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## EVALUATING EXPERIMENTAL ACTIVITIES IN CZECH CHEMISTRY TEXTBOOKS: A CRITICAL ANALYSIS

**Abstract:** This study analysed the nature and integration of experimental activities in Czech lower-secondary chemistry textbooks which are currently in use. Focusing on four dominant textbook series (published since 1990's), and one recently (2019) published and certified, it investigated the offered types of student activities, their cognitive demands, placement in the educational process, and inquiry levels. The findings reveal two distinct groups of textbooks based on the quantity of experimental activities. Some textbooks align with traditional teaching methods, emphasising teacher-led demonstrations, while others attempt a balance between safety concerns and student engagement. However, a general lack of focus on higher-order cognitive skills and inadequate scaffolding for scientific process skills development was found. The results showed future research should investigate the impact of experimental activities on student outcomes, highlighting the need for more modern approaches in chemistry education.

**Keywords:** textbook analysis, experimental activities, chemistry education

### Introduction

Within the current framework of student-centred learning in education, the role of school instruction has evolved to be a collection of motivating factors that encourage student learning. Consequently, the role of teachers has shifted from being sole purveyors of knowledge to facilitators and orchestrators of various educational activities. Mastery of educational content alone is no longer adequate for teachers preparing for such dynamic classes [cf. 1]. Given the enduring influence of textbooks in the educational process [1-4], it is apparent that the calibre of tasks presented in textbooks plays a pivotal role [5, 6]. These tasks either drive the transition towards modern teaching methods or maintain the traditional status quo.

This study addresses a gap in current knowledge regarding chemistry textbooks, specifically the nature of experimental activities they contain. Our previous research [7] indicated that such activities are infrequently included. Potential reasons for this, aside from teachers' ongoing concerns about safety [8], may include a lack of necessary materials. The continuous presence of specific content in textbooks, particularly regarding their didactic tools [9], suggests that the issue may lie in the quality or nature of the textbook tasks themselves.

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Therefore, this research builds upon previous studies that have examined textbook tasks [5, 6, 10, 11], focusing specifically on experimental activities as a key component of these tasks.

## **Theoretical background**

### *Textbook trends and shifts (in Czech Schools)*

In recent years, despite several gloomy prognoses, textbooks, being the most frequently used and dominant educational tools, have received considerable attention from researchers [12]. Although textbooks are primarily intended for student use, research has shown that they mainly serve teachers, who use them to prepare for their lessons [1, 2, 13, 14]. This finding transforms the way textbooks need to be looked at. For this research, the context of Czechia needs to be explained. By law, textbooks are provided free of charge to every lower-secondary student, and schools manage additional funding available for purchasing any textbook that has received the so-called approval clause from the Ministry of Education. Consequently, publishing houses face free competition, as teachers occasionally choose new textbooks. Yet, their preferences seem not to be changing too much, as two of the top-four mostly used textbook series [13] were designed earlier and therefore follow the previous chemistry curriculum [15].

Textbooks are known to contain very similar components and therefore offer comparable extent of teaching opportunities [9]. Similarly to textbook in other countries, they overemphasise symbolic representations [16, 17] and the included tasks follow a specific genre [5, 6, 11]. Currently, there are four textbook series published since 1990s' and re-edited whose usage can be considered dominant [6], and one series was published in 2019.

### *The double-faced experimental activities in chemistry education*

Experimental activities have become a controversial aspect of chemistry instruction. The current literature presents least two viewpoints on practical activities in chemistry. On one hand, many authors view experimental activities as beneficial for stimulating students' interest and attitudes towards science [18, 19], a sentiment echoed in various forums for teachers. Additionally, students are known to enjoy experiments [20]. On the other hand, some authors argue that the glorification of experiments is, at best, unfounded. Hofstein and Lunetta, in their two studies, found no evidence of laboratory science having a positive impact on students' learning outcomes [21, 22]. Similarly, Osborne [23] cautioned against excessive optimism regarding practical work, citing limited evidence. Other authors have criticised the contemporary nature of practical work in schools, which - in an outdated manner - focuses on "doing science" rather than using practical work to learn about science [24]. Tobin [25], and later van den Berg [26], noted the lack of effectiveness in the persistent cookbook-style of laboratory assignments.

Despite this, several authors continue to seek improved approaches in this field [27-29]. Moreover, a recent study by a member of this paper's team [8] found that experimental activities are quite rare at all levels of education in Czechia. When they do occur, they are mostly demonstrations or traditional lab work rather than inquiry activities for students. This finding aligns with Osborne's [23] and Abraham and Millar's [30] conclusions about the low impact of practical activities on their intended goal - the development of scientific literacy [31]. Kotulakova et al. [32] found the low impact could

be caused by teachers' misinterpretation and overestimation of research questions formulation, data analysis or drawing conclusions.

In the aforementioned study [7], teachers identified lower-secondary textbooks as one of the most frequently used sources of inspiration for experimental activities. However, this aspect of chemistry textbooks has not yet been thoroughly analysed. The only partial information available comes from overall evaluations of tasks [6, 11], but these did not specifically focus on experiments. Moreover, not every experiment-focused component in textbooks may include instructions for students and, as a result, might not have been categorised as a task for analysis. Considering the significant impact of textbooks on the shaping of (chemistry) education [1, 31, 33, 34] and the known uniformity in the conception of textbook tasks [5, 6], particularly regarding proposals for laboratory activities [10], the findings of this study could illuminate the overall conception of experimental activities on a more global scale.

## Aims

The objective of this study was to analyse experimental activity suggestions in Czech lower-secondary chemistry textbooks, guided by these research questions:

- What type of student activities do experimental activities offer?
- To which phase of the educational process are the experimental activities suggested?
- What is the cognitive demandingness of the tasks offered by these activities?
- For student-designed experimental activities, what level of inquiry is involved?

*Didactic equipment* in this context refers to elements contributing to a textbook's didactic value, including components presenting material, guiding learning, and aiding in textbook navigation.

## Methods

### Analysed textbooks

In the current study, which builds upon prior research [13], it was identified that four textbook series predominantly serve 95 % of schools. Following the publication of this research, notable developments were observed in the educational publishing landscape. Specifically, Fraus Publishers released a re-edition of one of their textbook series, and Taktik Publishers introduced a new series to the market. Considering the potential of these updated and new series to replace older textbooks, they were incorporated into the research sample.

The selection criteria for textbooks in this study were stringent, including only those that had received approval from the Ministry of Education following the implementation of the Framework Educational Programme for Elementary Education. This criterion also applied to the newly introduced chemistry textbook series by Taktik Publishing House, despite its lack of official ministry approval. The inclusion of this series was justified by the open market system governing textbooks in Czechia, which grants schools autonomy in selecting textbooks.

### Data analysis

In all the analysed textbooks, tasks targeting any form of experimental activity were identified. These tasks were then coded according to their impact on student engagement,

categorising them into activities such as student experiments, observations, measurements, or others.

Table 1

Overview of analysed textbooks

Authors	Textbook title	Publishing house	Year of publishing	Abbreviation
Beneš P, Pumpr V, Bynýr J	Základy chemie 1	Fortuna	2021	ZCH
Beneš P, Pumpr V, Bynýr J	Základy chemie 2	Fortuna	2021	
Beneš P, Pumpr V, Bynýr J	Základy praktické chemie 1	Fortuna	2021	PCH
Beneš P, Pumpr V, Bynýr J	Základy praktické chemie 2	Fortuna	2021	
Mach J, Plucková I, Šibor J	Chemie pro 8. ročník	Nová Škola	2016	NS
Šibor J, Plucková I, Mach J	Chemie pro 9. ročník	Nová Škola	2015	
Škoda J, Doulík P	Chemie 8 (nová generace)	Fraus	2018	FR
Škoda J, Doulík P	Chemie 9 (nová generace)	Fraus	2018	
Budínská G, Štikovcová K, Jelínková L, Jandová J	Hravá chemie 8	Taktik	2019	TA
Budínská G, Krizanová A, Nývtlová V, Toman P	Hravá chemie 9	Taktik	2019	

At the study's outset, all experimental procedures were systematically recorded in a Microsoft Excel spreadsheet. This step was followed by an in-depth coding process, conducted by a primary researcher. This process involved coding various dimensions, including the type of activity, educational phase, and involved actors, among other aspects (as previously described). To validate the coding process, a secondary researcher independently coded about 10 % of these activities. This was done to assess inter-rater reliability. The results of this cross-verification showed almost perfect agreement in coding, thereby affirming the reliability of the coding schema.

As a result, the primary researcher undertook the majority of the coding tasks. For any activities that were considered problematic, codes were established through mutual consensus. In later stages of analysis, some codes or categories showing significant overlap were combined to simplify the classification framework.

### Task types

The textbooks employ various methods to guide users. The NS textbooks clearly differentiate between teachers' demonstrations and students' experiments, lab work, observations, and long-term projects. In contrast, the FR textbooks do not distinguish between teachers' and students' experiments, so the actors were inferred from the activity's nature for this study's purpose. These textbooks also explicitly include instructions for inquiry. The TA textbooks describe "experiments to confirm or reject hypotheses" and uniquely differentiate between school and home experiments. The ZCH textbooks graphically distinguish passages of an experimental nature and include more such instructions in the footnote "task banks". A similar approach is found in the PCH textbooks by the same authors.

As a result, the following codes - types of activities - were chosen:

- Student-Centred Practical Activities: Tasks that necessitate active participation from students. They are encouraged to engage in experiments, measurements, observations, and to draw conclusions based on their empirical findings.

- **Teacher-Led Practical Demonstrations:** Tasks designed for presentation and demonstration by teachers in a classroom setting. Students are expected to observe the process, engage in discussions about the phenomena observed, and derive conclusions from these observations.
- **Home-Based Practical Activities:** Tasks structured to be feasible outside the traditional school setting, potentially with parental or guardian assistance. The aim is to foster students' abilities and interest in chemistry beyond the school environment.
- **Laboratory Work:** Tasks which involve experiments in a school laboratory. It includes practical activities where students follow procedures outlined in textbooks. This allows students to apply theoretical knowledge in a practical setting, conduct measurements, utilise laboratory equipment, and process the data obtained.
- **Task-Oriented Assignments:** Tasks formulated for students to complete based on their theoretical knowledge and practical skills. Positioned at the end of chapters, they prompt responses to questions, problem-solving, and the formulation of independent procedures. This category also includes topics from the FR curriculum, marked as inquiry-based tasks and interesting facts, as well as observational guides and long-term projects from the NS textbook.
- **Interactivity:** This category, used exclusively by publisher TA, incorporates the use of hybrid textbooks and video links. Publisher FR combines it with written descriptions of activities for most tasks. Only two tasks could be classified under this comprehensive term.

#### *Activities' placement in the phases of education process*

Based on their nature, the activities were coded as activities for the *motivation*, *exposition*, *fixation*, and *diagnostic* phase. This coding was mostly made based on the position of the experimental activities in the textbook. In case of laboratory practice placed usually at the back of the textbooks, the codes were assigned according to the tasks' conception.

#### *Actors*

The authors make a clear distinction between experimental activities designed for students and those intended for teachers. In the few instances where this distinction was not explicitly made, codes were assigned based on other factors, such as the chemicals used or the overall conception of each activity. Through this analysis, the following categories were inductively established:

- Teachers' activity,
- Students' experiment,
- Students' lab work,
- Students observe a picture or a video,
- Students observe an experiment,
- Students solve a task,
- Students work in a group.

### Cognitive demands

To code the experimental tasks' cognitive demands, the revised Bloom's taxonomy [35] was used. Both the cognitive domain and the knowledge domain were used to assess the activities.

## Findings and discussion

### The overall comparison

Technically speaking, in terms of experiments, Czech chemistry textbooks can be divided into two groups. The first group, represented by the FR and ZCH textbooks, includes approximately twice as many experimental activities as the second group (refer to Table 2). In this regard, the two textbook series offer around two experimental activity suggestions per lesson, whereas the other textbooks offer about one. Considering previous research indicating that experiments are utilised approximately once a month in lower-secondary schools [7], the results imply that teachers utilise only a fraction of the available experiments. Another finding, consistent with earlier studies, is the significantly lower number of experimental suggestions in textbooks for the 9th grade, particularly in topics like organic chemistry and chemistry in society. This trend might explain why experiments are less frequent in 9th grade: if teachers select about one experiment per month from four or (in the case of FR and ZCH) eight options, then the number of available experiments for 9th grade chemistry needs to be larger.

Table 2

Comparison of the number of topics for practical activities with a focus on students

Abbreviation	Total number of topics for practical activity		The difference between 8 <sup>th</sup> and 9 <sup>th</sup> grade	Practical activities for students (8 <sup>th</sup> grade/9 <sup>th</sup> grade) [%]
	8 <sup>th</sup> grade	9 <sup>th</sup> grade		
<b>NS</b>	67	70	+3 (+4 %)	61 /47
<b>FR</b>	124	101	-23 (-19 %)	48 /50
<b>TA</b>	55	25	-30 (-55 %)	62 /76
<b>ZCH</b>	170	106	-64 (-38 %)	26 /16
<b>PCH</b>	76	57	-19 (-25 %)	9 /9

Note: The difference in the number of topics between years is given in absolute numbers and then converted into percentages in parentheses

Upon closer analysis, the approach of the authors of the analysed textbooks in incorporating experiments becomes evident. The authors of the NS and PCH textbooks seem to have designed the textbooks with the intent of providing an experiment for each lesson. This approach indicates a leaning towards the previous science teaching paradigm [36], as not every chemistry topic has the potential, and not every aspect of scientific literacy can be effectively developed through an experiment. In contrast, the TA textbooks contain fewer experiments, with available experiments for less than half of the lessons in the TA series for the 9<sup>th</sup> grade.

## How textbooks guide students' learning activity

### *Actors*

As discussed earlier [1], textbooks are often used as direct inspiration of a lesson plan. In this scenario, textbooks also suggest the experiment incorporation. From this point of view, the coherence with the contemporary student-centred approach can be evaluated via actors of the experimental activities' point of view.

As shown in Table 2, most of the textbooks include more experiments for teachers (except for NS for 8<sup>th</sup> grade and TA 9<sup>th</sup> grade). This may be interpreted as either authors' vision of chemistry instruction or an attempt to avoid unclear safety issues [8] by bypassing students' contact with the chemicals. In this respect, the NS, ZCH and PCH textbooks contain a considerable number of experimental activities for teachers and therefore offer the opportunity for students to develop observation skills. Nevertheless, the teacher-centred approach in this respect points to these textbooks' overcome conception.

The FR textbooks present an intriguing approach by emphasising the role of the teacher in cases where safety concerns prevent students from directly working with chemicals. This approach leaves the decision of who conducts other activities open, allowing teachers the flexibility to design these activities as they see fit.

Regarding the nature of educational experimental activities, the utilisation of video experiments emerges as a logical alternative to mitigate safety risks. However, it is somewhat unexpected that the newest textbook series on the market, TA, only employs this method in the 8<sup>th</sup> grade textbook, while the second newest series, NS, does not utilise video experiments at all. In this aspect, these textbooks adhere to the same pattern [13] observed in the original ZCH and PCH series. Notably, even in their latest editions, these textbook series now include links to school experiments, indicating a shift towards integrating more diverse experimental methods.

### *Experimental activities' position in a lesson*

Beyond the role of the actor, textbooks also convey educational concepts through the placement of experimental activities within the lesson plan. The analysis revealed that experiments are typically situated after the teacher's content explanation, thus reinforcing the dominant traditional model of chemistry instruction. Despite the often-claimed motivational role of experiments, they are rarely utilised in the motivational phases of lessons. Additionally, when included in the exposition phase, they are predominantly used to confirm the teacher's subject-matter explanation, rather than as a presentation of a phenomenon from which students could independently derive key lesson insights. This conclusion is further supported by a point that will be discussed in the following chapter: textbook experimental activities are not framed as tasks. Consequently, they are infrequently placed in the fixation or diagnostic phase of the educational process. This indicates the perceived role of experiments in chemistry instruction - they are meant to be demonstrated. However, their actual impact on student development, particularly in achieving educational goals, remains, at best, uncertain.

### **Experimental activities' cognitive difficulty**

Textbook experimental activities were also assessed based on the cognitive operations they require. Surprisingly, most experimental activities do not necessitate cognitive operations and are not learning tasks in the true sense of the word (see Figure 1). Similar to

textbooks in countries like Turkey [37], these activities predominantly involve observation. However, they usually lack tools for deliberately fostering or evaluating students' progress, making it difficult to determine if skill development is a targeted outcome. While the ability to observe is indeed a skill students need to develop, a textbook, as a guide for activity implementation [31], should demonstrate to teachers how this can be achieved. Without scaffolding, gradual steps, or evaluation of the process, simply having students watch a teacher's demonstration is insufficient for enhancing their observational skills.

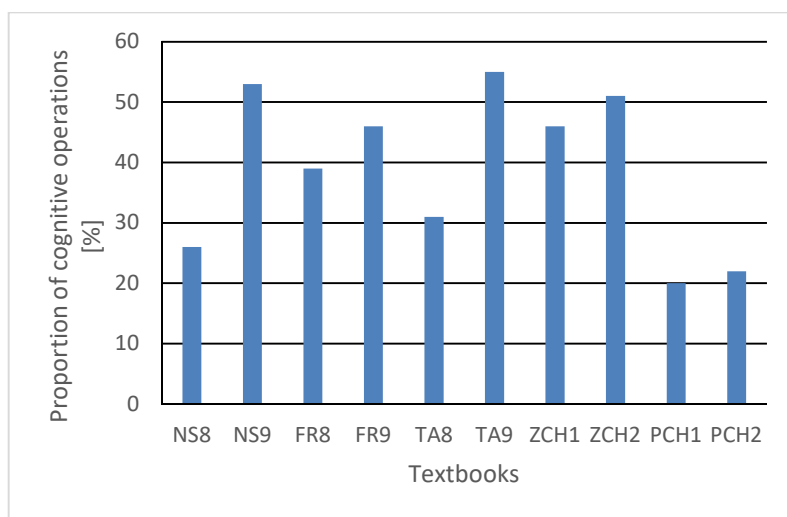


Fig. 1. Percentage representation of subjects for practical activity developing cognition

The same applies for cognitive operations. As shown in Figure 2, the experimental activities mostly target lower order thinking which agrees to the overall textbook trend [5, 6]. The extraordinarily high proportion of remember-oriented tasks are typical of NS and FR textbooks, on the other hand the other textbooks mostly focus on students' understanding. Interestingly, it is the oldest textbooks (ZCH and PCH) which offer a more balanced portfolio of activities including application and tasks fostering students' creation. In this respect TA textbook chose the same approach, showing unbalanced conception of the books for the 8<sup>th</sup> and 9<sup>th</sup> grade.

When the overall spectrum of experimental activities is assessed based on their variability, the ZCH, PCH and NS textbooks offer the most. These results further confirm the textbook authors' perceived role of experiments. The textbooks do not deliberately focus on scientific literacy development and do not target science process skills [38]. Also in this respect, Czech textbooks resemble others [39, 40].

The authors' textbook conception regarding the use and of experimental activities is also shown in the activities' targeted knowledge domains (see Figure 3). This finding is difficult to analyse as the textbooks vary significantly and no clear pattern was found. Also in this respect, there are similarities to textbooks in other countries [41].

Again, the NS and FR textbooks similarly develop factual and conceptual knowledge. On the other hand, the accent on procedural knowledge is almost non-existent in FR textbooks showing how little the process-site of chemistry is included in this textbook.



This textbook series is also unique as it includes two tasks targeting metacognitive operations which is something no other textbook did.

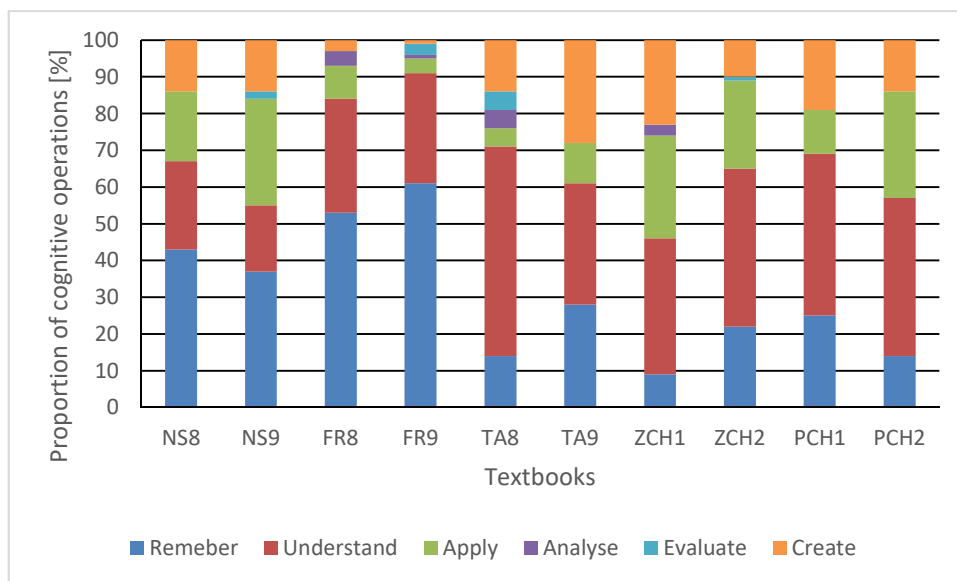


Fig. 2. Cognitive domains targeted in chemistry textbooks

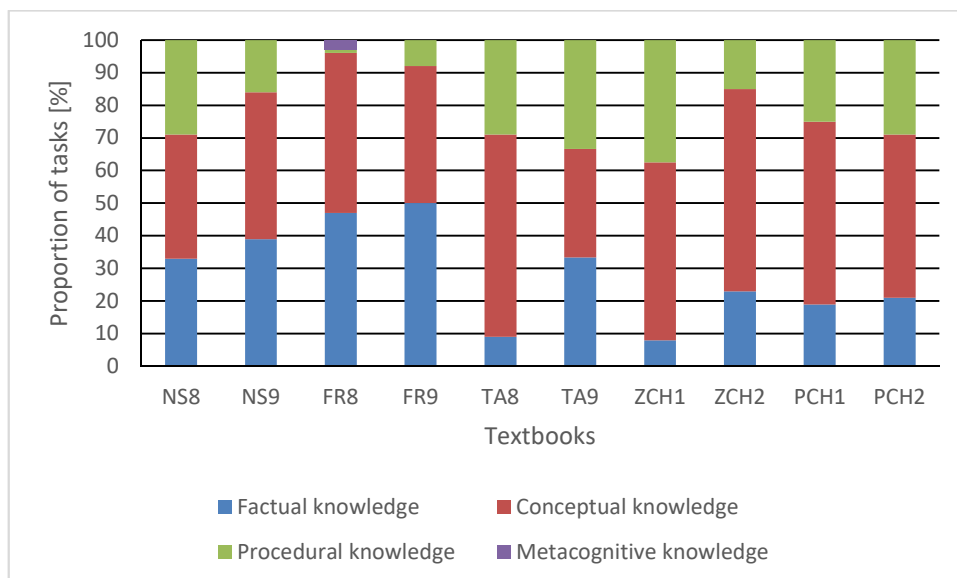


Fig. 3. Knowledge domains targeted in chemistry textbooks

In the TA, ZCH and PCH textbooks, the conceptual domain dominates. The only exception is TA 9<sup>th</sup> textbook which contains equally distributed tasks. As for the procedural knowledge, TA and PCH are the only textbook series which have this domain over 20 % in both textbooks.

### Overall textbook comparison

The findings are supposed to direct teachers in their textbook selection. The following Table 3 provides an overview of suitable textbooks for a certain purpose (naturally, only from the experiment activities' point of view).

Table 3

Purpose of textbooks

Purpose	Suitable textbook
An abundance of ideas in one place	ZCH, FR
A reasonable number of experimental activities	NS, PCH
Student-centred approach	NS 8 <sup>th</sup> , TA 9 <sup>th</sup> grade
Fostering higher-order skills	ZCH, PCH, NS
Equal (or close to equal) knowledge domain	NS, PCH

The results, with a certain simplification, point to NS and PCH textbooks as the two most teachers would find suggestions for experimental activities which lead to meaningful activities aiming at curricular goals.

### Conclusion

The study focused on the conception of chemistry experimental activities contemporary textbook authors propose to teachers. Notable disparities in among the analysed textbooks' approaches to experimental activities, both in the quantity and nature of tasks for students, such as cognitive demands and targeted knowledge were uncovered. A commonality was observed in how these textbooks incorporate experimental activities, predominantly to confirm teachers' explanations. While some textbooks adhere to traditional teaching paradigms focused on teacher-led demonstrations, others attempt a balance between safety concerns and student engagement. Overall, there is a noticeable lack of focus on higher-order cognitive skills and insufficient scaffolding to develop scientific process skills, highlighting the need for a more contemporary and comprehensive approach in chemistry education.

It was found that textbooks primarily offer suggestions, yet their composition often mirrors direct lesson plans, implying that the portrayal of experimental activities in these textbooks likely reflects the authors' recommended methodology. This study highlights areas for textbook authors and chemistry education researchers to focus on, as the presentation of experimental activities in textbooks diverges from the modern conception of chemistry instruction.

The interpretation of this study's results should take its limitations into account. It focused solely on Czech textbooks, although previous research cited indicates a general uniformity in textbooks and their usage by teachers. Additionally, the descriptions of activities in textbooks might not precisely reflect their real classroom implementation. A thorough assessment would necessitate direct classroom observations. However, given the infrequent use of experiments in schools, extensive observation time would be required,

or alternatively, attendance at specially arranged lessons, which may not reflect typical classroom dynamics. Furthermore, the approach to evaluating activities could overlook nuanced elements due to the inherent subjectivity in categorising these activities, a potential bias mitigated by having a second researcher review the initial categorisation. The study assessed the potential of the activities, considering the feasibility of experimental activities as described in textbooks. Any significant divergence from this potential in classroom practice would indicate a departure from the textbook guidelines.

Future research study should consider including textbooks from other countries for a comparative analysis. Examining the impact of experimental activities on student learning outcomes, especially their role in enhancing scientific literacy and critical thinking, is essential. In this context, the proposals for textbook experimental activities should be compared with other frequently utilised (online) resources. Research into teacher training and support for effectively implementing textbook activities would provide deeper insights into evolving educational standards and scientific understanding. Pursuing these research directions could greatly enhance the current understanding of the role of textbooks in science education and inform future educational strategies and materials.

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