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EXPERIMENTS SAFETY - THE STATE OF ART AT SCHOOLS IN CZECHIA

Abstract: Chemistry experiments have been an issue of vivid discussion for more than fifty years now. Though there are many who hold a stand-offish position, there is a general notion chemistry experiments inherently belong to chemistry instruction. In this study, attention was given first to the frequency that Czech teachers at both lower and upper-secondary schools use experiments, demonstrations, laboratory work etc. A random, generalisable sample of 354 teachers filled in a questionnaire. The results showed experiments are used only seldom at lower-secondary schools and lyceums, more frequently at grammar schools, yet just "at least once a month". Safety showed as one of the barriers. The teachers expressed general knowledge about a norm which covers the topic, however in their further responses they expressed a lack of awareness of the compounds their students are allowed to work with. These findings are a call for measures such as: developing a database of well-described procedures including safety regulation remarks or a simplified, easy to follow list of up-to-date regulations.

Keywords: Chemistry experiment, science instruction, safety issues, teachers' attitudes

Introduction

The topic of experimental activities in chemistry education has recently been given attention especially thanks to the Journal of Chemical Education's special issue *Chemical Safety Education: Methods, Culture, and Green Chemistry* from January 2021, as well as a special issue called *New Visions for Teaching Chemistry Laboratory* announced in October 2021. Moreover, a wave of reports on experimental activities' performance in various teaching conditions during the pandemic naturally re-opened the issue of chemistry experiments' importance. A closer look at the literature (see below), nevertheless, reveals an interesting discrepancy. On one hand, there is the general notion that experimental activities are crucial for chemistry education. On the other, a significant number of authors questioned such activities' effectiveness and even/therefore the reason for their presence in chemistry instruction.

In traditional settings, a teacher's monologue leads students' listening (filtering) and note-taking. When watching a demonstration, watching their teacher conduct an experiment or conducting an experiment themselves, students' tasks are different, and so are their learning opportunities. On the contrary, in a student-centred setting, the teacher only drops a question (sometimes not even that) and students get to work. Naturally, during activities of experimental nature, students' performance also differs greatly. It is therefore important

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to distinguish among their different types, which are usually hidden under several labels in the literature. Abrahams and Millar [1] used the term 'practical work' to describe the science instruction method as an 'experiment', particularly in philosophy of science, generally taken to mean a planned intervention in the material world to test a prediction derived from a theory or hypothesis (p. 1947). The term 'laboratory work' describes only one of the organisational forms usually associated with a specialised classroom. Probably the most established distinction in this respect was presented by Banchi and Bell [2] who defined confirmatory, structured, guided and open inquiry based on the amount of scaffolding given to students. This definition serves the student experiments; however, it does not specify a teacher's - is she supposed to provide the question, methods/tools or even results? The same can be applied to *teacher demonstrations*. Does it only show a reaction or a phenomenon which supports the theory they just explained? Is it (just) a show which entertains, attracts, amazes students but does not bring any learning gain? Or does it initiate students' thinking, hypothesis formulation, observation or problem-solving skills with other intervening parameters being controlled by a teacher? The learning process towards the goals of science/chemistry education is obvious. Why not employ experimental activities in everyday chemistry instruction?

As the aforementioned is not always distinguished by researchers, the term *practical work* will be used to describe all activities of experimental nature in chemistry teaching in this paper.

The splendours and miseries of experimental work

At the beginning of the previous century, Smith [3] mentioned that chemistry topics should be generally presented to students first through textbooks, then laboratory exercises. Herewith, students know most of the experimental work results before it is performed. From a contemporary perspective, they get a little mental training and are dependent on what others say and develop little ability to know for themselves.

In general, researchers [4-7] agree that laboratory experience contributes to students' interest and attitude towards learning science, define students' experience in science, and might cause students to disengage from the subject area if it was poorly done [8]. According to Murray and Reiss's research [9], students find experiments enjoyable.

Recently, inquiry-based science education has become modern in science education. Promoted among others by Rocard et al. [10], this method is supposed to activate students and have them walk in scientists' shoes. Nevertheless, despite it being promoted for more than 15 years now, the tradition of so-called cookbooks still persists (see [11]). Experiments devised to exemplify chemical principles frequently make no contact with the students' experience and as such are not sufficiently impressed on their consciousness. Therefore, authors concluded that the purpose of the experiment turns out to be unnecessary and the method of executing it is inefficient. As early as the 19th century, Rowland [12] claimed that "in order to produce men of action, they must be trained in action". He explained that if students study science, they should enter the laboratory and stand face to face with nature; they must learn to test their knowledge constantly. A laboratory is used to train the mind in right mode, to bring it in contact with the absolute truth and to give it a pleasant and profitable exercise. A more recent study [1] however showed that, in most cases, practical work activities provided to teachers are designed in a way strongly resembling the Smith's [3] notion criticised above.

On the opposite side of the general notion that experiments are unsubstitutable, Hofstein and Lunetta [13] already questioned the “black-and-white” view of practical work’s role in science education 40 years ago. Later, these authors [14] revisited their previous findings only to conclude the same. In the same respect, Osborne [15] argued that the role of practical work in science is overemphasised and misunderstood. Science is distinguished by the fact that it is a set of ideas about the material world and not by empirical enquiry. The latter is only one of six styles of reasoning used to develop scientific ideas in students’ minds. Osborne also mentioned the lack of clarity around the role of practical work in science, often resulting in poor science instruction. And, until its role is clarified, attempts to assess it are of little value [15]. Similarly, Hawkes [16] argued that laboratory classes do not help students understand how chemical principles affect their universe and that laboratory work did not make a significant difference in information, practical application, scientific attitude or laboratory performance tests. On top of that, Tobin [17] criticised the common “cookbook” style, van den Berg [11] reached the same conclusions in his literature overview. They argued that laboratory instruction needs to enable students to construct their knowledge of phenomena, related to scientific concepts. This is not achieved by students following a written set of certain steps. Bretz [18], in her argument of little evidence of their impact, mentioned the significant cost and time investment stressing the hands-on importance of experiments in chemistry instruction needing to be better investigated before the means are spent.

Roehring and Luft [19] found five main constraints: teachers’ understanding of the nature of scientific inquiry, content knowledge, pedagogical content knowledge, teaching beliefs, concerns about management and students. Cheung [20] provided a relevant literature search and arrived at 11 major barriers which keep teachers from employing inquiry-based laboratory work: lack of time, teacher beliefs, lack of effective materials, pedagogical problems, management problems, large classes, safety issues, fear of abetting student misconceptions, student complaints, assessment issues and material demands. Boesdorfer and Livermore [21] mentioned the following limits: teachers’ beliefs, teachers’ knowledge and curriculum materials. Some authors [18, 21, 22] also name expenses as one of the barriers.

From the lists of barriers, it is evident that some of them overlap and have been taken care of. However, some remain open. Artdej [23] associated the lack of experiments in chemistry instruction with underprepared pre-service teachers as far as safety knowledge, skills and awareness are concerned. It is this group, however, who needs the necessary skills so they can successfully engage students [24]. This issue is even more thorny in the stiffening safety regulations which (in one chemistry teacher’s career span) progressed significantly from “not breaking glassware, not burning holes in one’s clothing, and keeping the occasional fire or explosion to a small scale” [22] to detailed regulations regarding compounds’ storage, manipulation and also the allowed concentrations of many compounds students are allowed to work with. Recently, papers about failings in chemical compound storage [25], overlooking potential risks in chemical reaction uncertainty in Chinese materials [26] or challenges in safety and management (70 % involving laboratory chemicals posing a risk to the students) [27] were published. In addition, Fivizzani [28] pointed out with increasing attention to lab safety, questions about where and when should it be done arose. He concluded that special courses promoting safety should be designed.

In this study, attention was given to teachers' beliefs and safety issues. From this point of view, beliefs translated to the frequency of teachers' use of practical work, types of experiments, feeling prepared for practical work and safety issues are being addressed.

Chemistry education related safety issues in Czechia

The abovementioned resources suggest safety issues are one of very possible sources of teachers' reluctance to involve practical work in their chemistry instruction. In contrast to the US Guidelines for Chemical Laboratory safety in schools [29], these issues are partially named in the School Law [30], which very generally orders schools to create safe conditions for their students. With respect to chemistry education, there is a Ministry of Health promulgation 180/2015 [31] which prevents underaged students from working with certain compounds and mixtures. Nevertheless, there is a parallel promulgation 61/2018 [32] from the Ministry of Education which allows students to work with certain compounds and mixtures under a teacher's supervision. This makes the safety issues considerably confusing. Apart from the above-mentioned, occupational safety is also treated by a Czech State Norm, ČSN 01 8003, which defines safety issues, requirements on equipment in chemistry labs, including school ones. It also includes instructions for waste treatment, storing chemicals etc. It is probably the only legal enactment teachers can use to inform their practice.

As a result, it is obvious that many teachers may be confused, and their reluctance to include experimental activities in chemistry teaching is partly justified by the confusing safety measures. This rationale served as the starting point for a project, TL02000226 Evaluation of Safe Practice Teaching Practices in Schools, supported by the Technology Agency of the Czech Republic. Its main goal is to produce videos of safe laboratory practice from basic tool manipulation to chemistry experiments with detailed safety and methodical comments. The background for the experiment database was gathered via research among Czech lower and upper-secondary chemistry teachers.

Goals and methods

Research questions

This research aimed to map chemistry experiment conditions in Czech schools. It is a follow-up to a previously published study [33] which mapped chemistry experiments' nature and frequency in schools. The following research questions were investigated:

RQ_1: What is the frequency of experimental activities in chemistry instruction?

RQ_2: How do teachers perceive safety issues with regards to chemistry experimental activities?

RQ_{2a}: To what extent are teachers familiar with safety norms?

RQ_{2b}: How do teachers evaluate their knowledge of safety measures in relation to experimental chemistry activities?

RQ_3: How do teachers perceive further education within safety measures relating to experimental chemistry activities?

RQ_{3a}: How frequently do teachers undergo safety-focused further training courses?

RQ_{3b}: How do teachers perceive pre- and in-service teacher training in relation to safety measures in chemistry experimental activities?

The research questions were evaluated for the entire group of the study's participants and for their different groups based on their: school level, length of teaching practice, second field of study, size of their school. Hypotheses were formulated to evaluate the *differences between the teachers in relation to issues set in the RQs.*

Research tool

This study used quantitative methods with a questionnaire as a research tool. It consisted of four major parts: Participants' identification, School experimental activities, Safe experimental practice, Teachers' recommendations and wishes. It was constructed and piloted within the authors' collective. Afterwards, it was piloted with 18 chemistry teachers, with only little changes being made in the items' formulations. Subsequently, the questionnaire was transformed in the 1Ka app and sent to a selected chemistry teacher sample.

Firstly, to map the lesson context, experimental activities' frequency was ascertained:

- *How often do you employ demonstrations/students' demonstrations or student experiments?*

Every chemistry lesson, at least once a week, once a month, less than once a month, don't include in my lessons.

Secondly, attention was given to safety issues. The questions targeted teachers' knowledge of corresponding safety norms:

- *How would you assess your knowledge regarding chemistry education safety measures?*

  answer on a scale 1-5 very good to very poor.
- *Do you know the norm ČSN 01 8003 Safe work in chemistry laboratory policy?*

Yes, and actively follow it; Yes, but do not use it; No, but I know it and; No, never heard of it.

- *When was the last time you absolved training focused on occupational health and safety focused on work with chemicals?*

  Less than a year ago, max. 2 years ago, more than 2 years ago, never
- Free comment on the topic

Study participants

This study targeted chemistry teachers in lower-secondary schools (ZS), and upper-secondary schools: grammar schools (G) and lyceums (L) in Czechia. The sample was stratified to be representative for particular districts as well as teacher proportion at different types of schools, while respecting the minimum sample size (according to Raosoft14).

From the Czech Ministry of Education, Youth and Sports' address book [34], some types of school were excluded: special schools, practical schools and all schools without chemistry education or with a direct focus on chemistry education. Further, the schools were selected according to their location. At selected schools, all chemistry teachers or teachers who teach chemistry were addressed. In total, 466 teachers filled in the questionnaire, the whole questionnaire was completed by 354 teachers (see [24]).

Data analysis

The 1Ka app was used for primary analysis. More advanced statistics were done in IBM SPSS 26. With respect to the data's nature, a non-parametric Kruskal-Wallis test was used [35]. To evaluate the effect-size, *r* was used.

Results and discussion

The study's respondents

A typical respondent - a chemistry teacher in Czechia - is a female teacher (81 %) with a practice longer than 20 years (52 %) who has a degree in chemistry education (76 %). 29 % of the teachers in the sample had a practice 11-20 years long, there were over 4 % of teachers with less than 3 years of practice. There were 13 % of teachers who studied chemistry and almost 7 % of teachers who studied education in different fields.

There were 65 % of lower-secondary, 47 % of grammar school and 5 % of lyceum teachers in the sample - 79 teachers reported a combination of two types of schools simultaneously.

Chemistry experiments in schools (RQ_1)

All the observed experimental activity variants (teacher's demonstration, students' demonstrations, students' experiments) play a vital role in chemistry education. Each of them though focuses on different phenomena. They are only effective when students are activated [36]. Students' experiments of an inquiry-based nature were expected to be the least employed. This was confirmed by the reported frequency - see Table 1.

Table 1

Variants of experimental activities (teacher's demonstration, students' demonstrations, students' experiments)

Type of school	Demonstrations	Students' demonstrations	Students' experiments
Lower-secondary	At least once a month	Less than once a month	Less than once a month
Grammar school	At least once a month	Never	At least once a month
Lyceum	Less than once a month	Less than once a month	Less than once a month

The test results ($p < 0.001$) for the first hypothesis: *Chemistry experimental activity frequency differs in grammar school, lyceum and lower-secondary school chemistry lessons* showed teacher's demonstrations are being employed in significantly different frequency. Lower-secondary and grammar school teachers employ demonstrations more frequently than lyceum teachers, however, the effect size $r < 0.20$ values showed only a small effect in the difference. The results suggest students experience practical work and even demonstrations rarely in general chemistry education [33].

With an increasing breadth of subject matter as well as more lessons, upper secondary schools are expected to provide students with more experimental opportunities. In the case of grammar school chemistry, the number of chemistry lessons is one half greater. Significant differences between different types of schools were also found for demonstrations performed by students themselves ($p = 0.002$). This method is significantly more employed by lower-secondary school teachers than grammar school teachers ($p = 0.001$). The effect of this difference ($r = 0.773$) showed a medium effect. This finding can be explained by the nature of the demonstrations, which are more likely to be on an elementary level at lower-secondary schools and therefore use compounds students can handle themselves. On the contrary, once topics are explained in more detail with no support or extension via experiments, chemistry teaching is only theoretical and, in a way, contradicts the very nature of natural sciences.

Also, with respect to student experiments, significant differences were found among the types of schools ($p < 0.001$). With increased capacities (specialised classrooms as well as number of lessons), students conduct experiments more frequently in grammar schools than lower-secondary schools as well as lyceums ($p < 0.001$, resp. $p = 0.004$). However, the effects of the difference are only small ($r = 0.234$, resp. $r = 0.186$).

As far as the second hypothesis: *Chemistry experimental activities' frequency is affected by the size of schools* was concerned, the test showed significant differences in student experiment frequency among the schools ($p = 0.022$). The school's size was judged bases on the number of students. In schools with less than 200 students or 300-500 students, experiments are conducted less frequently than in schools with 500-1000 students ($p = 0.01$, resp. $p = 0.013$), although the effect is small ($r = 0.201$, resp. $r = 0.123$). There seems to be a small difference. However, in the overall low frequency of students' experiments, this finding does not seem to promote further investigation. This finding is surprising as bigger schools were expected to dispose of labs and chemical equipment, in contrast to smaller schools which are known to have reduced such specialised classrooms after the paradigm shifted from scientific to humanistic [7].

The differences between the use of experimental work were also evaluated from the teachers' education point of view (hypothesis: *Chemistry experimental activities' frequency differs based on teachers' second field*). Teachers whose second field is of scientific nature were expected to have a more positive aptitude to experiments in education. From the field of science, teachers with a physics background were expected to include more experiments in their chemistry teaching compared to biology or geography teachers.

The data showed teachers who studied chemistry and biology education employ student experiments significantly more than math or physics teachers ($p < 0.001$, resp. $p = 0.038$). The effect of the difference is, however, small in both cases ($r = 0.238$, resp. $r = 0.195$). This could be due to the nature of the subjects - maths does not build on experiments in this respect, physics experiments are of a different nature than chemistry or biology experiments. On the contrary, teachers who combine chemistry with biology employ less students' experiments than teachers who combine chemistry with other science subjects or more subjects other than science ($p < 0.001$). The effect of the differences is, again, small ($r = 0.286$, resp. $r = 0.295$). Yet it seems these teachers seek to connect the subject-matter of their fields and therefore see experiments (at least partly) serving this purpose.

The findings targeting the first research question put other researchers' [1, 14, 37] arguments in a different perspective. Not only the nature of the tasks, but also their actual realisation in schools needs to be taken into account when remedies are planned. Cheung [20] offered an explanation to this phenomenon by identifying teachers' concerns when it comes to their implementation of practical work (inquiry-based laboratory work): lack of class time, shortage of effective instructional materials, and the need to teach large classes.

Teachers' perception of safety issues (RQ_2)

As already mentioned above, safety issues are a barrier to teacher's use of experiments. The issue of safety was followed via teachers' perception of safety measures and their perceived knowledge regarding the regulations in this study (i.e. the other aspect of the teachers' implicit preparedness).

First, the extent to which teachers are familiar with the safety norms was evaluated. The results showed a significant difference among the teachers from different study backgrounds. Statistically significant differences ($p = 0.09$, resp. $p = 0.009$) were found between teachers who studied chemistry education and "teaching chemists", i.e. teachers who studied chemistry but teach, as well as teachers who studied another field than chemistry "non chemistry teachers". In both cases, teachers with a chemistry teaching background expressed a slightly higher opinion of their safety knowledge (though Med = 2). Nevertheless, the effect of the difference ($r = 0.144$, resp. $r = 0.154$) is small. Between the group of "teaching chemists" and "non chemistry teachers", the statistically significant difference and effect size ($p = 0.009$, $r = 0.445$) suggest a statistically significant difference of medium effect. Due to expectations, teachers who do not have a chemical background admit a certain lack of knowledge in this respect. Although, it is important to stress neither chemistry teachers nor teaching chemists showed the highest confidence with respect to the safety issues. This could be a probable cause of the lower frequency of experiments employed in education. The fact this did not show in the experiment frequency is due to the already low use of experiments in education.

To gain more concrete information about safety, teachers' familiarity with the safety norms was evaluated. Considering the safety norms contain the key regulations as far as the compounds and their concentrations allowed are concerned, the teachers' answers are alarming. Teachers answered they are aware the norms exist, however do not use/follow it actively. Similarly, to the questions above, differences were found between the groups of teachers ($p = 0.002$), "non chemistry teachers" and both chemistry teachers and "teaching chemists" ($p = 0.008$, resp. $p = 0.013$). The effect of the difference is small for both cases ($r = 0.134$, resp. $r = 0.259$) but suggests the "non chemistry teachers" are aware of the norms but do not follow them, whereas the chemistry teachers or the "teaching chemists" are familiar with them and do not use them actively.

Similarly, teachers' length of practice was shown to be a factor. Whereas teachers with a shorter career answered they do not know the norms, teachers with longer practice mentioned they know them but do not use them actively. This suggests, teachers seem to learn about the norm later in their career, perhaps when they become responsible for the lab and storage of chemicals. Nevertheless, this does not apply to the group of teachers with the longest practice in the sample (over 20 years). They seem to have relinquished this duty to their younger colleagues.

This finding is supported by the significant differences found between the groups with 3-5 years of practice, the groups with 11-20 and over 20 years of practice ($p < 0.001$, resp. $p = 0.023$). The effect of the difference is small in both cases ($r = 0.176$ resp. 0.216). Similarly, the most-experienced teachers' group in the sample showed differences with the groups with 6-10 and 11-20 ($p = 0.018$, resp. $p = 0.015$) years' experience, although the medians of their answers were the same, which also suggested the small effect size for both differences ($r = 0.157$, resp. $r = 0.164$).

A supplementary question targeted the frequency of students' safety instructions. Whereas the teachers' education and length of practice showed not to be a factor - the teachers mostly reported giving safety instructions before encountering every experimental activity, the school type showed to be a factor. Teachers at lower secondary schools and lyceums reported the instructions before every experimental lesson, whereas grammar school teachers only before those tasks which require special attention. This may be due to these students' greater experience, however, based on their potential contact with experimental activities, there hardly seems to be an explanation for such a practice.

The results then confirmed that even after almost two decades, the safety issue seems to remain one of the barriers [38].

Teachers' opinion on (further) education within safety measures (RQ_3)

Overall, the teachers underwent some sort of occupational and work safety schooling more than 2 years ago. There were statistically significant differences between the teacher groups according to their second field of study found (p = 0.012). Teachers who studied chemistry with mathematics absolved such schooling longer (more than two years) ago than teachers who studied chemistry in combination with more science fields (1-2 years ago; p = 0.033). The effect of this difference is small (r = 0.18). Also, the type of school the teachers teach at was shown to be a significant factor (p = 0.045). Grammar school chemistry teachers underwent schooling a significantly (p = 0.019) shorter time ago (1-2 years) than lyceum chemistry teachers (more than 2 years ago). The effect of the difference (r = 0.19) was small. In-service teacher training then does not seem to support teachers' use of experimental work.

Solutions for this situation were investigated within the study participants' answers to the last item: How they see the role of universities in both in-service and pre-service teacher training. There were no statistically significant differences among the teachers according to any of the followed factors. The teachers, in accordance, mentioned that they received information about occupational safety only within instructions before lab courses.

Another valuable source of information was the teachers' response to an open-ended question on experimental activities. Altogether, 24 teachers provided a response relevant to this study's topic. Most teachers (11) mentioned a lack of a list of chemicals they are allowed to use with students. Seven of them mentioned students are not allowed to work with the majority of chemicals. Four mentioned a need for some materials which would comprehensively describe safety regulations. Two mentioned students were not skilled enough to perform (survive) in a chemistry laboratory. These responses suggest there is a considerable gap in teachers' knowledge, which may be the real reason for their scarce use of experiments.

Limitations

The results of this research are especially limited by the data gathering method. The use of a questionnaire shows only teachers' perspective or perhaps their ideal vision. Deeper understanding would be received if lessons were observed and students interviewed too. Also, as obvious from the data, teachers' views are quite homogenous and the effect-size of the expected differences were only small. Next research should focus specifically on teachers who employ practical work and teachers who do not and evaluate their drivers.

Conclusion

Despite chemistry being an empirical discipline, students are not confronted with its natural face enough. Experiments in various forms are seldom in schools. Based on the data gathered in this study, this is partly due to school equipment, and partly due to teachers' careful attitude towards the safety issues. This mostly concerns teachers who teach chemistry but who did not study the discipline or its teaching. Not surprisingly, safety is not such a barrier for teachers who studied chemistry and chemistry teaching, which only stresses the need to employ only professionals for chemistry teaching as the others' teaching is likely to suffer from their lack of lab-related experience. Especially in the times of school law novelisation, which might technically allow anyone with a university diploma to teach when a school's principal considers it fit, this finding may serve as one of many arguments for the contemporary state of the art's preservation.

Another valuable finding shows the direction of further teacher support. Chemistry safety legislation is seen as unclear by many. This affects their use of experiments. Teachers would require clear guidelines on safe procedures as well as a list of chemicals students are allowed to work with, in accordance with the chemistry curriculum topics.

In reaction to these findings, a database of chemistry experiments was created along with detailed information about safety. It is available free of charge at ebedox.cz

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