personal protection equipment, such as gloves, in some textbooks, are becoming more and more popular, even in the Eastern and Middle Europe households. This confirms the outdated approach of the authors of certain textbooks. This situation calls for a change. A teacher who experiments with concentrated acids, bases, or bromine water solutions, etc. should use personal protective equipment and the students must be accustomed to handling potentially dangerous substances.

The disposal of chemical wastes remains a neglected subject in textbooks. On the one hand, when dealing with less hazardous and diluted substances, special attention should be paid to heavy metal salt solutions, halogens, organic solvents, and chlorine derivatives of hydrocarbons.

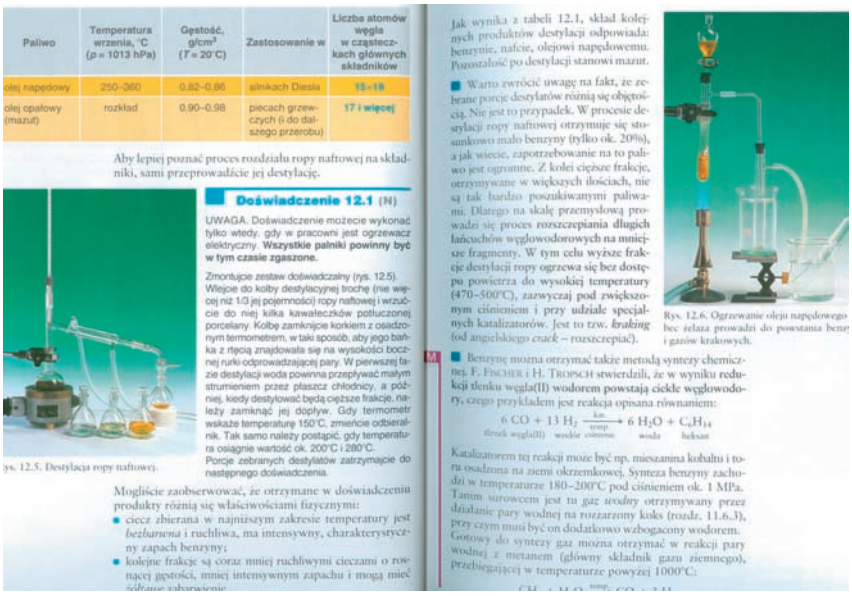
On the other hand these problems could not be solved in actual school environments in Poland. This is reflected in the contents of the textbooks.

The disposal of chemical wastes remains a neglected subject in textbooks. Special attention should be paid to heavy metal salt solutions, halogens, organic solvents, and chlorine derivatives of hydrocarbons

Iconographic Analysis

The errors (incorrect representation) in drawings, pictures and photos are worrisome for various reasons, such as:

- A misunderstood approach to saving on space (Editor's decision?): Two process stages are combined in one illustration while in reality they take place at different locations and times. For example, a flaming evaporating dish is placed underneath a cooler one which apparently represents distillation and ignition of one of the products *after* the process is complete (see fig.4).
- Negligence (?) — A picture showings diesel fuel being heated with an open flame, while on the previous page of the same textbook a heating jacket is used for crude oil distillation (see fig.5).



Paliwo	Temperatura wrzenia, °C (p = 1013 hPa)	Gęstość, g/cm³ (T = 20°C)	Zastosowanie w	Liczba atomów węgla w cząsteczkach głównych składników
olej napędowy	250–360	0.82–0.86	silnikach Diesla	15–18
olej opałowy (mazut)	rozkład	0.90–0.98	piecach grzewczych (i do dalszego przerobu)	17 i więcej

Aby lepiej poznać proces rozdziału ropy naftowej na składniki, sami przeprowadźcie jej destylację.

Doświadczenie 12.1 (N)

UWAGA. Doświadczenie możecie wykonać tylko wtedy, gdy w pracowni jest ogrzewacz elektryczny. **Wszystkie palniki powinny być w tym czasie zgaszone.**

Zmontujcie zestaw doświadczalny (rys. 12.5). Wlejcie do kolby destylacyjnej trochę (nie więcej niż 1/3 jej pojemności) ropy naftowej i wrzućcie do niej kilka kawałeczków porcelany. Kolbę zamknijcie korkiem z osadzonym termometrem, w taki sposób, aby jego bańka z rtęcią znajdowała się na wysokości bocznej rurki odprowadzającej pary. W pierwszej fazie destylacji woda powinna przepływać małym strumieniem przez płaszcz chłodnicy, a później, kiedy destylować będą cięższe frakcje, należy zamknąć jej dopływ. Gdy termometr wskaże temperaturę 150°C, zmieńcie odbieralnik. Tak samo należy postąpić, gdy temperatura osiągnie wartość ok. 200°C i 280°C. Porcje zebranych destylatów zatrzymajcie do następnego doświadczenia.

Rys. 12.5. Destylacja ropy naftowej.

Możliście zaobserwować, że otrzymane w doświadczeniu produkty różnią się właściwościami fizycznymi:

- ciecz zbierana w najniższym zakresie temperatury jest *bezbarwna* i ruchliwa, ma intensywny, charakterystyczny zapach benzyny;
- kolejne frakcje są coraz mniej ruchliwymi cieczami o rosnącej gęstości, mniej intensywnym zapachu i mogą mieć żółtawe zabarwienie.

Jak wynika z tabeli 12.1, skład kolejnych produktów destylacji odpowiada: benzynie, nafcie, olejowi napędowemu. Pozostałość po destylacji stanowi mazut.

Warto zwrócić uwagę na fakt, że zebrane porcje destylatów różnią się objętością. Nie jest to przypadek. W procesie destylacji ropy naftowej otrzymuje się stosunkowo mało benzyny (tylko ok. 20%), a jak wiecie, zapotrzebowanie na to paliwo jest ogromne. Z kolei cięższe frakcje, otrzymywane w większych ilościach, nie są tak bardzo poszukiwanymi paliwami. Dlatego na skalę przemysłową prowadzi się proces rozszczepiania długich łańcuchów węglowodorowych na mniejsze fragmenty. W tym celu wyższe frakcje destylacji ropy ogrzewa się bez dostępu powietrza do wysokiej temperatury (470–500°C), zazwyczaj pod zwiększonym ciśnieniem i przy udziale specjalnych katalizatorów. Jest to tzw. *kraking* (od angielskiego *crack* – rozszczepiać).

Rys. 12.6. Ogrzewanie oleju napędowego bez żelaza prowadzi do powstania benzyny i gazów krakowych.

Benzynę można otrzymać także metodą syntezy chemicznej. F. Fischer i H. Tropsch stwierdzili, że w wyniku redukcji tlenku węgla(II) wodorem powstają cieklе węglowodory, czego przykładem jest reakcja opisana równaniem:

$$6\,CO + 13\,H_2 \xrightarrow[\text{temp.}]{\text{kat.}} 6\,H_2O + C_6H_{14}$$

tlenek węgla(II) wodór ciśnienie woda heksan

Katalizatorem tej reakcji może być np. mieszanina kobaltu i toru osadzona na ziemi okrzemkowej. Synteza benzyny zachodzi w temperaturze 180–200°C pod ciśnieniem ok. 1 MPa. Tanim surowcem jest tu *gaz wodny* otrzymywany przez działanie pary wodnej na rozżarzony koks (rozdz. 11.6.3), przy czym musi być on dodatkowo wzbogacony wodorem. Gotowy do syntezy gaz można otrzymać w reakcji pary wodnej z metanem (głównym składnikiem gazu ziemnego), przebiegającej w temperaturze powyżej 1000°C:

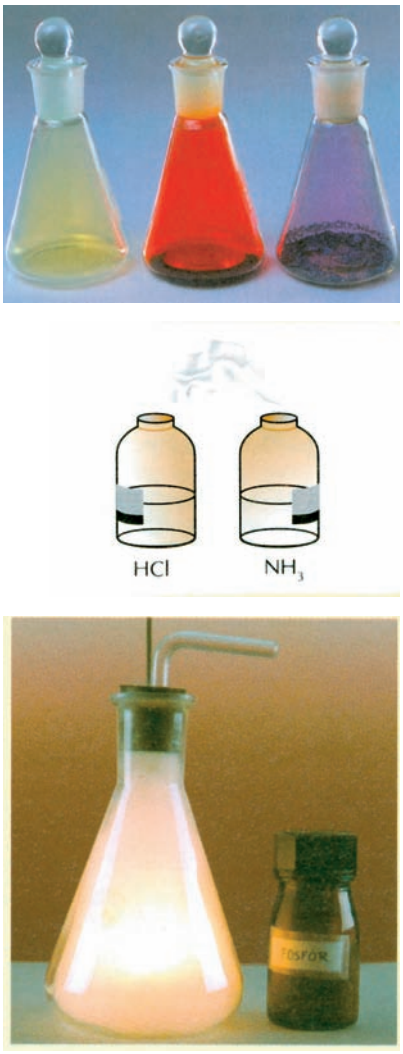


Fig. 6. Examples of simplified pictures Cl_2, Br_2, I_2, acid and base, burning of phosphorus.

In some textbooks, individuals who are conducting experiments are not wearing any protective equipment. Therefore this scenario must be considered in the following two ways:

- One idea is that the drawings and photos are simplified (see fig.6), and some details, for example a rendition of hand, do not distract the students, but rather allows them to concentrate on the most important issue. Which is chemical reaction
- On the other hand these kinds of drawings confirm their distance from reality, as the experiments are not carried out by themselves, and written instructions (for example, always wear gloves when you handle concentrated acid solutions) are not as effective as a visual image.

Likewise, the same may apply to photographs which show students in their usual clothing (textbook 6, see fig.7)) or in the laboratory coats.

- A student wearing a laboratory coat is unusual in Polish schools (apart from in the cases of professional education or extra-curricular activities), therefore this photograph could be construed as something unreal and distant from everyday school life
- Conversely, it seems that the photographs shown in a textbook should illustrate good laboratory practice, even though it may not be fully achieved it still serves as a good example.

Not all textbooks depict bottled substances, used in experiments, depicted in drawings or photos. Even if they are shown, they aren't properly labeled, with the exception of very new products (see fig.8).

On the other hand these kinds of drawings confirm their distance from reality, as the experiments are not carried out by themselves, and written instructions are not as effective as a visual image

Fig. 7. Student presents proper way of smelling chemical substances.

Fig. 8. Packing of chemical substances.

B) Comparison of guidebooks for teachers

Guidebooks can be very different (see table 3). A lack of guidance regarding safety remarks in some of the guidebooks is surprising when:

- Performing experiments is obligatory in the curriculum,
- Selection and description of an experiment is an obligatory task during the final examination.

C) Comparison of chemistry textbooks reviews

The review of chemistry textbooks by experts of PAU, contains 124 pages with a maximum of 41 lines on each page (total 5084 lines). Chemical safety issues are described on only 35 lines, which equates to 0.69 % of the total. This may suggest that:

- Safety issues are well described in textbooks,
- Reviewers do not find chemical safety issues important.

In the books that were looked at, we have shown that the experiments weren't sufficiently described, and that the reviewer's hadn't placed enough emphasis on these issues.

Some of the reviews contradict each other (see table 4). This could be caused by the different levels of experience that the reviewers have had in an actual classroom.

There are also some controversial and puzzling statements in the reviews:

"A necessity to wear protective rubber gloves is mentioned within a description of experiment to be conducted by the teacher — but the teacher should already know about it themselves." It appears that there cannot be sufficient warnings, in particular, if a number of chemistry teachers who had graduated from different faculties who had never had an opportunity to work in a

Guide	Number of experiments mentioned	Number of experiments described including safety issues	General remarks regarding safety issues
Guide 1	16	5	Safety goggles as a part of laboratory equipment
Guide 2	0	0	No mention of safety requirements for chemical experiments
Guide 3	99 (basic)	99 (basic) each experiment from corresponding textbook	Safety rules for carrying out experiments, emergency procedures, first aid kid
Guide 4	100	100, see above	Nothing more
Guide 5	33	33, see above	Nothing more
Guide 6	0	0	Fulfillment of legal regulations, final examination

Table 3. Comparison of guidebooks for teachers.

Reviewer	Textbook	Advantages of particular textbook	Disadvantages and other remarks
Reviewer III	Textbook 3	Many interesting and informative experiments, clear distinctive demonstrations and warnings on experiments ensured fulfillment of safety rules, general rules are described at the beginning of textbook.	Some of the experiments are too dangerous for students, especially in the schools which do not have properly equipped labs. Solvent evaporation using open fires. Lack of information about waste disposal. Better to use Mg than Na and Ca in the experiment with oxygen. Production of HCl(g) should be done using an exhaust. S + H2 too dangerous an experiment.
Reviewer II	Textbook 3	Many experiments, proper selection, experiments possible to conduct in a poor school lab.	Dangerous experiments: dissolving of gaseous HCl in water in order to obtain hydrochloric acid. The source of white phosphorus is not provided.

Table 4. Comparison of reviewer opinions.

There is lack of guidance regarding safety remarks in some of the guidebooks

In the books that were looked at, we have shown that the experiments weren't sufficiently described, and that the reviewer's hadn't placed enough emphasis on these issues

There are also some controversial and puzzling statements in the reviews

chemistry laboratory to a sufficient level of experience. Of the fifty-three chemistry teachers who took part in in-service teacher training at the Faculty of Chemistry at the Jagielonian University in 2007, fifty were biology graduates and only 3 teachers were chemistry graduates

"... only the dose is the deciding factor to influence physiological process in the living organism"— quote from textbook. "That is not true — since the type of chemical compound is a factor here" - quote from review. In this particular case, that textbook statement should be accepted as true (for example: excess of pure water could be harmful to human body) — although there are some substances with various concentrations which may potentially cause a possible hazard, for example, NaCl compound does not show allocations of R and S phrases, although a single dose of about 21 g for an adult weighing approximately 70 kg may be fatal (Toksykologia, 2005).

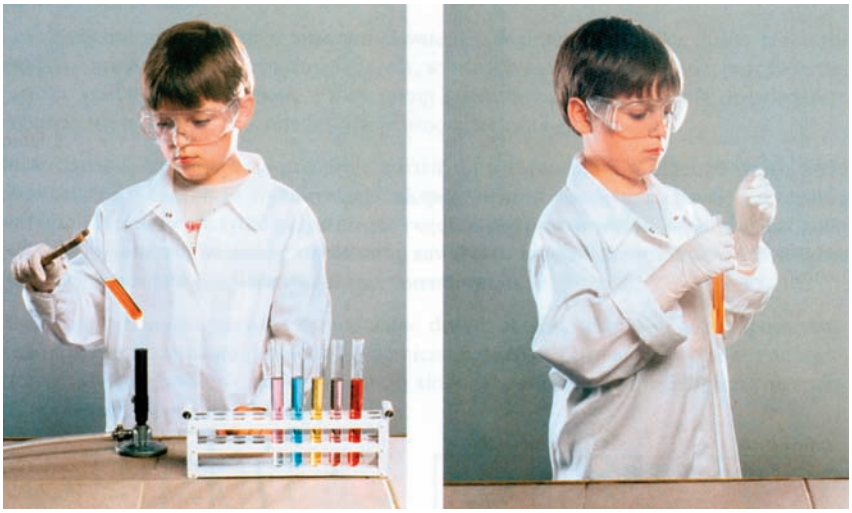


Fig. 9. Personal protective equipment presented in a new edition of a textbook published in 2009.

Recommendations

One of the fundamental questions, a researcher should ask is whether the undertaken research is useful and will contribute to improvements of the existing situation. For this reason, the research described above leads to the following recommendations for textbook authors and reviewers.

Textbooks

1. The selection of experiments recommended for teachers and students, and the methodology of descriptions always requires in-depth consideration of the number of experiments, the degree of difficulty, the degree risk, etc.

2. The reason why, in the majority of textbooks, there isn't a separate chapter describing the mandatory safety rules in a chemistry laboratory should be investigated to stop the situation continuing. The absence of this chapter in majority of textbooks and lack of information pertaining to the MSDS, should both be properly revised in future editions.

3. A recommendation to use personal protective equipment should be introduced even in cases of relatively safe experiments.

4. Information about waste disposal methods should be introduced, at least, in teacher's guidebooks.

5. Illustrations used in textbooks require full consideration, in order to achieve a balance between the simplicity of drawing and its usefulness, as well as the relationship between the realization of the experiment and good laboratory practices. Only properly labeled bottles should be shown. The conclusions of textbook editors must not lead to errors in the laboratory.

Illustrations used in textbooks require full consideration, in order to achieve a balance between the simplicity of drawing and its usefulness, as well as the relationship between the realization of the experiment and good laboratory practices

Guidebooks

Teacher guidebooks should put more emphasis on safety issues, which remain new and difficult for teachers. As these issues are of the utmost importance for a teacher student safety is the paramount objective.

Recently published textbooks for lower secondary education have shown an improvement in safety issues in the laboratory. 2011 will see the publication of new textbooks for the first year of upper secondary education. I hope that this improvement will continues (fig 9).

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