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Contents

Nakladatelství Karolinum

Special Issue: Research on Textbooks in Science and Mathematics Education

The COVID 19 pandemic suddenly turned education upside down, opening up several major questions. One of the pillars they have in common is the need of solid ground, a beacon which would navigate learning on the suddenly stormy educational waters. Soon after the schools were closed (for the first time), teachers started to look for materials in various social media outlets. It almost seemed that, at that instant, the intended materials for face-to-face teaching were not sufficient enough. Several highly-adaptable teachers gained popularity with their educational videos, many shared their slides and looked for others. Almost as if they were not equipped with the most-spread educational tool – textbooks.

This could be due to teachers' effort to diversify home learning for their students. However, this could also be an indicator of teachers' attitude towards textbooks as far as students' activation is concerned. There is a significant body of research showing textbooks are still a very influential agent in education: they represent a translation of the curriculum for many teachers (Chiappetta & Fillman, 2007), are the main source of information (cf. Mullis et al., 2012) or analogies (Harrison, 2001) for teachers and even a subscription of lesson content including methods (Lepik et al., 2015; Mullis et al., 2012). Yet, information about the use of textbooks for student activation show a rather reserved trend. Son and Kim (2015) reported teachers providing their students with tasks of a lower cognitive difficulty and even splitting more demanding tasks for their students, thus depriving them of the possibility to develop certain skills or thinking patterns. Vojíř and Rusek (2021) found teachers building their lessons based on simplified texts and graphics rather than sets of tasks.

The teachers' behaviour, however, might suggest textbooks serve as good material for in-school lectures but do not serve as good materials for distance teaching. This brings more serious questions: Are textbooks suitable for contemporary students' independent learning? Is the text adequate (comprehensible, readable, structured)? Are the visual components self-explanatory enough? Or do students need a guide (teacher) to help them study from the book?

The uncalled-for opportunity to re-evaluate settled teaching practices and educational tools also highlighted the role of textbooks. For this reason, *Scientia in educatione* opened a call for a special issue to bring forward research on the role of textbooks in science and mathematics.

Papers included in the special issue target chemistry, biology and mathematics textbooks. Three papers submitted a textbook segment to a thorough evaluation. Zupanc and Devetak looked into electrolyte chemistry pictorial materials used in Slovenian lower-secondary chemistry textbooks. Representations are one of the most important topics within chemistry education research due to their potential to mediate abstract phenomena to students in a more comprehensive way (Johnstone, 1991; Taber, 2013; Talanquer, 2011). With only a limited segment to be seen by the naked eye in electrolyte chemistry (not only there), macroscopic representations need to be accompanied by micro and symbolic representations. Naturally, modern technologies also offer comprehensive hybrid representation constructions. The presented study, however, showed sub-microscopic and hybrid representations to be the least common in the analysed textbooks. This is in accordance with research by Šubová (2020) from the Czech environment, which points to a possible global trend in chemistry subject-matter representation.

Another type of representation, this time in biology – diagrams – was analysed in Machová's study. As shown in other research (e.g. Dees et al., 2014; Halverson et al., 2011), many students (even university students) hold misconceptions as far as phylogenetic trees are concerned. Learning materials' analysis is therefore a logical step towards improvement. Czech biology textbooks for secondary schools were submitted to an analysis of phylogenetic trees' characteristics. Evolutionary diagrams were evaluated according to the cladistics. The results showed almost a half of the analysed diagrams do not support the current scientific understanding of evolution, putting stress on ladder thinking and, in the majority of cases, lacked scaffolding which would lead students to reading the diagrams successfully. As shown by Jian (2021), when provided appropriate instruction, students focus more on the text in diagrams, and therefore learn. Similar to Zupanc and Devetak's paper, Machová concluded her paper with several suggestions for new textbooks or contemporary textbook improvements.

Zenkl's study, on the other hand, focused on the above-mentioned textbooks' role in supporting teachers. His paper focused on presenting combinatorial concepts and its compliance with a concept development theory in secondary school mathematics textbooks. It was built on the theory of generic models (Hejný, 2012) aimed at selected combinatorial concepts and procedures' presentation in mathematics textbooks. The paper's secondary goal, in accordance with Zupanc and Devetak, was to look into visual representations, which proved essential also in combinatorial problem solving (Lockwood & Gibson, 2016). The research showed combinatorial problems are insufficiently motivated in the analysed textbooks. Graphical representations are rare and lack diversity. Moreover, learners are not encouraged to create their own graphical representations. One textbook was identified to stand out. It contains prompts for creating personalised representations, works purposefully with isomorphic problems and encourages the reader to generalise specific procedures. In accordance with the aforementioned papers' implications, this textbook could serve as a model for other textbooks, at least in this respect.

A study standing on the borderline of teacher- and student-focused analysis was conducted by Vojíř and Rusek, who focused on the role of teacher's books and workbooks. Compared to the other papers included in the special issue, this research used a questionnaire survey. Whereas 63% of respondents considered workbooks important for education, 4% reported frequent use of a teacher's book with only 24% mentioning their occasional use. The results showed workbooks are, according to expectations, mostly being used at the end of lessons and as a source of homework. However, interestingly, a considerable share of teachers mentioned the use of workbooks for lesson preparation, which supported Erol's (2017) finding about workbooks being considered a type of textbook due to their mostly informative content. The absence of a teacher's book, probably as a result of publishers' market surveys, together with teachers' considerable reluctance to use a teacher's book even when available, revealed their approach to teaching preparation. It seems teachers search for educational content or even methods in a textbook (Lepik et al., 2015; Sikorová, 2005) without being interested in the explanation of goals and methods' explanation and the rationale of further topics' conception. The authors confirmed teachers' traditional approach towards lesson preparation built mostly on subject-matter transfer with only a limited focus on student activity.

The last paper included in the special issue also focused on chemistry textbooks, however, stands out with its focus which is transferable to other fields within STEM but also others. Tóthová and Rusek performed a literature review focused on the use of eye-tracking methodology on chemistry textbooks' evaluation. This technology has found various use not only in science education research (Lai et al., 2013) and provides closer insight into students' reading patterns, problems with text-graphics combination, suitability of a platform (e-books vs. traditional textbooks) and the effect of textbook component placement on the distribution of students' visual attention. It is reasonable to expect more research with such methodology to instruct textbook creation in the future. For the time being, several key findings can help teachers to use textbooks efficiently, teacher trainers to direst pre-service teachers towards more effective textbook use and textbook authors to structure the chapters of new textbooks in a more suitable manner.

The papers included in this special issue thus showed several different angles disclosing certain textbook sets' aspects which need a special attention. Although focused only on narrow aspects (e.g. phylogenetic trees, visual representations in electrolyte chemistry or presenting combinatorial concepts), the research has the potential to guide similar research within the fields covering other topics or aspects. The special issue also contains a look at the other textbook-set components focusing on the use of workbooks and teacher's books providing information useful for publishers but also for chemistry educators or researchers in the field as it provides indirect information about the conception of chemistry teaching. Last but not least, the use of hi-tech equipment which is also becoming popular in education research – eye-tracking – is a pioneering attempt to promote this method among actors within textbook research or production.

This special issue's mission is to enhance further research on textbooks in order to provide a medium which teachers could rely on and which would reflect modern evidence-based trends in education. I hope that readers feel their time is well spent, that researchers and textbook authors can find a lot of inspiration and that the papers' authors receive a lot of positive feedback, including prestigious citations.

Martin Rusek
Special issue's editor

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The Analysis of Electrolyte Chemistry Pictorial Material in Lower Secondary School Chemistry Textbooks in Slovenia Based on Developed Quality Criteria

Analýza obrazových materiálů z tématu chemie elektrolytů ve slovinských učebnicích chemie pro základní školy s využitím vytvořených kritérií kvality

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The textbook as a learning tool and learning resource contributes significantly to the effectiveness of the teaching or learning process itself, while at the same time promotes and facilitates independent learning. The main purpose of this research was to develop quality criteria after which textbooks for Chemistry in lower secondary school were evaluated. This paper presents the analysis of electrolyte chemistry pictorial material presented in chemistry textbooks. When it comes to validating textbooks in Slovenia, there are no unified criteria. The development of the criteria included an overview of the objectives set in the chemistry curriculum. Criteria were made for textbooks used in 8th and 9th grade of lower secondary school (students age 13–15 years). Chemistry textbooks were validated in the school year 2018/2019. When analysing criteria related to textbook representations, the sub-microscopic representations and hybrid representations are the least common features in the textbooks.

Key words:
lower secondary school, chemistry, textbooks, quality criteria of textbooks, pictorial material.

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Učebnice jako učební nástroj a prostředek významně přispívá k efektivitě samotného vyučovacího procesu a zároveň podporuje a usnadňuje nezávislé učení. Hlavním účelem tohoto výzkumu bylo vytvořit kritéria kvality, na základě kterých byly hodnoceny učebnice chemie pro základní školy. Tento článek obsahuje analýzu obrazového materiálu použitého v tématu chemie elektrolytů v učebnicích chemie. Pokud jde o ověřování učebnic ve Slovinsku, neexistují jednotná kritéria. Vypracování kritérií zahrnovalo přehled cílů stanovených v kurikulu pro obor chemie. Kritéria byla vytvořena pro učebnice používané v 8. a 9. ročníku základní školy (žáci ve věku 13–15 let). Učebnice chemie byly analyzovány ve školním roce 2018/2019. Při ověření kritérií týkajících se učebnicových reprezentací jsou submikroskopické a hybridní reprezentace nejméně běžnými v analyzovaných učebnicích.

Klíčová slova:
základní škola, chemie, učebnice, kritéria kvality učebnic.

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1 Introduction

Learning in the digital age is characterised by a richness of information from different sources, provided to learners by various means, usually supported by Information and Communication Technology (ICT), such as the internet, etc. However, textbooks play a central role in supporting effective teaching and learning of science, as their intention at certain levels of education means that they should be correlated with the national curriculum for a given subject. The textbook is related to the subject or module and to a specific education level. The textbook as a learning tool and learning resource contributes significantly to the effectiveness of the teaching or learning process itself, while at the same time promotes and facilitates independent learning. In the textbook, scientific content is appropriately structured, revised and simplified because the users (students) do not have sufficient prior knowledge of the content to be able to understand it in its unprocessed form (Kovač, 2005). Marentič Požarnik (2016) points out that it is important that learning from the textbook is adapted to the student. She suggests that textbooks authors should consider: (1) taking into account the students' cognitive ability, understanding and experience, (2) using a language appropriate to the student's level of cognitive ability, (3) structure the subject and increase the transparency of the text (titles, subheadings, footnotes), (4) promote reading comprehension and higher cognitive activities in various ways, (5) pay attention to illustrations in the text (diagrams, sketches, pictures). The research TIMSS 2007 showed that 53% of Slovenian students in the 8th grade had teachers that use a textbook as a primary source of teaching, which is the same as average international results show (Svetlik et al., 2007). A textbook as an additional source of teaching is used among 47% of teachers; this is slightly above the world average according to the research. 34% of teachers in Germany reported that they use the textbook to broaden their own knowledge (Bölsterli et al., 2014). Mohammed and Kumari (2007) analysed teachers experience with the use of science textbooks and found out that teachers had difficulties recognizing mistakes in the textbooks.

2 Theoretical background

One of the most cognitive challenging topics for students in lower secondary school chemistry is electrolyte chemistry. Research show (Devetak et al., 2009a, 2009b; Devetak et al., 2004; Mulford & Robinson, 2002; Šegedin, 2000) that many misconceptions can be developed if this topic is not presented adequately in the chemistry classroom. Students develop different misconceptions such as not knowing the particles in basic aqueous solutions (Devetak et al 2009a). Devetak et al. (2004) reported that secondary school students do not understand the particulate nature of the solutions and are not able to present graphically the arrangement of particles of the solvent in the solution. They either draw the particles so that they were not randomly arranged or they draw a solution in which the arrangement of the particles represented the solvent as a precipitate, at the bottom of the beaker. The results of the research (Devetak, et al., 2009b) show that the most frequent misconceptions (73.7% of all sub-microrepresentations) regarding solutions of ionic substance was the wrong particle (molecule) drawn in the solution instead of separate ions. The results also indicate that students show many different inconsistencies regarding the explanations of the drawn particles with their names in the legend. Mulford and Robinson (2002) researched students understanding of chemical reactions and they stated that the correct sub-microrepresentation of the reaction mixture after the reaction, based on the given reaction equation and reactant legend, was chosen correctly by only 11% of the students in the pre-test and 20% in the end-of-semester test. However, more than 60% of the test takers in both tests chose answers that gave an incorrect sub-micropresentation of the final state according to the law of conservation of mass. A similar research was conducted by Šegedin (2000) who found that only 9% of students correctly converted the chemical reaction equation into a sub-microrepresentation of the mixture of product and excess reactant after the reaction between hydrogen and oxygen. However, a sub-microrepresentation with a legend for the reactant mixture before the reaction was given. He also noted that as many as 16% of the students did not draw oxygen molecule that were not used in the chemical reaction. Even 58% of the participants did not adhere to the law of conservation of mass in any way.

In the textbooks we find various visual representations, i.e. photos, diagrams, tables, drawings and graphs. According to some authors, representations should not be to complex and should be adapted to student's cognitive level (Cook, 2008). The work of Levias Pozzer and Roth (2003) indicates that textbook authors attend to the appropriate integration of the different representational means so that they assist students' in making sense of the content. Furthermore, the use of single photographs often does not allow a reader to disclose what really matters , a series of contrasting photographs, on the other hand makes salient variation that are more likely to lead students' to identify the crucial and learning aspects. Levias Pozzer and Roth (2003) suggest that every photograph should have an appropriate caption associated with it through an indexical reference in the main text. The caption should add enough information to guide the reader through perceptual analysis and therefore interpretation of the photograph, identifying relevant details and associating the figure with the main text. For the indexical reference, the authors suggest that the illustration (photo and caption) should be explicitly linked to the main text by an indexical reference, preferably immediately after the first mention of the object or phenomenon in the main text. Centering or focusing the relevant object or phenomenon in the photo highlights what is important. In some situations, arrows and other signs placed directly over the photo can help highlight important details in the photos. However, when there is information to be obtained from the dialectically related caption and photo, students miss out on an important resource for understanding the topic they are studying.

The study of Lee (2010) reports that up to 50% of textbook space is devoted to illustrations in addition to a lack of coherence between the illustration and the associated content. Other studies show a worrying trend towards the increased use of photographs and other "decorative" graphics rather than explanatory illustrations to make texts more familiar and less challenging (Lee, 2010; Slough, 2010).

Mayer (2014) points out that representations draw the student's attention to certain specific elements that enable him/her to make mental connections between the elements and thus promote meaningful learning that forms the basis for problem solving. His theory of multimedia teaching states that a person who accepts information from two sources (e.g. image and word) remembers more than if he/she receives information from a single source, and that is why textbooks should include both. In textbooks we can find different types of representations. Realistic representation represent reality according to the optical perception of people, drawings or photographs can be counted among the realistic images. Conventional representations may include diagrams, sketches, charts, maps, models of molecules. Hybrid representations combine a realistic and conventional way of representation (Devetak et al., 2010).

In chemistry, concepts can be presented on three levels, the macroscopic, the sub-microscopic and the symbolic level, which could be imagined as the corners of a triangle in which no form of presentation is superior to the others, but rather complements one another (Johnstone, 1991). All three levels must

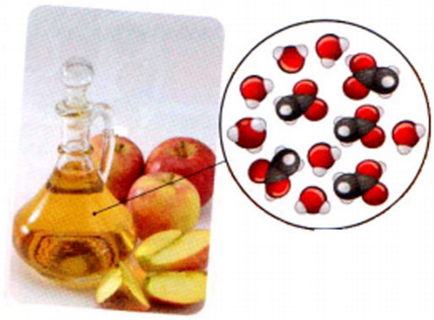


Fig. 1: Example of a hybrid image in a textbook represents acetic acid on a sub-microlevel and vinegar on a macroscopic level (Cvirn Pavlin et al., 2016)

overlap meaningfully in the learning process in order to create a suitable mental model of the concept (Devetak & Glažar, 2007). The effective overlapping of all three levels also allows students not to create misconceptions. Macroscopic imaging is about the actual state of a phenomenon (Johnstone, 1991). This means that the phenomenon is concrete for the student and can be described adequately (Devetak, 2007). Observations that are recognized by students at the macroscopic level are explained by theories based on atomic, molecular or ion level (Johnstone, 1991). Like the macroscopic level, the sub-microscopic level represents the actual state of a particular phenomenon and is the key to understanding chemical concepts before they are symbolically illustrated (Johnsotne, 2000). Sub-micro representations (SMRs) can be used to represent chemical concepts at the particle level, which can be represented as static or dynamic representations (Devetak & Glažar, 2010). The application of the macro, sub-micro, and symbolic levels of chemical concept representations (chemistry triplet) at all levels of education is an essential part of teaching and learning chemistry, textbooks should include all three levels. Researchers have subjected the ideas of the chemistry triplet (presented by Johnstone) to different adaptations and reinterpretations (Taber, 2013, p. 158).

It is often assumed that students understand the SMRs and learn efficiently with them because textbook authors (usually chemists) can use them simultaneously as part of a triple representation of chemical-chemical concepts. However, the presence of SMRs in a textbook does not guarantee efficient learning. According to Stieff et al. (2016) representational competence encompasses certain set of skills for constructing, selecting, interpreting and using disciplinary representations for communication, learning or problem solving. Research findings (Stull et al., 2012) indicate that the learning success of students with SMRs is significantly influenced by representational competence in chemistry. Kozma and Russell (2005) explained their role in the learning of chemistry, since in order to acquire professional competence in this field, students need to master a certain set of skills, e.g. the ability to analyse characteristics of a representation, to transform one representation into another. In accordance with Davidowitz and Chittleborough (2009) the use of chemical representations at the sub-micro and symbolic levels is as important as those on macroscopic level, the symbolic level helps students to understand the relation between the macro and sub-micro level of different chemistry phenomena.

Gabel (1999) found that while teaches are able to translate between different representational levels, they do not make an effort to integrate these levels in chemistry class.

Gkitzia et al. (2011) developed a rubric form that was applied for analysis of Greek grade 10 textbooks. They found that 23.6% of the representations are at the macroscopic level, 19.1% of representation are at the sub-microscopic level and 23.6% of the representations are at the symbolic level. The most common type of representation is a combination of macroscopic and symbolic representation. With to relatedness to text, more than half of the images were completely related to the corresponding chemical phenomena, but on the other hand, findings on the existence and properties of captions showed that about half of the visual representations were either problematic or had no caption.

Nyachwaya and Wood (2014) used the rubric form developed by Gkitzia et al. (2011) to investigate the nature and types of representations used in physical chemistry textbooks in the US. The results show that 85% of the representations were symbolic representations.

Kapici and Acikalin-Savasci (2015) analysed visual representations about the particulate nature of matter across grades 6–8 science textbooks used in Turkey. They found that macroscopic representations were the most common, followed by sub-microscopic, then symbolic. The fewest representations used were hybrid. Their results indicate that 4 out of 10 images were completely related and linked. A significant finding was that more than half (63%) of the images had no captions. Shehab and BouJaoude (2017) performed an analysis of representations in of Lebanese textbooks grade 10 and grade 11. They found out that in grade 10 textbooks, 53% of textbook representations were on a macroscopic level, followed by the sub-microscopic level (23%), for grade 11 textbooks the rate was 67% of representations were on macroscopic level and 18% of representations were on sub-microscopic level. Only 2% of representations in both textbook grades were classified as Hybrid. Most of the representations were completely related to the text, but were not accompanied by proper captions (Shehab & BouJaoude, 2017). Demirdöğen (2017) examined chemical representations presented in four Turkish high school chemistry textbooks. His findings revealed that representation most frequently used were at macroscopic level. The representations were completely related to the text. Marinč (2010) did a similar analysis on Slovenian chemistry school textbooks that were validated in the school year 2009/2010. She analysed the visual material in chemistry textbooks in the 8th and 9th grade of primary school in Slovenia and it she found out that the majority of representations in textbooks are on a symbolic level, followed by the macroscopic level representations. Text also plays a major role in chemistry textbooks, since comprehending new information depends on both student and textual characteristics (Rusek & Vojíř, 2019). Research has shown that inaccurate or incomprehensible texts can cause students' misconceptions (Bergqvist & Chang Rundgren, 2017); Pedrosa & Dias, 2000; Sanger & Greenbowe, 1993). Rusek and Vojíř, (2019) conducted an analysis of text difficulty in lower secondary Czech chemistry textbooks. Their research is focused on semantic difficulty by comparing particular textbooks in one textbook series and the difficulty of selected topics within the textbooks. The method used in their research is called Nestler-Průcha-Pluskal and it is based on variety of term categories (Rusek & Vojíř, 2019). They found that in the analysed Czech chemistry textbooks (for grade 8 and 9) no systematic approach towards scientific literacy and reading literacy was found, the text difficulty was not constant. Rusek and Vojíř (2019) also discovered that there were textbook series where the 8th grade textbook was more difficult, semantically and syntactically, than the 9th grade textbooks (Rusek & Vojíř, 2019, p. 7). The discovered inequality suggests that that text difficulty should also be considered as a criterion in textbook analysis.

3 Aim of the research

The main purpose of the research was to develop quality criteria after which we evaluated textbooks for Chemistry in primary school. This paper focus on the criteria developed for analysing pictorial elements in chemistry textbooks. When it comes to validating textbooks in Slovenia, there are no unified criteria; therefore, we can spot inconsistencies in validated textbooks, not to mention that validation might be under pressure from the publisher. The development of the criteria included an overview of the objectives set in the chemistry curriculum. The criteria for evaluating textbooks are useful in chemistry education because they determine: whether the textbook is appropriate for the students at the specific cognitive level, whether it motivates students to learn chemistry, whether the textbook contains contemporary findings in the field of chemistry and the natural sciences, and whether it follows research driven modern trends in chemistry education (Stern & Roseman, 2003). Due to the developed criteria, the electrolyte chemistry pictorial material in selected textbooks was analysed and some suggestions which textbooks fits best to the specific level of chemistry education were made.

Research Questions:

1. What general characteristic of pictorial representations are included in the analysed textbooks?
2. What type specific pictorial representations are included and how frequently the triple nature of chemical concepts is included in analysed textbooks.

4 Methodology

The research is based on a quantitative research approach. A descriptive, non-experimental method of educational research was used (Sagadin, 1993). The criteria were developed based on literature studies of comparable criteria for the validation of textbooks used in other countries and adapted for Slovenian chemistry textbooks. The criteria were used for the analysis and comparation of chemistry textbooks in the 8th and 9th grade in Slovenian primary schools, which were valid in the school year 2018/2019 and are still available in the current school year to the students. This paper focus on the criteria developed for analysing pictorial material in chemistry textbooks. Based on theoretical starting points and a review of literature, a matrix was created for the analysis of textbooks. The data collected were processed using quantitative methods according to the type of criterion.

4.1 Sample

The Sample represents textbooks for chemistry in the 8th and 9th grades of lower secondary school, which were validated in the school year 2018/2019. Textbooks with the same title and authors, a more recent edition of the textbook was analysed. In textbooks where the electronic and the physical version are identical, the physical version was analysed.

Tab. 1: List of analysed textbooks

Original textbook title (translated textbook title)	Author(s)	Publisher	Year of publication	Number of pages	Grade
Kemija 8, i-učbenik (Chemistry 8, i-textbook)	Sajovic, I., Wissiak Grm, K., Godec, A.,Kralj, B., Smrdu, A., Vrtačnik, M., Glažar, S.	Zavod RS za šolstvo	2014	264	8
Moja prva kemija (My first chemistry)	Vrtačnik, M., Wissiak Grm, K. S., Glažar, S. A., Godec, A.	Modrijan	2015	240	8, 9
Od atoma do molekule 8 (From atom to molecule 8)	Smrdu, A.	Jutro	2012	128	8
Kemija danes 2 (Chemistry today 2)	Graunar, M., Podlipnik, M., Mirnik, J.	Dzs	2016	152	9
Peti element 9 (Fifth element)	Devetak, I., Cvirn Pavlin, T., Jamšek, S.	Rokus Klett	2011	77	9
Pogled v kemijo 9 (Look into chemisty 9)	Kornhauser, A., Frazer, M.	Mladinska knjiga	2005	140	9

All the analysed textbooks contain topics with concepts that are defined by national chemistry curriculum.

4.2 Research Instrument

A matrix for analysing textbooks in Excel was created. The criteria have been divided into two main strands: a) the content-didactic criteria and b) the organisational-technical criteria. Strand a) was further divided into: (1) thinking, (2) tasks, (3) vocabulary and language, (4) content. Strand b) was further divided into: (5) text and representations, (6) internal structure, (7) external appearance. For the purpose of this paper, only the results of the analysis of the category (5) test and representations are presented. The results were processed using Microsoft Office Excel. No textbook was considered preferential.

Table 2 presents the analysis criteria for organisational and technical criteria covering the text and representations and a description of the subject of the analysis for each criterion.

Tab. 2: Criteria related to text and image, and subject of the analysis of the criterion

Criteria related to text and representations	Subject of analysis
The representation is on the same page as the text (Piht et al., 2013).	In this context, it was analysed whether the representation was on the same page as the text (i.e. whether the Mayer principles were respected).
Formulas and schemes are understandable and logical (Piht et al., 2013).	It was analysed whether the schemes, formulas and the graphs were understandable and in correlation with text.
Characters/Illustration/diagram does not contain more than 7 elements or objects (Piht et al., 2013).	How many items are displayed in images/illustrations/schemes has been analysed.
Figure/Illustration/scheme is in correlation with text (Piht, et al., 2013).	It was analysed whether the images/illustrations/ in chemistry textbooks are related to text.
In the textbook we find presentations at macroscopic level (e.g pictures, sketches, photographs, film cuttings, . . .) (Bölsterli et al., 2017).	It was analysed how many presentations in the chemistry textbooks are at macroscopic level.
In the textbook we find presentations of particles at sub-microscopic level (2-D or 3-D sub-microprezentation) (Bölsterli et al., 2017).	It was analysed how many sub-micro representations are in the chemistry textbooks.
In the textbook we find presentations at the symbolic level (mathematical formulas, symbolic chemical language) (Devetak et al., 2007)	It was analysed how many of the presentations are in the chemistry textbooks at the symbolic level.
The textbook contains conventional images (graphs, sketches, schemes, maps, molecular models) (Devetak et al., 2010)	It was analysed how many conventional images are in chemistry textbooks.
The textbook contains hybrid images (Devetak et al., 2010).	It was analysed how many hybrid images are in chemistry textbooks.

4.3 Results

The results are presented only for the organisational and technical criteria covering the textual and pictorial elements in textbooks. The results are presented for the topic: electrolyte chemistry. The topic occurs in textbooks for 8th grade and three textbooks for 9th grade, because textbook authors are not obligated to write textbook topic in the same order as the topic (objectives) that are written in the chemistry curriculum for primary school.

Tab. 3: Textbook representations on the electrolyte chemistry in Slovenia lower secondary chemistry textbooksgeneral characteristics

Criteria (YES/NO)	Kemija danes 2	Peti element 9	Pogled v kemijo 9	Od atoma do molekule 8	Moja prva kemija	i-učbenik kemija 8
The representation is on the same page as the text.	YES	YES	YES	YES	YES	YES
Formulas and schemes are understandable and logical.	YES	YES	YES	NO	NO	YES
Characters/Illustration/diagram does not contain more than 7 elements or objects.	YES	YES	YES	YES	YES	YES
Figure/Illustration/scheme is in correlation with text.	YES	YES	YES	YES	YES	YES

For the analysed topic, the authors of the textbooks took into account that the pictures are on the same page as the text and that they have a reference to the text. All the formulas and schemes analysed were understandable and appropriate, except for the presentation of the aqueous solutions in the textbook From atom to molecule 8, in which the water molecules are drawn and the background is coloured blue, this representation can cause misunderstanding and representation in textbook My first chemistry where you can not read why the chlorine ione is highlighted in purple.

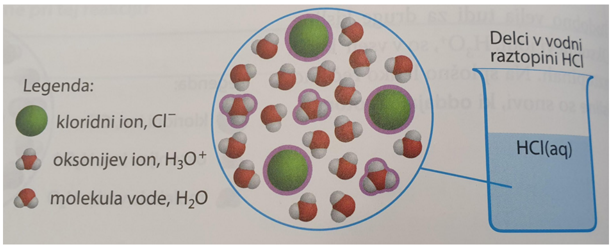
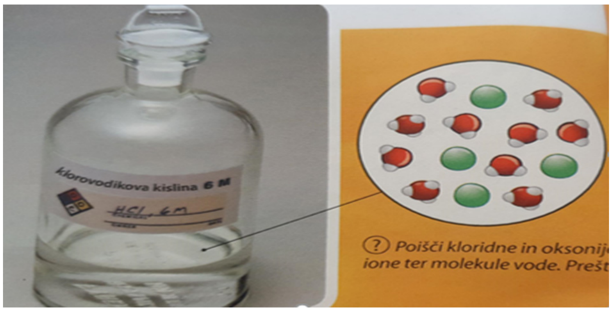
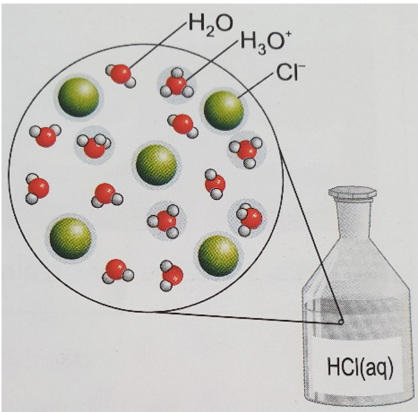
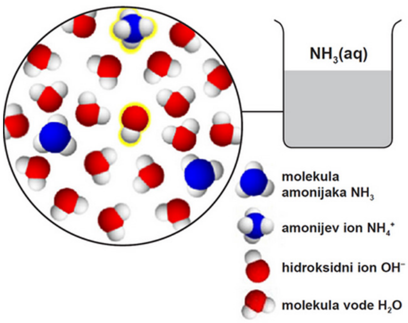
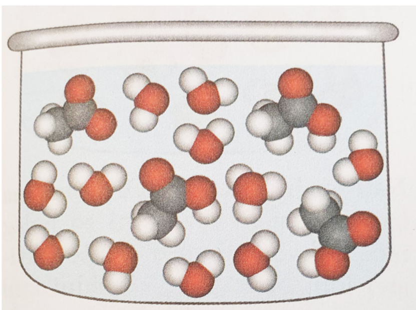
Tab. 4: Textbook representations on the topic electrolyte chemistry in Slovenia lower secondary chemistry textbooks at thetriple nature of chemical concepts

Criteria (f)	Kemija danes 2 (f)	Peti element 9 (f)	Pogled v kemijo 9 (f)	Od atoma do molekule 8 (f)	Moja prva kemija (f)	i-učbenik kemija 8 (f)
In the textbook we find representations at macroscopic level (e.g pictures, sketches, photographs, film cuttings, ...)	45	18	20	32	24	30
In the textbook we find representations of particles at sub-microscopic level (2-D or 3-D sub-micropresentation)	10	7	0	3	12	11
In the textbook we find representations at the symbolic level (mathematical formulas, symbolic chemical language)	50	20	2	46	13	20
The textbook contains conventional images (graphs, sketches, schemes, maps, molecular models)	23	9	4	11	10	3
The textbook contains hybrid images	8	6	0	2	9	6

In the analysed textbooks we find most representations on the symbolic level, most of them in the textbook Chemistry today 2 ($f = 20$), and none in the textbook Look into chemistry 9 ($f = 0$). The macroscopic level is most represented in the textbook Chemistry today 2 ($f = 45$) and in the textbook From atom to molecule 8 ($f = 32$). In the analysed chapter, all textbooks contained very few sub-microrepresentations. Textbook Look into 9 had only 2 sub-microrepresentations ($f = 2$).

Most of the conventional representations are found in textbook Chemistry today 2 ($f = 23$) and in Textbook From atom to molecule 8 ($f = 11$), at least in the I-textbook chemistry 8($f = 3$) and in Textbook Look into chemistry 9 ($f = 4$). Most of the hybrid representations can be found in the textbook My first chemistry ($f = 9$) and in the textbook Chemistry today 2 ($f = 7$) and Fifth element 9 ($f = 7$), From atom to molecule 8 had only two hybrid representations ($f = 2$). The textbooks Look into Chemistry 9, did not have any hybrid representations.

Tab. 5: Examples of sub-microrepresentation form analysed textbooks

<table>
<tr><th>Textbook</th><th>Example</th></tr>
<tr><td>My first chemistry</td><td>
</td></tr>
<tr><td>Fifth element 9</td><td>
</td></tr>
<tr><td>Chemistry today 2</td><td>
</td></tr>
<tr><td>Chemistry 8, i-textbook</td><td>
</td></tr>
<tr><td>From atom to molecule 8</td><td></td></tr>
</table>

The textbooks Chemistry 8, i-textbook, Chemistry today 2 and My first chemistry did have a legend for particles that are presented in the sub-microrepresentation. In all of these textbooks the text was related to the sub-microrepresentation, containing an explanation of the image, followed by questions such as: which particle indicate that the solution is acid or base, and which particles indicate the solution is an electrolyte. In the textbook Chemistry 8, i-textbook, the text did not state why some particles are yellow coloured. The textbook Fifth element 9 did not have a legend for particles presented on the image, but the text under the image did ask students to pick which particles are water molecules and which are hydronium ions. The sub-microrepresentation in textbook From atom to molecule 8 can cause some misunderstanding, because in the solution we see water molecules but the background is also coloured blue (which represents water). The textbook Look into chemistry 9 did not have any sub-microrepresentations present.

5 Discussion

The purpose of this paper is to present the characteristics of the pictorial material in Slovenian chemistry textbook for students in lower secondary school. The first research question deals with general characteristics of pictorial representations in analysed textbooks. All the authors of analysed textbooks acknowledged Mayer's (2014) principles, so all the pictorial material is on the same page as the text it refers to. All analysed textbooks, except the textbook My first Chemistry (Moja prva kemija) meet the criteria for general characteristics. The second research question deals with type specific pictorial representations and how frequently the triple nature of chemical concepts are included in analysed textbooks. Our results for the second research question are consistent with the findings of (Nyachwaya & Wood, 2014; Shehab & BouJaoude, 2017 and Gkitzia et al., 2011) who reported "a bias towards a macro-symbolic orientation in the textbook". In the introductory chapters of textbooks, it is expected that textbooks macroscopically present chemical phenomena, as this (macroscopic) level a representation has potential to attract and stimulate students' interest in chemistry (Upahi & Ramnarain, 2019). In a longitudinal study by Lee (2010), the author examined the extent to which representations in textbooks published in the United States have changed over the past six decades. It was found that high-fidelity images, such as photographs, were more likely to be used than the schematic and explanatory images to promote student familiarization. In explaining the criteria for evaluating the quality of science textbooks, Devetak and Vogrinc (2013) noted that visual materials are sometimes used to stimulate recall of prior information. Although many variables related to graphic features were considered, the researchers failed to extract the overall graphic/representative quality of elementary science textbooks.

The results of our study indicated a very small proportion of sub-microscopic representations in the textbooks and this fails to address the important point that many chemical phenomena are understood at the particulate level (Davidowitz & Chittleborough, 2009). It is equally important that textbook authors give attention to this form of representation. In a study of Kapici and Acikalin-Savasci (2015) on how visuals that focus on the particulate nature of matter are used in middle school science textbooks, it is also reported a less frequent use of the sub-microscopic levels in chemical explanations. Analysed textbooks contained very few hybrid images. Researchers (Carney & Levine, 2002) recommend that illustrations/schematics/graphics in textbooks are simple and contain fewer elements, as unnecessary additions only confuse the students. Hinze et al., (2013) suggests that understanding the kinds of information and inferences that the visualisations in various learning materials provide requires explicit instruction and practice. In all analysed textbooks, representations were on the same page as the text. The importance of relatedness of text to representations in terms of completeness and linkage is that students do not have to try to establish a link and interpret the image in relation to the text by themselves (Levias Pozzer & Roth, 2003). Irez (2010) examined five secondary biology textbooks and investigated the treatment of the nature of science. Lee (2010) examined the design and use of representations that have changed over six decades in the United States and argued that the diagrams used in textbooks are becoming increasingly iconic. Science was found to be represented as a collection of facts rather than a dynamic process of generating and testing alternative explanations about the nature of science. The study identified a problem in the textbooks that may be generating alternative ideas about science as the scientific domains were presented as collections of facts rather than dynamic processes. Hegarty and Just (1991) who classified diagrams used in science teaching context into three types which include: Iconic diagrams, schematic diagrams, and charts and graphs. Iconic diagrams are realistic pictures or drawings of concrete objects. They are effective in helping students identify appearance and structure that are amenable to visual inspection. Schematic diagrams are highly abstracted from real-world entities and preserve only the physical relationships of the target information. Consequently,interpreting a schematic diagram requires learners todecode the abstract content of the diagram and make a connection to the target concept. The third category, diagrams and graphs,represents the relationships of quantitative data. It is often necessary for the reader to identify all independent variables before making an interpretation because abstract meanings and numerical data are embedded in charts and graphs

6 Conclusion

Chemistry requires the integration of chemical representations to understand phenomena in textbooks and during classroom instructions, for effective teaching and learning of chemical concepts to take place. When the teacher may be limited in portraying these phenomena during class, textbook becomes a vital and indispensable tool for conveying an adequate understanding of the underlying concepts and principles of a chemical phenomenon.

The goal of this study was to develop criteria for textbook analysis that can help the commission in the process of textbook validation, as well as the teacher in the selection of a textbook. In addition, the criteria can be a good tool for authors in designing new textbooks. The criteria were developed for 8th and 9th grade elementary chemistry textbooks. In the 2018/2019 school year, the validated textbooks for chemistry in primary school were analysed. The results in this paper are presented only for the organisational and technical criteria covering the pictorial elements. Textbook authors need to acknowledge that if different levels of chemistry representations are well-integrated in textbooks, they have the potential to reduce students' difficulties in understanding chemical concepts and promote their learning. However, teachers who understand the role of pictorial material in chemistry and its connection to textual part of the textbooks they use in classroom may also be able to use these textbooks more efficient to promote meaningful learning at each level of education.

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Phylogenetic Trees and Other Evolutionary Diagrams in Biology Textbooks and Their Importance in Secondary Science Education

Fylogenetické stromy a další evoluční diagramy v učebnicích přírodopisu a biologie a jejich význam v sekundárním přírodovědném vzdělávání

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Diagrams describing relationship between organisms, and their overall evolution, commonly in the form of phylogenetic trees or other evolutionary diagrams, have become a part of even lower secondary biology textbooks. These diagrams can help promote basic science literacy, yet their design may also strengthen misconceptions about evolution. Therefore, based on the content analysis of 112 Czech biology textbooks for secondary schools (ISCED levels 2 and 3), characteristics of introduced phylogenetic trees and other evolutionary diagrams were recorded and evaluated according to the cladistics to see if their construction supports the current scientific understanding of evolution. The content analysis indicates that the design of nearly half of all diagrams in current lower (ISCED 2) and upper secondary (ISCED 3) textbooks promotes ladder thinking. More than 80% of all diagrams were not accompanied by instructions on how to read them, meaning that students did not have sufficient scaffolding to understand them. Mainly ISCED 3 textbooks did not introduce additional problem tasks that would support the use of the diagrams in the lessons. Therefore, authors of textbooks should focus more on the construction quality of these diagrams while also supporting their correct application during the educational process. This is likely to prevent a further increase in student misconceptions.

Key words: phylogenetic trees, evolutionary diagrams, systematics, biology textbooks, secondary education.

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Fylogenetické stromy a další evoluční diagramy zobrazující vztahy mezi organismy a jejich evoluci se již staly součástí učebnic biologie a přírodopisu určených pro sekundární vzdělávání. Tyto diagramy mohou rozvíjet základní přírodovědnou gramotnost, ale nevhodný způsob jejich zobrazení může také posilovat miskoncepce žáků o evoluci organismů. Ke zhodnocení této problematiky v ČR byla provedena obsahová analýza 112 českých učebnic biologie a přírodopisu pro sekundární vzdělávání (vzdělávací úrovně ISCED 2 a 3). Zaznamenány byly charakteristiky zobrazených fylogenetických stromů a dalších evolučních diagramů a dle kladistiky zhodnoceno, zda jejich stavba podporuje současné vědecké chápání procesu evoluce. Bylo zjištěno, že způsob zobrazení téměř poloviny všech diagramů v učebnicích pro druhý stupeň (ISCED 2) i střední školy (ISCED 3) podporuje tzv. žebříkovité myšlení (ladder thinking). Více než 80 % diagramů neobsahovalo instrukce k jejich čtení a žáci tak nemají oporu, která by jim umožnila diagramy správně pochopit. Především učebnice pro střední školy neuváděly dodatečné problémové úlohy, které by podporovaly využití těchto digramů ve výuce. Doporučením při tvorbě učebnic je tedy zaměřit se na zkvalitnění konstrukce těchto diagramů a podporu jejich využití ve výuce, což by mělo bránit dalšímu nárůstu žákovských miskoncepcí.

Klíčová slova: fylogenetické stromy, evoluční diagramy, systematika, učebnice přírodopisu, sekundární vzdělávání.

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1 Introduction

Determination of relations among organisms and their evolution in time are studied nowadays more than ever thanks to the growth of molecular genetics methods (Zrzavý et al., 2004). These findings are then visualised in a form of branching diagrams commonly known as phylogenetic trees (Baum, 2008; McLennan, 2010). And as knowledge of systematics (consisting of both taxonomy and phylogenetics) grew over the last few decades, various phylogenetic trees and other types of evolutionary diagrams found their way even into the lower secondary school textbooks (Catley & Novick, 2008).

Although these diagrams have the potential to both introduce students to the diversity of organisms on the Earth and their relations as well as promote basic science literacy and a deeper understanding of evolution (Gregory, 2008; Sandvik, 2008), they, unfortunately, showed as problematic. Firstly, they are not self-explanatory and requires instructional scaffolding, and secondly, their design can also reinforce various misconceptions, mainly ladder thinking and inappropriate level of anthropocentrism (Sandvik, 2008).

These fallacies in understanding the concepts of phylogeny and evolution seem to be rather hard to overcome. Even university students of biology often showed these misconceptions while dealing with the phylogenetic trees (Dees et al., 2014; Halverson et al., 2011; Kummer et al., 2016) – they were unable to correctly interpret the relations between taxa (Phillips et al., 2012; Sa'adah et al., 2017; Sandvik, 2008) and showed a wrong understanding of evolution (Sa'adah et al., 2017). Both biology graduates and undergraduates tended to read the phylogenetic trees from left to right assuming that organisms on the left always show more ancestral traits (Novick et al., 2012; Omland et al., 2008). Even graduates of evolutionary biology and phylogenetics courses struggled to read and build the correct phylogenetic trees (Phillips et al., 2012; Schneider et al., 2012).

This raises the question of whether phylogenetic trees should be even introduced at lower educational levels. On the other hand, the introduction of correctly made phylogenetic trees during the lessons accompanied by instructions on how to understand them can be a tool to challenge students' way of thinking and target their misconceptions about the evolution of organisms (Angielczyk, 2009; Sandvik, 2008). As a special type of diagram, they can be also used to promote not just basic science literacy but also statistical and reading literacy (in other words to promote several key competencies). Therefore, phylogenetic trees can be a very useful part of biology education even at the secondary level if used in the right way.

As evolutionary biology is already introduced at the end of a lower secondary level (ISCED 2), phylogenetic trees can help to visualize its basic principles. This stresses the need to design these trees correctly using cladistic principles. The way the tree is depicted influences how the viewers read and understand it (Dees et al., 2018; Novick et al., 2012), therefore, an inappropriately constructed phylogenetic tree can do more harm than good as it can support the scientifically incorrect ways of thinking mentioned above (Sandvik, 2008).

Unfortunately, only little is known about if biology textbooks help to promote students understanding of phylogenetic trees or if they use them to support the correct concept of evolution and organisms' relations. In the case of Czech ISCED 2 and 3 biology textbooks, there is nothing known about the overall amount or the quality of phylogenetic trees and other evolutionary diagrams as well as their integration into the presented curriculum – neither in the current textbooks nor from a historical perspective.

Therefore, this study aims to explore the following:

- Are basics of phylogenetics and taxonomy (as how relations among organisms are established) introduced in the Czech ISCED 2 and 3 biology textbooks?
- When did the phylogenetic trees and other evolutionary diagrams become a part of Czech ISCED 2 and 3 textbooks?
- What types of phylogenetic trees and other evolutionary diagrams can be found in the Czech textbooks?
- What kind of information do these types of diagrams show (i.e. their characteristics)?
- Does the design of these diagrams support the scientifically correct understanding of evolution (tree thinking)?
- Do the current textbooks contain sufficient scaffolding on how to read and understand these types of diagrams?

2 Theoretical framework

Diagrams showing the development and relations between organisms became emblematic visuals of modern biology. Today, these diagrams are commonly grouped under the term phylogenetic tree (or synonymously evolutionary tree) (Reddy, 2011).

2.1 Brief history of taxa relations determination

The history of these diagrams began in the second half of the 19th century. At that time, relations among organisms were studied by systematics and their determination relied only on the morphology and anatomy of organisms (Fendrych, 1947; Hoßfeld et al., 2017). The first phylogenetic trees are attributed to Charles Darwin (Gregory, 2008) and were published in his 'On the Origin of Species' in 1859 (Darwin, 1859). In the very next decade, these branching diagrams spread and were used by other scientists (Hoßfeld et al., 2017; Mivart, 1865).

Progress of genetics during the second half of the 20th century gave rise to the modern phylogenetics that determines relations of organisms according to their heritable traits – not just morphology, but also their DNA (Reddy, 2011; Zrzavý et al., 2004). The shape of phylogenetic trees and methods of their construction then gradually changed – from morphological-based ladder trees such as Haeckel's trees of life (Dayrat, 2003) to a currently popular form of right-angled chronograms based on molecular genetics methods (Omland et al., 2008; Yang & Rannala, 2012). This resulted in many new findings from major changes in the classification of certain taxonomic groups to the discovery of cryptic species, but it also enabled more precise reconstruction of evolutionary history (Zrzavý et al., 2004).

2.2 Definition and characteristics of phylogenetic trees

The term phylogenetic tree is derived from its visual form. Such diagram shows a branching pattern, where every branch represents a certain group of organisms. Branches end up with tips that can represent either higher taxon, a single species or in some cases even a specific gene (Reddy, 2011; Scott & Baum, 2016). Taxa showed at the tips of the branches are mostly extant, but can be also extinct or represented by fossils (Scott & Baum, 2016).

Branches divide into nodes that represent speciation events and the last common ancestor of organisms that are represented by the branches descending further from the node (McLennan, 2010); Scott & Baum, 2016). Therefore, branches can be turned (rotated) at the nodes without a change of diagram's meaning (Fig. 1) (Baum, 2008). This means that it is the topology of branches that really matters and not the order of taxa at the tips of branches (Sandvik, 2008).

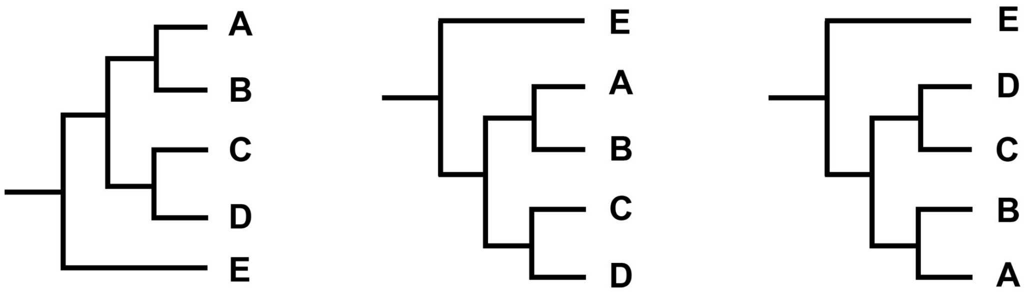

Fig. 1: Three hypothetical phylogenetic trees, each taxon labelled with a letter. All three trees show the same information about the taxa relations, only the branches were rotated in nodes on different levels

In the node, the branch splits into two – if more than two branches are descending from one node, it means that relations among these taxa remain unclear (referred to as polytomy or multifurcation) (Novick & Catley, 2016).

Phylogenetic trees can be unrooted or rooted, where rooted means that there is one branch representing the last common ancestor of all depicted taxa at the beginning of the tree, and all the other branches are successive to this one (Reddy, 2011; Scott & Baum, 2016).

To create a branching pattern that is easy to read and visually clear, branches are often connected in 90° angles. Therefore, every tree can be visualised in several different ways without a change in a branching pattern (McLennan, 2010). Types commonly used in the scientific literature are for example (Baum, 2008) rectangular tree that can be easily transformed into circular or ladder tree (diagonal) (see Fig. 2).

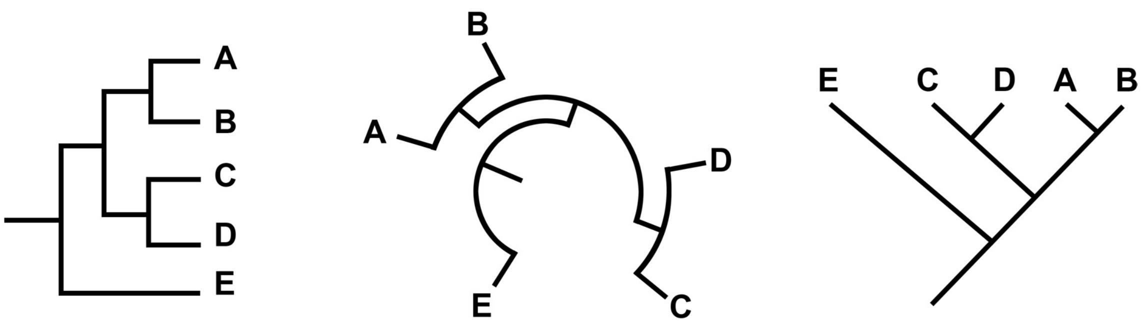

Fig. 2: Three different shapes of the same tree, from the left: rectangular, circular, ladder (diagonal)

Phylogenetic trees are constructed using various methods, but they all share the common principle – organisms are grouped according to their shared unique characteristics (anatomy, morphology, DNA sequence, etc.) (McLennan, 2010; Morrison, 1996). This applies both in the case of analysis of currently living organisms relations as well as relations among extinct and extant taxa (Morrison, 1996). To address these characteristics, it requires specific terminology. Characteristics are described as (McLennan, 2010; Scott & Baum, 2016):

- plesiomorphy – ancestral state of certain characteristic
- apomorphy – derived state of ancestral characteristic, referred to as a synapomorphy if certain apomorphy is shared within a group of organisms (clade) and as an autapomorphy, if this characteristic is found only in one taxon

Notably, only characteristics of taxa can be assigned as plesiomorphic or apomorphic, not the taxa themselves as they always combine both types of characteristics (Zachos, 2016).

According to the type of represented information, we can divide phylogenetic trees into several categories. In all cases, the hierarchical branching pattern of the tree (broadly referred also as dendrogram) shows the same relations among taxa, but the information given by the branches varies (Podani, 2019; Reddy, 2011; Scott & Baum, 2016; Zachos, 2016):

- cladogram – shows only relations of taxa through the branching pattern and does not show ancestor-descendant relations (extant taxon cannot be ancestral for another extant taxon), represents only relative time (if rooted and consisting of extant taxa, the root represents the past and the tips of the branches present, but nodes themselves do not represent specific points in time)
- phylogram – the length of branches represents the amount of characteristics' change, therefore, the tips of the branches are not equidistant from the root
- chronogram – the length of branches represents the absolute time, and all the tips of the branches are equidistant from the root (in the case they represent extant taxa)
- special types as spindle diagram (also referred to as romerogram, where the thickness of branches represents the diversity of taxa in time) or tree of life (aims to visualise the evolution of life, the root represents the last universal common ancestor of all organisms on Earth)

Till today, various types of phylogenetic trees became ordinarily used at the university level but also found their way into secondary school textbooks (Catley & Novick, 2008), which requires the ability to read and understand them correctly.

2.3 Misconceptions in understanding and reading the phylogenetic trees

The ability to understand and read phylogenetic trees became one of the important goals of biology education (McCullough et al., 2020) as they help students understand not only the relationships among living organisms but also the underlying principles of their origin and processes of evolution (Gregory, 2008; Schramm et al., 2019). Knowledge of relationships among taxa provides deeper insight into their ecology and ethology (Felsenstein, 1985; Wiens, 2004) as well as the process of transmission of infectious diseases and parasites among them (Ypma et al., 2013).

To achieve this understanding among students, it requires to introduce phylogenetic trees constructed according to the cladistics whose design does not promote common misconceptions or rather historical views on the process of evolution (Catley & Novick, 2008; Dvořáková & Schierová, 2019) such as ladder thinking and inappropriate level of anthropocentrism.

One of the biggest challenges while teaching the topic of evolution is to shift students understanding from the ladder to the tree thinking (Gregory, 2008). Ladder thinking represents an incorrect historical concept that the development of organisms can be simply depicted by aligning them according to their complexity (Zachos, 2016). Rooted in the concept of *scala naturae*, it shows evolution as a ladder from the simple unicellular to the more advanced multicellular organisms, often crowned by mankind on the top (Diogo et al., 2015).

Therefore, ladder thinking leads to the wrong assumption that the currently living organisms with the less complex characteristics are ancestors of the more complex or derived ones (Meisel, 2010) or that they are 'less evolved' (Kummer et al., 2016). One of the examples is a common misconception that humans evolved from chimpanzees or that the current unicellular organisms represent the ancestral state of all animals.

Such visuals (resp. diagrams) are already known by Ernst Haeckel (Dayrat, 2003), but they are not just historical, as they can be found even in current textbooks (Dančák & Sedlářová, 2011). Even modern cladograms published in scientific journals can imply this no longer valid concept by the arrangement of the organisms at the tips of the branches in left-right or top-down order (or reverse) according to the species richness of presented higher taxa (Zachos, 2016). Scientists themselves then tend to describe extant taxa wrongly as ancestral, while they only carry some ancestral traits (Zachos, 2016).

As the understanding of evolutionary mechanisms deepened, the scientific community shifted towards the current concept of tree thinking. This concept has not been properly defined but revolves around the idea that tree thinking is necessary to successfully extract information about relationships of organisms from phylogenetic trees (Schramm et al., 2019; Scott & Baum, 2016). The tree thinking skills consist of several main abilities as described by Novick and Catley (2016): understanding how phylogenetic trees depict relations and identifying relatedness of visualized taxa, identifying shared characteristics inherited from the most recent common ancestor (synapomorphies) and using these characteristics to reason about relations, identifying in which order did the new characters arose during the process of evolution, and understanding that rotation of the branches around their nodes does not change the relations of taxa as well as addition or removal of the branches.

Contrary to the ladder thinking, tree thinking promotes the view that all currently living organisms share common ancestors, and, no matter the complexity of their characteristics, they all share the ability to maintain their existence in the current environment and successfully overcame a long time of development that more or less shaped them to their current form (Zachos, 2016). Therefore, it implies that although some extant organisms have more complex characteristics than others, they cannot be perceived as better or higher, neither as having an ancestor-descendant relationship (Diogo et al., 2015; Kummer et al., 2016; Zachos, 2016).

The same applies to mankind. Both scientists and teachers very often face the common idea of strong anthropocentrism, which means positioning man on the top of all the living beings and understanding nature only from the perspective of human life. Humans are often presented as one of the most complex organisms on Earth, but it does not make them implicitly better or way more important than any other organisms they share Earth with. Anthropocentrism is often blamed for various phenomena in science education – as understanding microorganisms more as a cause of diseases than an important part of the ecosystem helping to decompose and cycle the matter (Byrne et al., 2009) or belief that cell death and ecosystem disturbance have always only negative implications (Coley & Tanner, 2012). Effects of anthropocentric thinking are also often discussed in environmental education while reasoning for environment protection (Cocks & Simpson, 2015; Kopnina, 2014).

In phylogenetic trees, anthropocentrism is emphasized by aligning the organisms according to their complexity with humans placed in some privileged position (as on the top of the tree or the very right side, as the trees tended to be read from left to right). This is mainly visible when the tree also promotes the ladder thinking and its branches are also not equidistant from the root. Similarly, as in the case of ladder thinking, trees can also end up looking anthropocentric if the taxa are aligned from the ones with the oldest common ancestors to the youngest.

All of these problems can be easily fixed by rotation of branches in their nodes and making all the branches tips with extant taxa equidistant from the root, so the reader focus more on the branching pattern rather than the order of the taxa on the branches tips (Zachos, 2016).

3 Methods

To evaluate the amount and the characteristics of all phylogenetic trees and other evolutionary diagrams in Czech science education, content analysis was carried out. It included Czech biology textbooks aimed for educational levels ISCED 2 and 3 and textbooks recommended for ISCED 3 students' final exams ('Maturitní zkouška'). To gain a historical perspective and reveal when the knowledge of systematics and phylogenetic trees were first introduced in the textbooks, all textbooks that were published after the first edition of Charles Darwin's 'On the Origin of Species' (1859) were included.

Textbooks were divided into four groups according to the year of publishing: archaic (published from 1859 to 1917), historical (1918–1948), post-war (published from 1949 to 1989), and currently used (still being available in stores and used by teachers, published after 1990 and later). Chosen periods represent the main events in the development of the Czech educational system, which were the end of the Austrian Empire after the 1848 revolutions, the establishment of the Czechoslovakia, socialist era, and the new development after the Velvet Revolution (Čornejová et al., 2020).

If it was possible to access more than one edition of a single textbook, they were compared. In the case of current textbooks (published after 1990), significant differences among various editions in content concerning the topic of systematics (i.e. taxonomy or phylogenetics) were only discussed. Therefore, only the newest editions were used in the content analysis itself. In the case of the textbooks published before 1990, editions with such differences were included in content analysis and counted as two separate books. Different editions of a single textbook that were compared but showed having the same content are cited in Appendix 1 (part C).

All textbooks were subjected to the content analysis of topics of phylogenetics and taxonomy, i.e. searched for any information about how are relations among organisms generally established and visualised both in the term of the taxonomic groups or individual species relations. Found content was divided into two categories: explanatory text and visuals (both text-based and diagram with pictures).

Explanatory text was either focused on the taxonomy (as the introduction of binomial nomenclature or Linnean categorization that enables to group related organisms), or phylogenetics in general (explanation of determination of organisms' relationships and phylogenetic trees construction and reading).

Visual (or graphic) elements were subjected to both qualitative and quantitative content analysis. All elements that were describing either taxonomic groups, their relationships, or development in time were included. As textbooks often do not use the same formats of displaying taxa relations as scientific literature does, there was a need to develop a specific categorization system. Therefore, Catley and Novick's (2008) categorization was adopted and partly altered. Four main categories of all textbooks' graphic elements related to taxonomy and phylogenetics were established:

- taxonomic overview – plain list of taxonomic groups with assigned lower subphyla (as classes, orders, families, etc.) without the depiction of their relations, unrooted, showing mainly polytomies
- linear depiction of evolution – organisms' development viewed exclusively as a linear change from one species to another, even though it should be portrayed as cladogenesis and not anagenesis (e.g. famous illustration of ape gradually changing to modern human)
- phylogenetic tree – in this study, this term is narrowed to the diagram constructed according to the basic cladistic principles, i.e.: representing relations among the depicted species without implying ancestor-descendant relations (e. i. species placed only at the tips of the branches), extinct taxa clearly differ from extant (labelled or their branches are visibly shorter), all extant taxa are equidistant from the root (unless it is phylogram), not using polytomies (or only in cases where taxa relations are not yet established); these phylogenetic trees were then divided according to their visual form into three groups (see Fig. 3) according to Catley and Novick (2008):
  - tree (rectangular) – branches create a clear levelled structure, could be both bifurcate at the right angle (most common in professional biology journals) or with branches rounded in nodes
  - ladder (diagonal) – branches are following one main diagonal line, branches can be rounded at nods
  - other types – branching structure does not show distinguished levels and no diagonal line is present

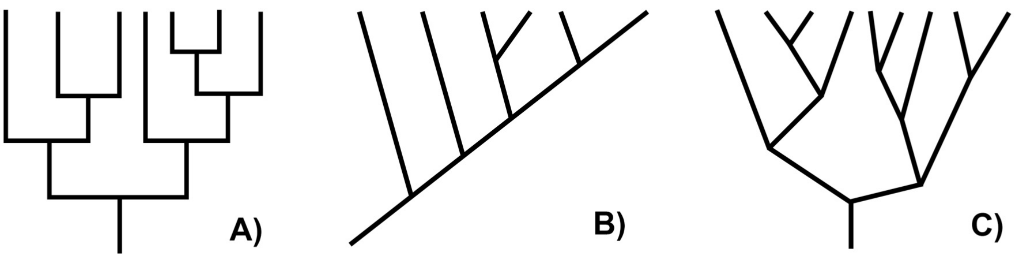

Fig. 3: Illustrations of types of cladograms distinguished in this study, from left: A) – tree cladogram, B) – ladder (diagonal) cladogram, C) – other

- other evolutionary diagrams – other established types of phylogenetic trees or any other evolutionary diagrams showing either only development or both development and relations between taxa with deviations from traditional cladistics (e.g. 'ancestry' taxa are placed in the middle of the branches, extant taxa in different distance from the root, depicted as a bar chart, or non-Darwinistic trees of life); these diagrams were further assigned to the several categories established in the scientific literature as:
  - Haeckel's tree of life – rooted, length of branches varies and has no meaning, supporting ladder thinking

- chronogram – branches show relations of the taxa and their length represents time, contains an additional timeline
- spindle diagram – showing an abundance of taxa during the time with or without their relations
- other – diagram bordering the characteristics of types above

Furthermore, several key characteristics of all phylogenetic trees and other evolutionary diagrams found in currently used textbooks were recorded. These characteristics were chosen according to how the diagrams:

- enable the reader to gain information about the introduced taxa, their relations, and their development in time
- influence scientifically correct understanding of evolution (tree thinking)
- resemble the phylogenetic trees commonly used in the scientific literature

Therefore, these characteristics related to the phylogenetic trees and other evolutionary diagrams were recorded:

- anthropocentric – humankind is explicitly placed in the privileged position among other organisms (as on the very right side, on the top, in much bolder colours etc.)
- supporting ladder thinking – organisms are aligned at the tips of the branches according to their complexity in left-right or top-down order or reverse
- polytomy – at least one clearly visible polytomy of the taxa, whose relations were already known by the time of publishing the textbook
- time-respecting – all currently living organisms are equidistant from the root, extinct organisms have visibly shorter branches
- rooted – visible root or marking of the last common ancestor
- right angles in the nodes – branches are connected always at the right angle
- time scale – additional time scale or time markings of important events in time
- hominids evolution – diagram contains the evolution of hominids (only or among other taxa)
- species illustrations – introduced taxa are represented by a picture of a certain specie
- coloured – diagram and the illustrations in it are colourful or only black and white
- instructions – any additional text instructions on how to understand and read the presented diagram, these can be both in the textbook's text or in the diagram's caption (i.e. simplified principles of cladistics and tree thinking), does not mean a description of taxa, branches division or a timeline that is already presented in the diagram

Notably, flaws in relations among taxa (f.e. use of paraphyletic groups) were not recorded as this topic itself is broad and would require a separate study.

4 Results

The analysis contained altogether 112 textbooks for ISCED 2 and 3 educational levels with different titles or different content of searched topics, several of them were found in two or more editions (see Tab. 1, whole list available in Appendix 1).

Tab. 1: Number of textbooks subjected to content analysis in all categories according to the year of publishing

Educational level	Year of publishing: archaic (1859–1917)	historical (1918–1948)	post-war (1949–1989)	current (1990+)	Sum per level
ISCED 2	3	12	7	39	61
ISCED 3	10	8	14	19	51

4.1 Phylogenetics and taxonomy in the textbooks

Explanation of concepts of binominal nomenclature and Linnean categorization and even a short description of phylogenetics as a science were all found already in historical textbooks. In post-war textbooks, description of binominal nomenclature and Linnean categorization were part of half of all the textbooks, while at least simple information about how the relations of taxa are determined according to their similarities was found in 38% of the cases.

In current textbooks, the introduction of taxonomy as a science, Linnean categorization of taxa and binominal nomenclature were part of at least one textbook from each edition aimed for ISCED level 2 and half of all the textbooks for ISCED level 3.

Phylogenetics, on the other hand, was introduced only in two current textbooks for ISCED level 2 – very shortly as a science focused on the development of species (Cílek et al., 2000; Pelikánová et al., 2016). Three current ISCED 3 textbooks contained a simplified description of how the relations among taxa are determined and how to understand the phylogenetic trees (Benešová et al., 2013; Kincl et al., 2008; Šmarda, 2003). Two textbooks, containing a full chapter devoted to this topic, were also published during the last decade (Flegr et al., 2017; Rosypal et al., 2003).

4.2 Types and amount of visual elements related to phylogenetics and taxonomy

The first published diagram showing relations among taxa was recorded in 1936 (Bartušek, 1936), but any other evolutionary diagrams did not appear in any other textbook until 1945 (Řehák, 1945 and began to be more abundant only later during the post-war era (Tab. 2).

Tab. 2: The number of textbooks containing any visual (graphic) elements related to taxonomy and phylogenetics. Total number of textbooks in individual categories: archaic = 13, historical = 20, post-war = 21 and current = 58. The percentage was counted from the sum of the textbooks in every individual category

Textbook category	Type of searched visual element and number of textbooks containing it: Nothing	Taxonomic overview	Linear depiction	Evolutionary diagram	Phylogenetic tree: tree	Phylogenetic tree: ladder	Phylogenetic tree: other
Archaic	6	7	0	0	0	0	0
percentage	*46%*	*54%*	*0%*	*0%*	*0%*	*0%*	*0%*
ISCED 2	2	1	0	0	0	0	0
ISCED 3	4	6	0	0	0	0	0
Historical	10	9	0	3	0	0	0
percentage	*50%*	*45%*	*0%*	*15%*	*0%*	*0%*	*0%*
ISCED 2	8	4	0	0	0	0	0
ISCED 3	2	5	0	3	0	0	0
Post-war	8	6	1	11	0	0	0
percentage	*38%*	*29%*	*5%*	*52%*	*0%*	*0%*	*0%*
ISCED 2	4	1	1	2	0	0	0
ISCED 3	4	5	0	9	0	0	0
Current	15	29	10	17	5	4	4
percentage	*26%*	*50%*	*17%*	*29%*	*9%*	*7%*	*7%*
ISCED 2	11	21	10	6	2	1	1
ISCED 3	5	8	0	11	3	3	3

Textbooks from the post-war era did contain various types of other evolutionary diagrams but no phylogenetic trees. The most commonly used were Haeckel's trees of life implying the principle of *scala naturae* ($N = 8$), also five spindle diagrams and three chronograms were found, where two showed phylogeny partly as a linear change of one species to another (Jílek et al., 1982; Poupa & Meisner, 1969). Only in one case, evolution was showed exclusively linear (evolution of hominids in Fleischmann et al., 1983).

A significant change in the amount and types of evolutionary diagrams between various editions of a single book was found only once. In textbooks for 9th grade by SPN, the oldest edition contained a spindle diagram while the newest one was free of all searched visual elements (Pauk et al., 1972, 1980).

In the current textbooks, phylogenetic trees and other evolutionary diagrams (both further referred to as diagrams) were found in both ISCED 2 and 3 textbooks through their quality varied (see Fig. 5). Altogether, ten phylogenetic trees of various type were found. Though Haeckel's trees were not that common type of other evolutionary diagrams anymore, they still appeared in six cases. There were also eight spindle diagrams, but the most common were chronograms and other diagrams, which were commonly cladograms that did not conformed to the definition of phylogenetic tree used in this study.

4.3 Characteristics of diagrams

In the post-war textbooks, 80% of all diagrams (both phylogenetic trees and other evolutionary diagrams) supported the idea of ladder thinking and showed unnecessary polytomies that were caused partly even by the shape of branches and unclear nodes due to avoiding clear 90° angle design (Fig. 4).

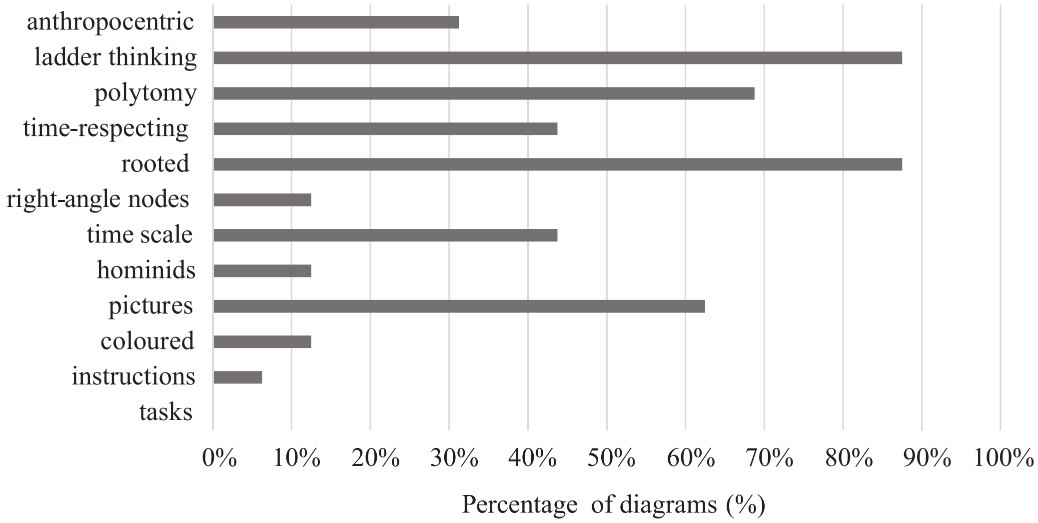

Fig. 4: Characteristics of all diagrams (both phylogenetic trees and other evolutionary diagrams, $N = 18$) presented in post-war textbooks. As there were only two diagrams from two ISCED 2 textbooks, ISCED 2 and 3 textbooks are not divided

Diagrams presented in current textbooks often reinforced misconceptions (Fig. 5). 50% of ISCED 2 and 40% of ISCED 3 diagrams supported ladder thinking by aligning organisms at the branches' tips according to the complexity of their characteristics. Half of all diagrams also showed unnecessary polytomies.

More than 80% of diagrams in all current textbooks were rooted and more than 60% time-respecting (extant taxa equidistant from the root). No distinction between currently living (extant) and extinct taxa was more common in ISCED 3 textbooks. Only ten diagrams showed branches connected strictly at the 90° angle, all were presented in ISCED 3 textbooks. In 10 out of all 14 ISCED 2 textbooks diagrams, branches were variously rounded at nodes, which made the precise points of the nodes less visible.

Any instructions on how to read the diagrams that would be placed right along the diagram itself were presented only in three ISCED 2 textbooks namely from Prodos and Fortuna (Dančák, 2015; Dančák & Sedlářová, 2011; Kvasničková et al., 2018) and four ISCED 3 textbooks (Benešová et al., 2013; Flegr et al., 2017; Kvasničková, 2013; Šmarda, 2003). Still, these instructions were only very short and superficial. More than 90% of ISCED 3 textbooks lacked any tasks enabling active use of the diagrams during the lessons (Fig. 5).

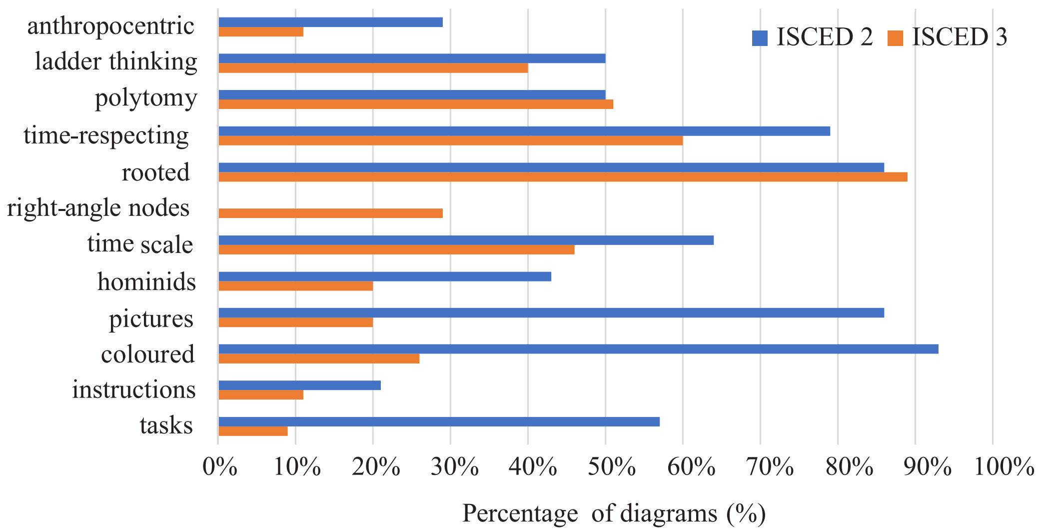

Fig. 5: Characteristics of all diagrams (phylogenetic trees and other evolutionary diagrams, $N = 59$) found in the currently used textbooks (35 diagrams from ISCED 3 and 14 from ISCED 2 textbooks)

4.4 ISCED 2 textbooks' visual elements

In ISCED 2 textbooks, phylogenetic trees and other evolutionary diagrams were overall less abundant, but in all cases either fully colourful or not entirely black and white (using colours combined with black and white silhouettes of species). Except for one diagram, they all contained pictures of introduced species.

Unfortunately, part of the diagrams contained very clear flaws. Diagrams of hominids evolution from three ISCED 2 textbooks partly showed evolution as a transformation of one species directly to the other one (Cílek et al., 2000; Drozdová et al., 2016; Pelikánová et al., 2016). Similarly, the textbook for 8^{th} grade by Prodos partly supported this idea (Navrátil, 2016), which was caused by the attempt to show both the species evolution as well as their expansion to the continents.

Diagrams of hominids evolution by Fraus and SPN textbooks for 8^{th} grade (Černík et al., 2015; Pelikánová et al., 2016) tended to be visibly anthropocentric (species sorting implies that the complexity grows from left to right). Though, the most visibly anthropocentric diagram was in the textbook for 9^{th} grade by Scientia, where humankind was placed in a very privileged position among other organisms and even distinguished by colour (Cílek et al., 2000).

This Haeckel-like tree diagram (Cílek et al., 2000) was also an example that evolutionary diagrams from ISCED 2 textbooks sometimes even lacked most information they could have shown (even relations among the taxa themselves). Similarly, as another tree diagram used in Prodos textbook for 6^{th} grade (Dančák & Sedlářová, 2011), they gave only the information about the diversity of living organisms while also implying the scientifically wrong principle of *scala naturae*. Notably, the same types of diagrams were also included in the older textbooks edition by Prodos (Jurčák & Froněk, 2004).

ISCED 2 textbooks often used the taxonomic overviews that served as a depiction of the diversity of organisms. Notably, textbooks for 6^{th} and 7^{th} grade by Taktik (Petrová et al., 2017; Žídková & Knůrová, 2017) and Nová škola (Hedbávná et al., 2017) contained big overviews accompanied by colourful pictures that served as a good reminder of the organisms' diversity and the taxa that were introduced in the textbooks. Textbooks by Fraus for 7^{th} and 8^{th} grade (Pelikánová et al., 2015, 2016) used similar smaller overviews at the beginning of the new topics accompanied by silhouettes or photos of species. On the other hand, various textbooks (Dobroruka et al., 2010; Kvasničková et al., 2019, 2020; Maleninský et al., 2004) used big taxonomic overviews as supplementary material at the end of their textbooks in form of a plain list of taxa, not accompanied by any pictures.

There were various good examples of the use of evolutionary diagrams. Although there were certain violations of cladistics, diagrams of hominids evolution in the textbook for 8^{th} grade by Fraus (Pelikánová et al., 2016) were easy to read and helped to visualise the evolution. They contained pictures of both living and extinct species, showed additional information (timeline), and were even accompanied by simple tasks that enabled students to work with the diagrams (as "describe the evolution" and "name ancestors of humankind"). Looking at the older edition of the same book, it was visible that Fraus also updated and improved the diagram of hominids evolution (Vaněčková et al., 2006).

Another example was textbooks by Prodos that proved that even linear depictions of evolution implying the generally wrong ideas about the speciation process can be used in the right way. In the textbook for 8^{th} grade, a famous picture of an ape evolving in a linear row into the human was used but with the caption 'gradual straightening of the figure during the evolution of the hominids' (Navrátil, 2016). This caption completely changed the meaning of the picture, therefore, it was not even categorized as linear depiction. Still, this type of picture without caption or directly implying the linear evolution in its description was used in several other ISCED 2 textbooks (Matyášek, 2019; Matyášek & Hrubý, 2019; Žídková & Knůrová, 2018).

4.5 ISCED 3 textbooks' visual elements

Phylogenetic trees and other evolutionary diagrams were overall more abundant in textbooks aimed for ISCED 3 level. The mean for ISCED level 3 was 1.8 diagram per book, while for ISCED level 2 it was only 0.4 diagram per book. However, according to the principles of cladistics, the quality of diagrams in ISCED 3 textbooks varied even more.

ISCED 3 textbooks contained various spindle diagrams ($N = 4$), chronograms ($N = 12$), as well as uninformative Haeckel's trees of life ($N = 4$) implying the idea of ladder thinking. Mainly textbooks by Fortuna (Kincl et al., 2008; Smrž et al., 2004; Šmarda, 2003) and Olomouc (Jelínek & Zicháček, 2007) introduced examples of phylogenetic trees resembling even the ones from professional biology journals (build clearly as tree or ladder cladograms with branches equidistant from the root).

Diagrams were proportionally less anthropocentric, though they still often supported ladder thinking as they tended to align organisms in left-right or top-down order from visually simpler to more complex (Smrž et al. 2004; Šmarda, 2003). The most unusual diagrams were introduced in 'Biologie v kostce' (Hančová & Vlková, 2017) – though they were rooted, showing branching pattern, and claimed to be depictions of phylogeny, they violated several cladistics principles, contained unnecessary polytomies, and no pictures of species, which made them look more as confusing taxonomic overviews.

As ISCED 3 textbooks were often only black and white (or contains only coloured attachments with photographs), diagrams were less visually interesting and only one quarter of them contained any colours. Only fifth of them was accompanied by schematic pictures of species.

5 Discussion and implications in practise

The first phylogenetic tree was introduced already in 1859 in Darwin's 'Origin of species' (Darwin, 1859, but it took a long time until evolutionary diagrams of any kind made their way into the Czech textbooks. With one exception of the evolutionary diagram (Bartušek, 1936), textbooks published before 1945 included only taxonomic overviews. During the post-war era, the abundance of evolutionary diagrams grew, but there were still no modern phylogenetic trees (cladograms or phylograms). Nevertheless, as modern phylogenetics is a young branch of biology sciences, it is no surprise that textbooks published before 1989 contained only a few evolutionary diagrams.

Although half of all currently used textbooks introduce bigger taxonomic overviews and all editions of ISCED 2 textbooks already introduce taxonomy and artificial taxa categorization, phylogenetics is in any form rather scarce to find. Biology education in the Czech Republic mostly uses the morphological-taxonomic approach while ordering topics in the school curriculum (Hlaváčová, 2017). The ability to assign organisms to their higher taxa is also demanded by the current national curriculum (NÚV, 2021). On the other hand, depictions of the relations among the taxa are not commonly used, mainly at ISCED level 2. An older study showed that schemes represent on average only about 16% of all graphic elements in ISCED 2 biology textbooks (Hrabí, 2006). It reflects the low abundance of phylogenetic trees as three-quarters of all ISCED 2 textbooks did not contain any diagram depicting evolution and relations among taxa.

If such diagrams were present in ISCED 2 and 3 textbooks, the majority of them did not conform to the modern cladistics or tended to variously support misconceptions about evolution and phylogenetics as a ladder or anthropocentric thinking. These problems were also recorded in textbooks used in USA (Catley & Novick, 2008). In some cases, diagrams also implied the process of evolution partly as a linear change from one species to the other or explicit linear depictions of evolution were present. This was already found in a previous study on the humankind evolution in the Czech textbooks (Dvořáková & Absolonová, 2017). Such graphic elements can negatively influence students' understanding of human evolution implying it as a gradual change from ape to human (Dvořáková & Schierová, 2019).

Some diagrams even lacked most information about the taxa relations given by continuous use of Haeckel's trees of life (Cílek et al., 2000; Dančák & Sedlářová, 2011; Jelínek & Zicháček, 2007). Even though the captions of these diagrams pursued the intention to show mainly the diversity of living organisms, the same can be easily visualised in a big taxonomic overview accompanied by pictures of the introduced species. Similarly, spindle diagrams showed the abundance of taxa during the time but did not always clearly depicted their relations (Cílek et al., 2000; Smrž et al., 2004). Flaws in the diagrams' construction were sometimes even visibly caused by graphic designers trying to fit the picture on the page, as when the names of extant taxa were placed at the roots of branches and not at their tips (Kvasničková, 2018), or when the distinction of extinct and surviving taxa was unclear from the branches length though the extinct taxa were labelled with crosses (Jelínek & Zicháček, 2007; Kočárek, 2010).

Similarly as in the USA textbooks (Catley & Novick, 2008), phylogenetic trees and other evolutionary diagrams were mostly superficially described and lacking instructions on how to read and use them in lessons. Most of the diagrams in ISCED 3 textbooks contained only short captions describing them as the depictions of evolution or relations among showed taxa with no more information. Textbooks for both ISCED level 2 and 3 mostly did not explain how to read these diagrams or only simply described content of a diagram (as higher taxa names, time of their origin, the way lineages divided) though it was already proven that phylogenetic trees are not self-explanatory diagrams and without any guidance and instructions they are interpreted wrong by students (Novick et al., 2012).

Around 40% of ISCED 2 textbooks did not contain ideas for tasks enabling students to work with the presented diagrams actively in the lessons and most ISCED 3 textbooks did not introduce any such tasks. Notably, even textbooks for ISCED level 3 devoting whole chapters or longer parts of the text only to the cladistics principles and phylogenetics itself (Flegr et al., 2017; Kincl et al., 2008; Rosypal et al., 2003) showed only very few examples of cladograms on which students can apply their newly gained knowledge. Two ISCED 3 textbooks (Jelínek & Zicháček, 2007; Smrž et al., 2004) also introduced the diagonal format of trees (ladder trees) that are not recommended to use as students find them much more difficult to understand than rectangular (tree) format (Novick et al., 2014).

To conclude, the main problem of the evolutionary diagrams and particularly phylogenetic trees used in secondary textbooks is not just the reinforcement of misconceptions but also unfulfilled educational potential.

As many researchers showed, phylogenetics itself is hard for students to comprehend even at the university level (Dees et al., citemach13; Halverson et al., 2011; Kummer et al., 2016; Phillips et al., 2012). Therefore, ISCED 2 and 3 students cannot be expected to perform better. However, introducing outcomes of phylogenetics as a science at the secondary level should not be used to learn students how to construct the phylogenetic trees or understand detailed principles of molecular phylogenetic methods, but to comprehend the basic skills of reading such diagrams and acknowledging the message behind the very basic phylogenetic principles.

The aim of secondary science education is mainly to gain basic environmental and science literacy, therefore, phylogenetic trees should be used to facilitate students understanding of the evolution process and the position of humankind among other organisms (Sandvik, 2008). It had also been shown among university students that reading the trees is a much more comprehensible task than their construction (Halverson, 2011).

Phylogenetic trees are not just one of the main outcomes of modern science serving very valuable information, but they also facilitate active learning and help to battle both ladder thinking and misconception of linear evolution, which is still commonly used in illustrations in the popular culture and media as well as in many ISCED 2 textbooks as this study showed. Therefore, biology textbooks for higher grades of ISCED 2 and textbooks for all grades of ISCED 3 should introduce at least one phylogenetic tree as the most basic depictions of taxa relations rather than the explanation of uninformative and artificial Linnean categorization (as definitions of family, order, class etc.) (Sandvik, 2008).

On the other hand, phylogenetic trees used in the textbooks should respect students' cognitive development. As they mostly did not meet with phylogenetic trees before, they do not know how to read and deeply understand this specific type of diagram. This stresses the need to accompany all such diagrams with instructions on how to read them (Novick et al., 2012). Even very young kids (age 7–11) were able to understand phylogenetic trees much better given only short instructions (Ainsworth & Saffer, 2013) and the same has been shown among university students (Phillips et al., 2012). As lectures strictly focused on phylogenetics are not obligatory at Czech faculties of education (as at the Charles University, the South Bohemian University, and the Masaryk University), these instructions will not serve just for students, but in many cases probably also for the teachers, which makes them even more important.

Authors of textbooks should always follow the basic cladistics principles during the construction of the used trees. At least some of these principles should be also described in the diagram's caption or the text, so students can navigate themselves how to read the presented tree correctly. This means statements like: all living organisms are at the tips of branches (in one line), branches can be turned at their nodes without changing the meaning (therefore, the species' order at the tips of the branches do not describe the species' complexity), lines and nodes of the branches do not represent extinct species but common ancestors, and so on.

As they tend to be very abstract, phylogenetic trees in the textbooks should be also more explicit than their counterparts in scientific journals and made easy to read using pictures of depicted species and preferably also clear timescale along with the right colour palette (for example to distinguish time periods or taxa). Rectangular trees should be also preferred over diagonal format (Novick et al., 2014). Although the branches connections do not have to be strictly at the right angle if it does not lead to the creation of artificial polytomies due to the poor visual differentiation of the nodes.

However, oversimplification of phylogenetic trees can result in nearly abstract pictures with no useful information (as Haeckel's trees of life). These can confuse the students and lead to the wrong understanding of taxa relations or origin (Sandvik, 2008), so they should not be used at all. In case the authors do not want to incorporate any phylogenetic trees, a much better option is to use a big taxonomic overview of taxa introduced in the book that will be accompanied by pictures of the most common or known species (see Fig. 6).

As supporting visualisations, phylogenetic trees can be great tools in hands of educators as a base for various problem tasks that enable active learning. For example, students can compare the morphology of related taxa to show examples of convergence and divergence during evolution, they can reconstruct the richness of human ancestors living at the same time on certain places on Earth, or reason which characteristics allows currently living taxa to survive. They can also answer some of the most popular biology questions like "Are we apes, or did we evolve from them?" or "Was it an egg or a hen that came first?" and many more. Such tasks can help students to deeper their understanding of many basic principles of science and should be more often embedded in science textbooks. There are already many other ideas for activities (Davenport et al., 2015; Gibson & Cooper, 2017; McCullough et al., 2020) and whole educational models developed that can serve as an inspiration for teachers in practice both at

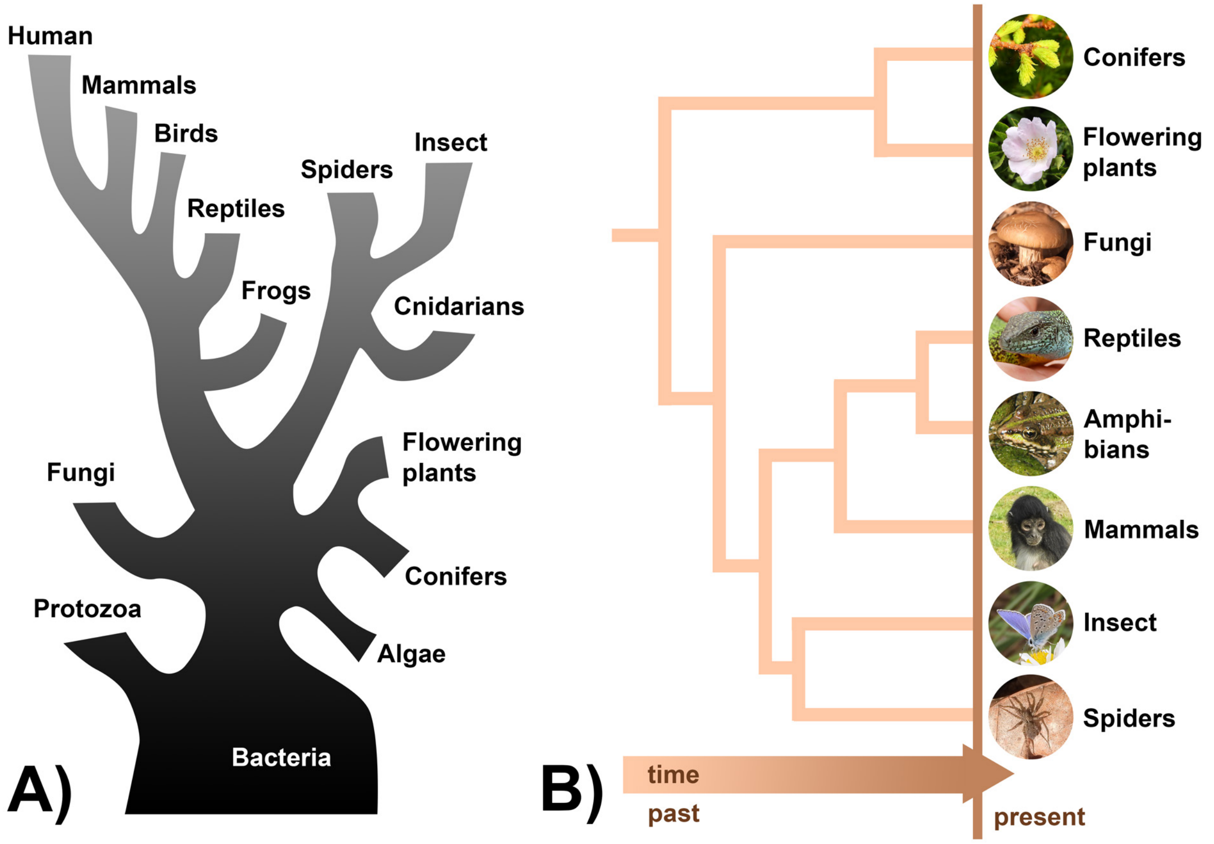

Fig. 6: Difference between evolutionary diagram promoting misconceptions and diagram made according to the basics of cladistics. On the left (A), there is a nearly abstract evolutionary diagram in a form of Haeckel's tree of life presenting some poly- or paraphyletic taxa. On the right (B), there is a modern colourful chronogram accompanied by pictures. In the left diagram (A), neither the thickness of branches nor their length has any meaning as well as their pattern. The diagram also implies ladder and anthropocentric thinking. In the diagram on the right (B), the branching pattern is clear, length of branches roughly represents time, and the diagram supports the tree thinking. (Used pictures made by the author.)

secondary and even at the university level (Eddy et al., 2013; Kong et al., 2017; Koupilová, 2020). Such activities can be also a very beneficial part of biology teachers' education. They can enable future teachers to gain a deeper understanding of the topic as well as adopt effective tools to help their own students in the future.

Many teachers complained to me that due to the recent growth of modern molecular methods phylogeny of organisms often changes, implying that textbooks will get outdated quickly after publishing. However, recent changes in the phylogeny of organisms did not affect most of those introduced in secondary textbooks neither their categorization, which is at the end only artificial (Sandvik, 2008). Also, outdated taxonomy seems to be a much bigger problem than phylogeny. Many textbooks used in this study still introduce such historical paraphyletic taxa as protozoans (Černík et al., 2007; Musilová et al., 2018; Pelikánová et al., 2014; Vieweghová, 2019) and even the new editions of the same textbooks did not update this. Nevertheless, many various problems of outdated taxonomy and phylogeny in secondary textbooks are not the aim of this paper and will require a whole separate study itself.

As there are no exact records of all the Czech textbooks ever published and used in schools, this study does not have to include all of them. Therefore, the proportions of textbooks introducing phylogenetic trees and other evolutionary diagrams does not have to be definite but should represent at least the majority of textbooks, as various physical and digital archives were combined during the search.

6 Conclusion

Although the first diagram depicting relations between taxa was introduced in the Czech textbook in 1936, evolutionary diagrams became more abundant only later during the second half of the 20th century and they were mostly supporting ladder thinking.

While taxonomy and binomial nomenclature are common parts of the biology curriculum and current textbooks at both ISCED 2 and 3 educational levels, relations between presented taxa are still introduced scarcely in current secondary school textbooks.

Current textbooks for both ISCED level 2 and 3 still mostly present various evolutionary diagrams rather than modern phylogenetic trees and some of them do not even contain nearly any valuable information and many promote wrong understanding of principles of both evolution and phylogenetics.

On the other hand, correctly built phylogenetic trees can serve as a way how to effectively visualise organismal diversity and evolution and support general science literacy as well as students' active learning.

Therefore, ISCED 2 level textbooks should be accompanied with either big taxonomic overviews of the main taxa presented in the textbook or a simplified phylogenetic tree accompanied by guidance on how to read this type of diagram, problem tasks enabling its active use during the lessons, and preferably also pictures of species and timescale for better visualisation. The same goes for the ISCED 3 textbooks, where the use of various correctly build and described phylogenetic trees should be a standard.

The results of this study should not be understood the way that detailed cladistic principles and molecular phylogenetics have to be a part of secondary education, but the main outcomes of phylogenetics should be used to help students visualise and understand the basic biology concepts and natural processes as evolution that are part of the common science curriculum and also to prevent the rise of misconceptions about these concepts and processes.

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Appendix

Appendix 1: List of analysed textbooks

Textbooks published before 1990 are sorted according to the year of publishing, current textbooks are in alphabetical order.

Part A) Archaic (1859–1917)

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Nosek, A. (1906). *Zoologie pro vyšší třídy středních škol.* Praha: Česká grafická unie.

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Rosický, J. (1920). *Přírodopis pro školy měšťanské: na základě biologickém.* Praha: Česká grafická unie, a. s.

Nosek, A. (1921). *Přírodopis živočišstva pro nižší třídy středních škol: podle pozorování života v přírodě.* 2. vydání. Praha: I. L. Kober.

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C. II: Other editions compared

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D. III: ISCED 3

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Presentation of Combinatorial Concepts in Mathematics Textbooks and Its Compliance with a Concept Development Theory

Soulad zavedení kombinatorických konceptů v učebnicích matematiky s teorií poznávacího procesu

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This article analyses the approach taken by five Czech secondary school mathematics textbooks to selected combinatorial concepts, in order to determine the extent to which they provide pedagogical support to teachers based on the theory of generic models, which is a theory of concept development. The analysis of textbooks in relation to this theory focused on the presence and quality of a) isolated models and non-models of future knowledge, b) prompts to generalise as a prerequisite for the creation of a generic model, and c) the supportive role of graphical representations in developing combinatorial thinking. Most notably, we identified insufficient motivation for combinatorial problems, few isolated models of future knowledge, the absence of explicit prompts to generalise and a consequent lack of a significant concept of isomorphism. Despite the research-proven positive influence of the creation of graphical representations on the development of pupils' combinatorial thinking, they are rare in textbook chapters about combinatorics, and lack diversity. With a few exceptions, textbook authors do not encourage readers to create their own graphical representations. One textbook stood out in that it frequently prompts the creation of personalised representations, works purposefully with isomorphic problems and encourages the reader to generalise specific procedures.

Key words: combinatorics, textbook, graphical representation, concept development theory, Theory of Generic Models.

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Článek analyzuje přístupy k vybraným kombinatorickým konceptům v pěti českých středoškolských učebnicích matematiky s cílem zjistit, do jaké míry tyto učebnice poskytují podporu učitelům pro výuku založenou na teorii poznávacího procesu v matematice. Analýza učebnic byla vedena na pozadí teorie generických modelů, přičemž důraz byl položen na přítomnost a kvalitu a) izolovaných modelů a nemodelů budoucího poznatku, b) výzev k zobecňování jako nutnému předpokladu tvorby generického modelu, c) grafických reprezentací jako nezbytné podpory rozvoje kombinatorického uvažování. Bylo zjištěno, že učebnice jsou si v mnoha směrech dosti podobné, ale v jistých ohledech se odlišují. V učebnicích jsme identifikovali mj. nedostatečnou motivaci pro kombinatoriku, nízký počet izolovaných modelů budoucího poznatku, absenci explicitních výzev k zobecňování a z toho plynoucí absenci významného konceptu izomorfismus. Navzdory výzkumně prokázanému pozitivnímu vlivu přítomnosti a vlastní tvorby grafických reprezentací na rozvoj žákovského kombinatorického myšlení se v učebnicích vyskytují reprezentace zřídka, a navíc s malou rozmanitostí. Autoři učebnic až na výjimky nevyzývají čtenáře k tvorbě vlastních grafických reprezentací. Od analyzovaných učebnic se odlišuje jedna, která obsahuje časté výzvy k tvorbě vlastních reprezentací, pracuje záměrně s izomorfními úlohami a vyzývá čtenáře k zobecňování konkrétních postupů.

Klíčová slova: kombinatorika, učebnice, grafická reprezentace, teorie pojmotvorného procesu, teorie generických modelů.

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1 Introduction

Mathematics can be taught in various ways, but teachers, textbook authors, and researchers in mathematics education agree that the goal is for pupils to have a good understanding of mathematics. Following Hejný and Kuřina (2009), we understand the educational process to consist of individual pupils constructing their own knowledge. Instruction designed according to how mathematics knowledge is built in pupils' minds is a prerequisite for understanding (Vinner, 2014). Our study is based on the assumption that textbooks can help the teacher to prepare instruction that is aligned with pupils' conceptual development. Indeed, textbooks have been shown to be one of the most important determinants in the teaching of mathematics (Fan, 2013). At the same time, it has been shown that the effect of textbooks on learning mathematics is mediated through their use in lessons by teachers (e.g., Tarr et al., 2006; Van Steenbrugge et al., 2013), leading to the question of whether textbooks provide appropriate support for teachers.

We pursue this question on the topic of combinatorics – a part of discrete mathematics that consists of calculating the selection and arrangement of objects in a finite set. Combinatorics has received attention since the early days of mathematics education research (e.g., Fischbein & Gazit, 1988; Hejný et al., 1990; Kapur, 1970). Combinatorial problems can be used to develop pupils' ability to make conjectures and generalise, and thus go beyond the field of mathematics. For example, it has been shown that the incorporation of combinatorial and logical problems into mathematics lessons enabled pupils to transfer their experience hereby to biology, physics and chemistry lessons (Stofflett & Baker, 2016). According to Grimaldi (2003), the ability to divide a problem into subproblems, which provides key insights into combinatorial reasoning, is similar to the ability to split a computer algorithm into several components, which are then "more easily workable programming tasks" (p. 41). Moreover, combinatorial reasoning helps pupils to grasp many related concepts including isomorphism, relations, or equivalence classes (Kapur, 1970). In short, combinatorics represent an important part of mathematics which merits investigation.

Based on the above, our study aims to determine how selected combinatorial concepts and procedures are presented in mathematics textbooks, and whether the textbooks support teachers in their effort to design instruction that is aligned with how pupils acquire combinatorial concepts. The theoretical background of our study is the theory of generic models (Hejný, 2012), one of concept development theories that have been created to describe how pupils acquire knowledge in mathematics. According to this theory, the appropriate motivation is an important pre-requisite of learning in mathematics and this learning starts with a series of isolated models of future knowledge. Thus, we will investigate how the content is motivated in the textbooks, and whether they provide a variety of isolated models of combinatorial concepts which could help pupils to develop a generic model as a precursor to gaining abstract knowledge with understanding.

Combinatorics provides a space for meaningful problems that can be solved in many ways with various representational tools, including manipulation (English, 2005). It has been shown that visual representations are essential to solving combinatorial problems (e.g., Lockwood & Gibson, 2016). Thus, our second focus is on the way the textbooks we analyse include and promote visual representations to solve combinatorial problems.

2 Combinatorial concepts and procedures selected for the study

In this section, we describe the concepts and procedures which are essential for the development of combinatorial thinking and which will be our focus in our analysis of selected textbooks.

The two following rules are at the heart of combinatorial considerations (e.g., Vondrová, 2019).

The Rule of Sum:

> If a first task can be performed in m ways, while a second task can be performed in n ways, and the two tasks cannot be performed simultaneously, then performing either task can be accomplished in any one of $m + n$ ways. (Grimaldi, 2003, p. 3)

The Rule of Product:

> If a procedure can be broken down into first and second stages, and if there are m possible outcomes for the first stage and if, for each of these outcomes, there are n possible outcomes for the second stage, then the total procedure can be carried out, in the designated order, in mn ways. (Grimaldi, 2003, p. 4)

Two of the main combinatorial configurations, namely, k-permutations and combinations, will be targeted. Any linear organisation of a collection of k objects out of n distinct objects with reference to order is called an k-permutation. A selection of k objects out of n distinct objects with no reference to order is called a combination (Grimaldi, 2003, pp. 7, 15). Table 1 shows the properties of these configurations without repetition. The formulas concern the number of collections and how to select or order k of n distinct objects.

Tab. 1: k-permutations and combinations without repetition

Order is relevant	Type of result	Formula
Yes	k-permutations	$V(n,k) = n(n-1)(n-2)\cdot\ldots\cdot(n-k+1) = \frac{n!}{(n-k)!}$
No	Combinations	$C(n,k) = \frac{n!}{k!(n-k)!} = \binom{n}{k}^*$

$^*\binom{n}{k}$ is called a combination number.

Visual representations are essential in the teaching of combinatorics (Arcavi, 2003; English, 2005; Lockwood & Gibson, 2016; Salavatinejad et al., 2021; Uptegrove, 2015; Vondrová, 2019; Zahner & Corter,

1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
1 5 10 10 5 1

Fig. 1: Six rows of Pascal's triangle

2010). One such visual representation is Pascal's triangle, in which the combination numbers are arranged in the shape of a triangle (Fig. 1).

The numbers in the rows can be generated recursively according to Pascal's identity

$$\binom{n}{k} + \binom{n}{k+1} = \binom{n+1}{k+1}, \qquad (*)$$

valid for $n, k \in \mathbb{N}_0$; $n \geq k$.

3 Theoretical framework and literature review

Many factors influence how pupils learn. According to Apple (1986, cited in Fan et al., 2013), it is the textbook that mainly supports material conditions for teaching and learning and influences how mathematics is taught by teachers and experienced by pupils. Teachers perceive that their choice of a textbook has an impact on pupils' performance (Van Steenbrugge et al., 2013), which also seems to be supported by research.

> District-adopted textbook strongly influences both what and how mathematics is taught to middle school mathematics students. Coupled with the high frequency of textbook use by teachers, these data suggest that textbooks likely impact students' mathematics experience in important ways. (Tarr et al., 2006, p. 200)

Textbook analysis plays an important role in our understanding of teachers' lesson design, provided that researchers go beyond descriptive analysis and comparison (Fan, 2013). Our study is not of a causal or relational nature; rather, it aims to augment the descriptive analysis by considering whether secondary school mathematics textbooks provide teachers with sound support when designing instruction that is aligned with how pupils learn mathematics. To this end, we use a concept development theory which is widely used in the Czech mathematics education context.

3.1 Theory of generic models as a concept development theory

Since the early days of mathematics education research, researchers have striven to capture how pupils acquire new knowledge in mathematics (Vinner, 2014) and to apply this knowledge to the design of instruction aimed at understanding. In this study, we use the *Theory of Generic Models* (here TGM), which is a process-object theory[1]. TGM was developed in the Slovak and Czech contexts and presents a theoretical model of how pupils appropriate new mathematics knowledge.

> Our model of the process of gaining knowledge is based on five stages. It starts with motivation and has at its core two mental shifts: the first leads from concrete knowledge (isolated models) to generalised knowledge (generic knowledge) and the second from generic to abstract knowledge. The permanent part of this process of gaining knowledge is that of crystallisation, which involves integrating new knowledge into the already existing mathematical structure [...] (Hejný, 2012, pp. 44–45)

Hejný (2012, 2014) presents TGM in more detail. Here, we will concentrate on how its elements can be incorporated into the presentation of content in mathematics textbooks.

[1] These theories are based on an ongoing feature of learning and doing mathematics, namely processes become objects to be acted upon by further processes. In this process, the actions do not lose their action quality but rather a dual perception originates (Mason & Johnston-Wilder, 2005)

Motivation in textbooks can take the form of motivational texts, historical or real-life or otherwise attractive contexts, questions and problems stimulating pupils' curiosity, etc. It should lead to pupils' active work with the content. An isolated model (IM) is a specific instance of future knowledge. IMs in textbooks take the form of problems and questions for pupils to solve or answer, which precede the introduction of abstract knowledge in the form of a mathematical definition or theorem. Hejný (2004) emphasises that for a good understanding of the subject matter, it is not sufficient to present pupils with examples (IMs) but also with non-examples (non-models) of future knowledge. The quantity and quality of IMs impact the opportunities afforded to pupils for dealing with content. Thus, it makes sense to investigate IMs provided by textbooks.

The process of generalisation leads to the stage of generic models (GMs).

> The generic model is created from the community of its isolated models and has two basic relationships to this community:
>
> 1. it denotes both the *core* of this *community* and the core of *relationships* between individual models, and
> 2. it is an *example* or *representative* of all its isolated models. (Hejný, 2012, p. 45)

"Finding a common core in seemingly different situations, in other words, seeing what is the same in given situations" means realising that "they are in a certain sense isomorphic" (Hejný, 2014, p. 151). This stage is of crucial importance in combinatorics (English, 2005).

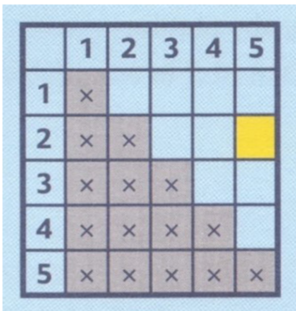
However, the process of generalisation cannot be directly observed as it takes place in pupils' heads. The generic model cannot be passed on to pupils; the teacher can only assist pupils by providing them with enough IMs and with enough opportunities to deal with them (Vondrová, 2019). Thus, in textbooks, this stage of learning is only encouraged in the form of indirect support, such as a task to look for common features of the IMs or a call to generalise from specific instances. Reaching a stage of GM for combinatorial problems mainly means that the pupil can identify a common structure of problems, that is, to recognise that the problems may vary in terms of context but are essentially isomorphic in their mathematical structure.

The process of abstraction leads to the stage of abstract knowledge. This differs from the stage of GMs by a change in language which the pupil is able to use while solving the problem (Hejný, 2014). In textbooks, it takes the form of mathematical definitions, theorems, or formulas, including symbolism, namely, algebraic language (see the formulas in Table 1).

3.2 Visual representations

It has been acknowledged that pupils' learning in mathematics benefits from visual representations (e.g., Arcavi, 2003). The development of combinatorial thinking is based on searching for an organisational principle (Hejný et al., 1990; Vondrová, 2019; Zahner & Corter, 2010), which helps pupils to find all k-permutations or combinations while avoiding counting some of them more than once. A suitable visual representation may significantly enhance the pupil's chances of finding such an organisational principle and/or its successful enactment in the calculation (e.g., Lockwood & Gibson, 2016). A better understanding of combinatorial problems is mediated by visual representation, which reduces the problems' complexity (Salavatinejad et al., 2021).

On the topic of combinatorics, Salavatinejad et al. (2021) distinguished the following categories of pupils' visual representations: trees, Venn diagrams, systematic lists, charts (other than tree graphs), tables, and figures. There are other types of visual representations, including Pascal's triangle, and positional or compartmental schemas. Zahner and Corter (2010) use similar categories for probability problems: pictures, spatial reorganisation of the given information, outcome listings, contingency tables (see Fig. 2), Venn diagrams, trees, and novel graphical representations.



	1	2	3	4	5
1	×				
2	×	×			
3	×	×	×		
4	×	×	×	×	
5	×	×	×	×	×

Fig. 2: A contingency table as a visual representation (Hejný & Šalom, 2017, p. 55)

Some research attention has been devoted to learner-generated visual representations when solving combinatorial problems (Hejný et al., 1990; Speiser et al., 2007; Uptegrove, 2015; Zahner & Corter, 2010). They are used to support both finding a mathematical model for the problem and recording the solution's progress and the result.

How secondary school pupils use representations of trees, tables, or arrays when solving problems in combinatorics has been documented (Fischbein & Gazit, 1988; Hejný et al., 1990; Uptegrove, 2015). However, after being introduced to combinatorics, the pupils were found to use trees only rarely and to prefer formulas (Batanero et al., 1997).

English (2005) brings forward a recommendation that pupils need to develop representational fluency, that is, the ability to work flexibly with different representational forms in combinatorics. Indeed, some studies document a positive influence of visual representations on pupils' solutions to combinatorial problems (Uptegrove, 2015; Zahner & Corter, 2010). For example, the use of systematic lists is positively correlated with the success of university students in solving problems (Lockwood & Gibson, 2016).

To sum up, the use of visual representations is considered to be essential for the development of pupils' combinatorial thinking. Therefore, it seems pertinent to investigate how mathematics textbooks work with such representations.

3.3 Research questions

The study presented in this paper aims to answer the following research questions:

RQ1: To what extent does the structure and presentation of content in Czech mathematics textbooks comply with the theory of concept development in mathematics (TGM)?

RQ2: How are visual representations presented and promoted in these textbooks? Is there diversity among them?

4 Methodology

In this section, the methods used to analyse and compare textbooks are discussed. First, the textbooks are introduced against the curricular context. Second, the selection of textbooks and the procedures of their analysis and comparison are described.

4.1 Curricular context

Since 2004, curricular documents have been developed at national and school levels in the Czech Republic.[2] The national level, produced by the Ministry of Education, Youth and Sports (MŠMT), includes Framework Educational Programmes (FEPs), which set binding educational norms across various educational stages. The school level consists of school educational programmes, which form the basis of education at individual schools.

According to the FEP for primary schools, pupils aged 12 to 15 are led towards "developing combinatorial and logic thinking, to critical reasoning and clear and concise argumentation via solving mathematics problems" (MŠMT, 2017, p. 31) Throughout the document, there is no mention of the propaedeutics of combinatorics.[3] The Czech curricular documents do not capitalise on the advantages that combinatorics bring in terms of pupils' learning of mathematics (see Section 1).

According to the FEP for secondary grammar schools (pupils aged 15 to 19), the only expected outcome in the field of combinatorics is that the pupil shall:

> Solve real problems with a combinatorial implication (characterise possible cases, form models using combinatorial groups, and determine their number), utilise combinatorial methods when calculating probabilities, transform terms with factorials and binomial coefficients. (MŠMT, 2016, p. 24)

The specific subject matter prescribed by the FEP consists of elementary combinatorial problems, k-permutations, permutations, combinations (without repetition), the binomial theorem, and Pascal's triangle. As the schools prepare their school educational programmes, they may add other combinatorial concepts and decide on the depth at which they want to deal with combinatorics. Once the learning outcomes are put into the school educational programme, they become obligatory for the school.

Secondary school mathematical textbooks in the Czech Republic are usually written in series comprising separate books on particular mathematical topics. The publishers ask the MŠMT for official approval;

[2] https://eacea.ec.europa.eu/national-policies/eurydice/content/teaching-and-learning-single-structure-education-7_en

[3] The propaedeutics of combinatorics is strongly recommended by Kapur (1970) or Hejný et al. (1990).

however, there are also textbooks on the market that have not been approved (and can be used at schools). It is common that teachers from the school decide on one textbook series they will use. However, individual teachers can also use other textbooks or no textbook at all (and give pupils their own compilation of material). Secondary school pupils have to purchase textbooks according to the recommendations of their teachers, unlike primary school pupils who are provided with the textbook by the school.

4.2 Data sources

First, we searched secondary school mathematics textbooks (aimed at pupils 15–19) written in Czech and currently available in the Czech Republic, and selected those containing combinatorics. In this way, we found four printed textbooks, none of which contain only combinatorics. All the textbooks have chapters on probability and statistics, too. The data was complemented by an electronic 'textbook' written by M. Krynický,[4] as our experience from conferences for teachers and social media shows that many secondary school teachers use it. Unfortunately, no official information is available showing the number of schools where the textbooks are used.

Table 2 presents an overview of the textbooks. Each is denoted by a letter (D, F, G, K, P). Textbooks F and P have an electronic version, which is mostly the same as the printed one and thus, only the printed ones were analysed. Textbook D is accompanied by a workbook, which was not included in our analysis as the other textbooks do not have a workbook. Only one of our textbook sample is accompanied by a teacher's book.[5] Krynický's texts are noteworthy as they include didactic notes in which the author summarises his teaching experience with the material and provides readers with pedagogical hints. The hints can serve a similar function to a teacher's book.

Tab. 2: Textbooks included in the study

Publisher	Textbook title (transl.)	Code	Authors, year	Printed/ electronic	Workbook/ Teacher book
Didaktis, spol. s r. o.	Matematika pro střední školy (Mathematics for secondary schools)	D	Horenský et al., 2015	yes/no	yes/yes
Fraus	Matematika s nadhledem (Mathematics with a view)	F	Tlustý, 2020	yes/yes	no/no
Prometheus, spol. s r. o.	Matematika pro gymnázia (Mathematics for grammar schools)	G	Calda & Dupač, 2012	yes/no	no/no
M. Krynický	Matematika SŠ.realisticky.cz (Mathematics SŠ.realisticky.cz)	K	Krynický, 2021a, 2021b	no/yes	no/yes
Prometheus, spol. s r. o.	Matematika pro střední školy (Mathematics for secondary schools)	P	Robová et al., 2013	yes/yes	no/no

4.3 Data analysis

For this study, we assumed that the authors planned the content to be presented to pupils in the textbook's order. Following Fan et al. (2013), we conducted a comparative textbook analysis in which each textbook was analysed separately, and then the results were compared.

First, we determined the space devoted to combinatorics within the whole series of textbooks.

Second, we considered the number of problems in the chapter on combinatorics. We restricted ourselves to problems set within a particular context and formulated in words and omitted problems in which manipulations on expressions were performed or equations and inequalities with factorials or combination numbers solved. Such problems were considered more important for algebra than for the development of combinatorial thinking.

Third, we analysed the following for each of the selected concepts and procedures (see Section 2):

- the presence and nature of motivation for combinatorial problems;
- the number and nature of problems that could be considered IMs of future knowledge;
- the elements of the text which could be viewed as prompts to generalise IMs into GM (in other words, a prompt bringing to pupils' attention that two or more problems are isomorphic, have the same inner structure);
- the place and nature of the presentation of knowledge in a symbolic language.

[4]This is, in fact, a collection of electronic texts written by Martin Krynický, a secondary grammar schoolteacher who placed his electronic teaching texts on the website http://www.realisticky.cz. For the sake of brevity, we will refer to it as a textbook.

[5]Czech secondary school textbooks are not usually accompanied by a teacher's books.

Fourth, we analysed the visual representations present in the textbooks. Each graphical representation found was categorised according to the classification presented in Section 3.2. Any opportunity for a pupil's production of a visual representation was noted. The results for each textbook were put together and compared. All percentages in the tables below are rounded to one decimal place.

5 Results

First, we present some descriptive results which will be followed by the results pertinent to each of the research questions. Finally, we present the comparison of content of two editions of one textbook.

According to Table 3, between 2.5% and 3.7% of the number of pages in the entire textbook series are devoted to combinatorics. It is noteworthy that there are no significant differences even though each series has a different format. The authors appear to place similar emphasis on combinatorics within the other secondary school topics.

Tab. 3: The number of pages and the share devoted to combinatorics within the whole series

Code	Number of pages in the whole series	Number of pages devoted to combinatorics	Percentage share
D	1 181	29	2.5%
F	1 214	38	3.1%
G	1 982	73	3.7%
K	593*	19	3.2%
P	cannot be determined**	38	cannot be determined

*For this textbook, the number of lessons is calculated, not the number of pages, as the textbook comprises individual files, each numbered from page 1.

**At the time of analysis, only five textbooks out of nine had been published.

Table 4 presents the frequency of problems included in the chapters on combinatorics. The majority of problems are formulated in text, that is, they include some context (often a real-world one) and call for combinatorial calculations. The rest of the problems concern numerical and algebraic calculations.

Tab. 4: Share of word problems among all the problems in the chapter on combinatorics

Code	Number of all problems	Number of word problems	Percentage of word problems among all
D	60	31	51.7%
F	81	46	56.8%
G	149	107	71.8%
K	182	118	64.8%
P	119	89	74.8%

5.1 Content presentation and the theory of generic models

Table 5 to Table 7 present results pertinent to the alignment between how the textbooks we analysed present concepts and procedures and the theory of concept development (TGM). The following indicators were included: the type of motivation, the number of IMs and non-models (the presence of the mathematics problems presented before the symbolic representation of abstract knowledge, that is, the definition, theorem or an algebraic formula, usually highlighted by a box), and prompts for search for the IM identity (as prompts to generalise IMs into a GM).

Tab. 5: The introduction of combinatorial rules of sum and product

Code	Motivation	Number of IMs	Number of non-models	Prompt to find IM identity
D	tasks, motivational text, history, and applications	2	1	no
F	real-life application, figures, games, attractive context of problems	0	0	no
G	history and applications	1	0	no
K	attractive context of problems	6	0	yes
P	history and applications	2	0	no

Tab. 6: The introduction of the concept of k-permutations and their number

Code	Motivation	Number of IMs	Number of non-models	Prompt to find IM identity
D	motivational text, images, and applications	4	0	no
F	real-life application, figures, and game	3	0	no
G	real problem	0	0	no
K	attractive context of problems	9	0	yes
P	None	2	0	no

Tab. 7: The introduction of the concept of combinations

Code	Motivation	Number of IMs	Number of non-models	Prompt to find IM identity	Pascal's triangle
D	motivational text, figures, and game	1	0	no	yes
F	attractions, figures, real problems, and the game	1	0	no	no
G	real problem	1	0	no	yes
K	attractive context of problems	5	0	yes	yes
P	None	1	0	no	yes

Regarding motivational elements, textbooks F and D contain the most variety in the motivational techniques they employed. Textbook K exclusively motivates for combinatorics using word problems with an attractive context; an example is in Fig. 5 below. It seems that when writing the text, the author had in mind specific classes he had taught, as the problems are often set within the context of a secondary class and events pertinent to secondary school life. Textbooks G and P motivate the reader through historical notes or real-life problems (an example is in Fig. 3). However, in textbook P, no motivation is included for the concepts and procedures.

Original

Translation

Did you know that...

During World War II, Hitler's Germany used the Enigma encryption machine, which provided an incredible 10^{114} different configurations by adjusting the disks?

Braille is a particular type of writing for the blind? All the characters are 2×3 rectangles, where in each of the six squares, there either is or is not a point. In this way, 64 different characters can be combined.

Fig. 3: Illustration of motivation by a real-life application in textbook F (Tlustý, 2020, p. 10)

We identified only one non-model for all the concepts and procedures under our scrutiny. After introducing the rule of sum, the authors explicitly warn that this rule cannot be used in some cases (Fig. 4). It can function as a prevention of over-generalisation.

The creation of GM is a crucial stage in concept development (Hejný, 2012). The number and nature of IMs are an important indicator of the textbook's opportunities for this creation. Table 8 compares the number of isolated models for the concepts studied and the procedures used in the textbooks. In terms of the absolute number of IMs, the textbooks are of three types: I. no or one IM, II. two or three IMs, III. more than three IMs. From Table 8, it is evident that textbook G belongs to type I in all aspects, textbooks P and F fall into types I and II, textbook D falls into all types, and textbook K is the only type III textbook.

Original

V některých případech však pravidlo součtu použít nelze.

Z vyplněných zdravotních dotazníků vyplynulo, že každý z dotazovaných měl nebo má nějaký zdravotní problém. Celkem 8 osob uvedlo, že se již podrobilo alespoň jedné operaci v celkové narkóze, 15 osob utrpělo během života zlomeninu horní nebo dolní končetiny a 13 osob má dlouhodobě zvýšený krevní tlak. Vypočítejte, kolik osob se zúčastnilo dotazníkového šetření.

A = Množina osob, které se podrobily operaci.
$|A| = 8$
B = Množina osob, které utrpěly zlomeninu.
$|B| = 15$
C = Množina osob trpících zvýšeným tlakem.
$|C| = 13$

Osoby lze rozdělit do tří množin, jejichž počty prvků známe.

Nemůžeme vyloučit, že osoba, která se podrobila operaci, neutrpěla rovněž zlomeninu nebo se neléčí se zvýšeným krevním tlakem…

Vzhledem k tomu, že ze zadání přímo nevyplývá, že jsou každé dvě uvedené množiny disjunktní, nelze celkový počet dotázaných osob určit.

Translation

In some cases, the rule of sum cannot be used.

The completed health questionnaires showed that each of the respondents had or has a health problem. A total of 8 people reported having undergone at least one operation under general anaesthesia, 15 have suffered a fracture of the upper or lower limb, and 13 have had long-term high blood pressure. Calculate how many people participated in the questionnaire survey.

A = The set of people who have undergone surgery. $|A| = 8$
B = The set of people who have suffered a fracture. $|B| = 15$
C = The set of people suffering from increased pressure. $|C| = 13$

The people can be divided into three sets; their numbers of elements are known.

We cannot rule out that the person who has undergone surgery has also not suffered a fracture or is not being treated for high blood pressure...

Since it does not directly follow from the assignment that every two mentioned sets are disjunct, the total number of interviewed persons cannot be determined.

Fig. 4: Illustration of a non-model from textbook D (Horenský et al., 2015, p. 7)

Tab. 8: The number of IMs before the introduction of the symbolic representation

Code	Combinatorial rules	k-permutations	Combinations	Total
D	2	4	1	7
F	0	3	1	4
G	1	0	1	2
K	6	9	5	20
P	2	2	1	5
Total	11	18	9	–

Another important indicator of the textbook's opportunities for creating a GM consists of explicit prompts to look for the problems' common structure. Similarly to the presence of non-models, we only found such prompts in textbook K. An example is in Fig. 5.

Original

Př. 1: Sportovního turnaje se účastní 6 týmů. Kolika způsoby mohou tyto týmy obsadit medailová místa v konečném umístění?

Př. 2: Na maturitním plese se 10 hlavních cen v tombole losuje z 250 lístků. Kolika způsoby může toto losování dopadnout?

Př. 3: Na zkoušení jsou připraveny dvě otázky (otázky nejsou stejné) a studenti jsou losováni náhodně. Kolika způsoby může losování dopadnout, pokud je ve třídě 31 studentů?

Př. 4: Najdi společné rysy všech předchozích příkladů.

Translation

Pr. 1: Six teams take part in a sports tournament. How many ways can these teams take medals in the final standings?

Pr. 2: At the prom, the 10 main prizes in the tombola are drawn from 250 tickets. How many ways can this draw turn out?

Pr. 3: Two questions are prepared for the exam (they are not the same), and students are drawn randomly. How many ways can a draw turn out if there are 31 students in a class?

Pr. 4: Find the common features of all the previous problems.

Fig. 5: Illustration of the prompt to search for IM identity from textbook K (Krynický, 2021a, p. 1)

Finally, Fig. 6 presents an example of the symbolic representation of abstract knowledge.

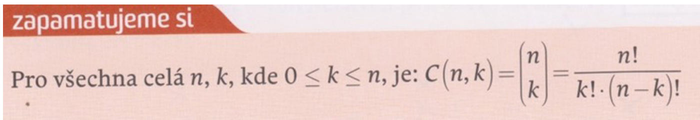
Original	Translation
	Let us remember For all integers n, k, $0 \le k \le n$, it is: $C(n,k) = \binom{n}{k} = \frac{n!}{k!\cdot(n-k)!}$

Fig. 6: Symbolic representation of abstract knowledge from textbook F (Tlustý, 2020, p. 22)

5.2 Visual representations

Table 9 shows the number of visual representations in each textbook and the number of prompts to make such representations. Textbook D contains the most visual representations, and textbook K the least. However, the latter contains many more prompts to create representations, compared to the other textbooks, where these prompts are exceptional. Tab. 10 presents the categories of visual representations.

Tab. 9: The number of visual representations in the textbook and prompts for their creation

Code	D	F	G	K	P
Number of representations	32	17	29	10	17
Number of calls for representations	1	1	1	10	2

Tab. 10: Categories of visual representations in the textbooks and prompts for their creation

Code	Category	Trees	Charts	Venn diagrams	Systematic lists	Tables	Figures	Other visual representations	Total
D	frequency	2	1	1	6	0	8	14	32
	prompts	0	0	0	1	0	0	0	1
F	frequency	1	2	0	8	0	1	5	17
	prompts	0	0	0	1	0	0	0	1
G	frequency	0	2	0	11	2	6	8	29
	prompts	0	0	0	0	1	0	0	1
K	frequency	0	1	0	3	0	3	3	10
	prompts	0	0	0	4	0	0	6	10
P	frequency	0	1	1	10	0	2	3	17
	prompts	0	0	0	1	1	0	0	2
	Total	3	7	2	46	4	15	39	–

The most frequently used representation in textbooks G and P (Tab. 10) is a mathematical one consisting of enumerating elements from the set of letters $\{a, b, c, \ldots\}$. In textbook F, most representations are also in the form of a statement of results, although in the form of a graphical representation with arrows, circles, card images, etc. The most common category of representation of spatial reorganisation in textbook D is a positional diagram.

For all the textbooks, we can order the categories of representations in terms of frequency as follows: systematic lists (46), other visual representations (39), figures (15), charts (7), tables (4), trees (3) and Venn diagrams (2).

The textbooks also differ in their graphical design, which directly impacts visual representation. Textbooks G and K hardly ever use colours, and thus schemes and visual representations are less illustrative (Fig. 7, left). On the other hand, textbooks D and F are the most colourful, which might help pupils to make better sense of the solution depicted (Fig. 7, right).

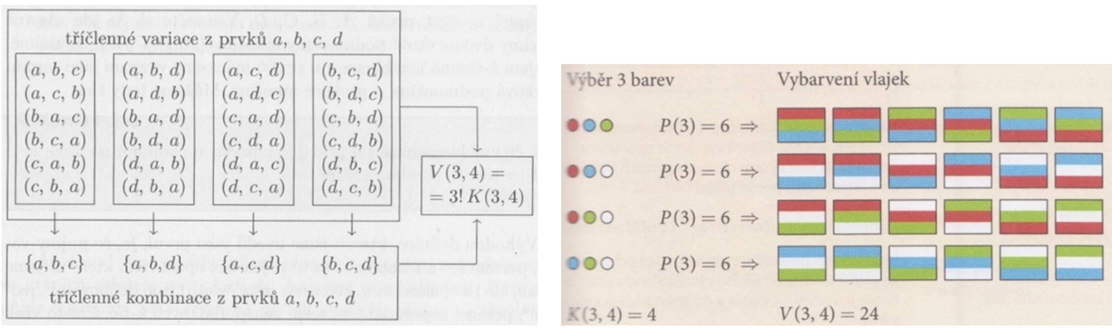


Fig. 7: Systematic lists in black and white, textbook G (Calda & Dupač, 2012, p. 13), in colour, textbook D (Horenský et al., 2015, p. 25)

Pascal's triangle is a particular type of visual representation. It is present in all the textbooks except F (Tab. 11).

Tab. 11: Number of occurrences of the Pascal triangle scheme in textbooks

Code	D	F	G	K	P
Number of occurrences of Pascal's triangle	5	0	4	1	2

All the textbooks introduce Pascal's triangle in several steps. First, some properties of combination numbers are summed up, including Pascal's identity (*), which is called *the property of combination numbers* and is always presented symbolically. The above properties are then used to solve some problems, and it is noted that a specific diagram can be made to depict them (see Fig. 8). The conception of Pascal's triangle in textbook G ("These properties of combination numbers can be illustrated in the following diagram, called Pascal's triangle." Calda & Dupač, 2012, p. 61) is similar to textbook K's ("Thanks to the relations for combination numbers, we can construct an interesting pattern. . . Because it is composed entirely of combination numbers, it is possible to demonstrate the relations that apply to them." Krynický, 2021b, pp. 3, 4). The validity of the properties of combination numbers is only illustrated or demonstrated in this scheme. Following this scheme, some problems related to Pascal's triangle and dealing with the enumeration of a row of Pascal's triangle, or the sum of several combination numbers are included. Finally, the textbooks relate Pascal's triangle to binomial coefficients.

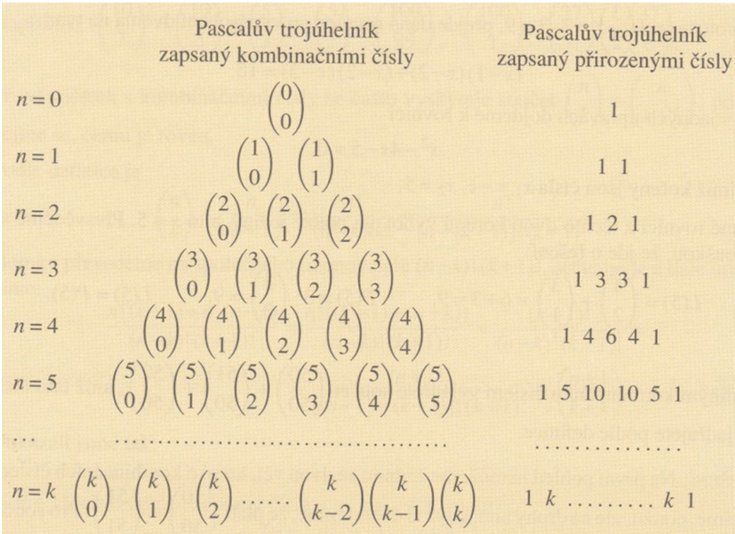


Fig. 8: Pascal's triangles with combination numbers and natural numbers from textbook P (Robová et al., 2013, p. 82)

An exception to the above is textbook D, which, unlike the other textbooks, contains many challenges to find different contexts in Pascal's triangle, e.g., fractals (see Fig. 9).

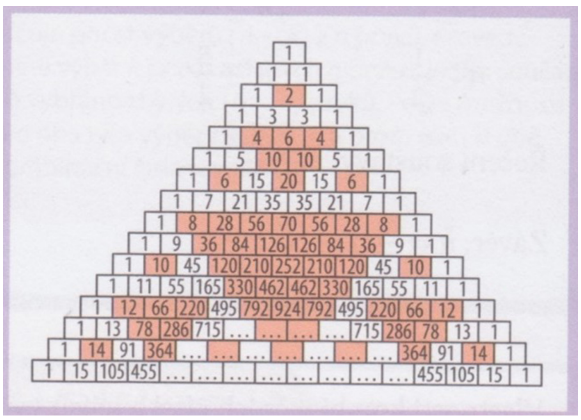


Fig. 9: Illustration of fractals included in Pascal's triangle from textbook D (Horeský et al., 2015, p. 32)

5.3 Two editions of one textbook

The first edition of textbook G was published in 1993, while the latest (fifth) is from 2012. The authors remained the same. We analysed both editions to see what changes had been made in the editions nearly 20 years apart, and found that they were almost the same. Only minor differences were found in the solved problems and the explanatory text. Seven new problems were added, but they deal exclusively with algebraic modifications of expressions, which contain combinatorial concepts including factorial or combination numbers. This type of solved problems was almost absent from the first edition, although unsolved problems with these concepts were included. These differences in the explanatory text are also present in the notes. In the fifth edition, two notes were added, which provide the reader with instructions on how to a) deal with combination number calculations, b) why the problem of placing identical objects in compartments can be likened to combinations with repetition.

6 Discussion

All the textbooks we analysed, except for textbook F, in which Pascal's triangle and the binomial theorem are absent, comply with the Czech national curricular material. They fulfil the outputs of the FEP and in many ways exceed them (textbooks G, K, D).

Recall that we conducted our analysis from the position that the presentation of combinatorial concepts and procedures complying with the theory of concept development in mathematics will enhance the possibility that teaching with such a textbook will lead to pupils learning the content with understanding.

6.1 The presentation of content in terms of concept development in mathematics

There is very little difference in how the textbooks approach the combinatorial rules (of sum and product) and the combinatorial categories (k-permutations, combinations) in terms of the prominence they are given. They are presented in the same way and summarised in the same graphical way (enclosed in boxes as in Fig. 6).

As for the first stage of learning, motivation, we found that while all the textbooks contained some motivational elements, they differed in their diversity. Some of the textbooks provide teachers with more support in motivating pupils towards this subject matter than the others.

Studies show that pupils have difficulty in identifying related problem structures (e.g., English, 2005), and thus their "ability to transfer their learning to new combinatorial situations is limited" (p. 135). To transfer their learning to new situations, pupils should be presented with enough isolated models to create a GM before being introduced to an abstract definition, theorem or formula. Such recommendations are common in combinatorics. For example, Lockwood and Gibson (2016) highlight the importance of the systematic list strategy and recommend that pupils are given enough problems that are solvable with this strategy and are led to look for the organisational principle before being introduced to the combinatorial formulas. Uptegrove (2015) describes how pupils can develop their combinatorial thinking and reach the stage of abstract knowledge by solving concrete combinatorial problems and considering their isomorphism.

Given the above, we focused on the number of IMs, non-models and prompts to generalise in the textbooks. The results for the number of IMs varied across both textbooks and concepts and procedures. It is natural, for example, that if the k-permutations are introduced before combinations, the number of IMs is large for the former. However, the textbooks differed vastly in terms of the total number of IMs for combinatorial rules, k-permutations, and combinations. Textbook G, with only 2 IMs, and textbook K, with 20 IMs, are on opposite poles. The situation is similar in the presence of non-models and prompts for generalisation. Both were found in textbook K and absent in the other textbooks (except for one non-model in textbook D).

The absence of non-models might have a serious consequence of over-generalisation, to which pupils might be prone if introduced to models only. Provided that the concepts of k-permutations and combinations are grounded in the isomorphism of concrete situations (English, 2005; Hejný, 2014; Kapur, 1970), it seems worrying that except for textbook K, the textbooks do not capitalise on this isomorphism. Of course, the other textbooks *state* directly or implicitly that some problems have the structure of, for example, combinations, but do not specifically *ask* pupils to look for this common structure. Such a prompt would foster independent thinking in combinatorics (English, 2005). The prompts for such a generalisation in the textbook might help the teacher (or pupils) see its importance. Except for textbook K, the other textbooks emphasise the end product (mathematics procedures and concepts presented via rules and definitions) at the expense of the process of reaching this end product. The teachers are expected to make the didactic reconstruction of these procedures and concepts themselves.

6.2 Visual representations

The importance of visual representation for solving combinatorial problems is generally acknowledged (e.g., English, 2005; Hejný et al., 1990; Lockwood & Gibson, 2016; Uptegrove, 2015; Vondrová, 2019; Zahner & Corter, 2010) as it provides support for the solution, visualises an organisational principle upon which this solution rests, or helps to communicate the solving strategy or the result of the solution. We focused on the presence and diversity of visual representations and on prompts for pupils to create such representations in the textbooks. Such prompts may be a way to support pupils' metacognition.

The diversity of visual representations in the textbooks varies from textbook D (the most diverse) to K (the least). While one textbook (K) includes several prompts for pupils to create their representations, such prompts are rare in the other textbooks. Neither textbook includes any suggestion to make representations in the form of a tree, chart, Venn diagram, or figure. It seems a paradox to us that the tree and table are the least used representations in the textbooks, although they are the recommended tools through which data can be clarified and visualised (e.g., Lockwood & Gibson, 2016).

It also transpired that some representations which appear to be natural and are known from the literature (Zahner & Corter, 2010) do not appear in the analysed textbooks at all, namely, a contingency table or problems solvable on grid paper. In the Czech context, such representations are widely used in a series of primary school textbooks (e.g., Hejný & Šalom, 2017) in which the propaedeutics of combinatorics is carefully developed. Fig. 10 gives an example.

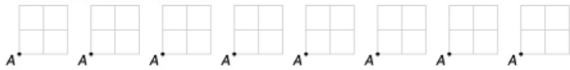
Original	Kolik rovnoramenných trojúhelníků ABC lze najít na tomto čtverci, když body B a C jsou dva mřížové body na hranici čtverce (bod B ani bod C neleží uvnitř čtverce). 
Translation	How many isosceles triangles ABC can be found on this square if points B and C are two lattice points on the boundary of the square (neither point B nor point C lies inside the square).

Fig. 10: Illustration of visual representation on a grid paper (Hejný et al., 2017, p. 39)

Pascal's triangle is a specific type of visual representation. The four textbooks that introduce Pascal's triangle also include Pascal's identity (*). However, Pascal's triangle is only presented to illustrate or demonstrate the previously introduced properties of combination numbers. Moreover, contrary to what is required by TGM, the potential IMs of this equality are always provided only after its symbolic presentation (and in some cases, after its proof). Thus, these instances cannot be considered IMs but rather concrete examples of the symbolic form of Pascal's identity.

Uptegrove's (2015) longitudinal study might offer inspiration for an opposite approach to the introduction of Pascal's triangle and Pascal's identity (*). The pupils in the study discovered an abstract piece of knowledge (*) based on the study of two combinatorial problems, the discovery of isomorphism and investigating the structure of Pascal's triangle. Thus, the introduction of Pascal's triangle can come before Pascal's identity (*).

7 Conclusions, limitations, and further work

Textbooks are an essential part of mathematics lessons and their content might provide teachers with important support when designing such lessons that have good potential to lead to learning the content with understanding. This study found that none of the five Czech textbooks on combinatorics we analysed can be seen as fully supportive. Textbooks K and D differ the most in terms of teacher support. A teacher using the former will receive ample support in teaching in compliance with TGM, that is, instruction focused on generalising and abstracting as the essential processes in mathematics (Vinner, 2014). A teacher using the latter might be directed towards using more formal teaching methods (from the definition to its examples). Note that we are not claiming that using a specific textbook will necessarily lead to just one way of teaching (and pupils' learning). Instead, we refer to how the textbook may or may not support the teacher in their quest to teach in a certain way.

Our analysis against the theoretical background of TGM helped to reveal insufficiencies in the presentation of content in the textbooks that would otherwise remain hidden, the most important of which s are the insufficient motivation of individual concepts, the low number of IMs, or the absence of non-models. With one exception, the textbooks do not lead pupils to search for isomorphisms of IMs or encourage them to generalise. Let us emphasise again that these processes are essential for the creation of sound abstract knowledge (Hejný, 2012; Vinner, 2014). We also identified a low number and variety of visual representations, and very few prompts to visualise in the textbooks. This can impede the quality of teaching, as the textbooks do not alert the teacher to the fact that visual representations are a crucial means for solving combinatorial problems (Lockwood & Gibson, 2016; Salavatinejad et al., 2021; Uptegrove, 2015).

The results summarised above may provide a starting point for other investigations. For example, we could focus on how the analysed textbooks are actually used in the lessons by both teachers and pupils. Is our assumption that the textbook influences how teachers design their instruction valid? Are teachers aware of the fact that the textbook, for example, does not sufficiently promote visual representations and do they lead their pupils to such representations? Such matters warrant more research.

Our results might assist the authors of teaching texts on combinatorics. Finally, the methodology used in the study (namely, the use of TGM) could help researchers wishing to investigate textbooks from other topics.

The results of our study have limitations. The first lies in the selection of textbooks. We could augment the study by analysing textbooks on combinatorics from abroad and by textbooks for the primary school, which should ideally include the propaedeutics of combinatorics (see, e.g., Hejný & Šalom, 2017).

The division of visual representations into categories represents another limitation, as other categorisations could be used (Corter & Zahner, 2007) or more specific subcategories elaborated. However, considering that the number of visual representations was relatively low, we doubt that this would bring noteworthy results.

We have used one specific theory of concept development to augment descriptive results. It might be worthwhile to complement our analysis with a different theory as a background. We could also focus on some more specific suggestions for teaching combinatorics (such as the problem-posing opportunities suggested by English, 2005) and whether and how they are projected in the textbooks.

Acknowledgment

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Role of Workbooks and Teacher's Books in Lower-secondary Chemistry Education in Czechia

Role pracovních sešitů a metodických příruček ve výuce chemie na základních školách v Česku

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Textbooks as a prominent product of educational content's didactical transformation are usually published as a series. Textbooks are often accompanied by workbooks and teacher's books. These publications are designed to support teacher's work and can have a significant impact on the teaching practice. To deepen the understanding of chemical education at lower-secondary schools, the goal was to map chemistry teachers' use of workbooks and teacher's books. An electronic questionnaire containing close-ended questions as well as scales was used for this purpose. Information about workbooks and teacher's books' use, frequency of use, perceived importance and purpose were gathered. Whereas 63% of the 387 respondents reported using workbooks they consider important for the quality of education, teacher's books are only used by 24% of teachers, with only 4% reporting their frequent use. The results indicate that workbooks are mostly used during chemistry lessons or for student homework, however a significant share of teachers mentioned using them for lesson preparation. The absence of a teacher's book, coupled with the teachers' reluctance to use them even when available, also pointed to their approach to teaching preparation based on the search for educational content and specific activities rather than methodological support in a broader sense.

Key words:
science education, lower secondary school, curriculum.

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Učebnice jakožto významná pomůcka představující didaktickou transformaci vzdělávacího obsahu jsou obvykle vydávány v sadách. Často jsou doplňovány pracovními sešity nebo metodickými příručkami pro učitele. Tyto publikace jsou zpracovány tak, aby podporovaly práci učitele a mohou tak mít významný vliv na pedagogickou praxi. Pro prohloubení porozumění chemickému vzdělávání na základních školách bylo cílem zmapovat využívání pracovních sešitů a metodických příruček z pohledu učitelů. K tomuto účelu byl využit dotazník v elektronické formě obsahující uzavřené otázky a hodnotící škály. Byly shromážděny informace o využívání pracovnách sešitů a metodických příruček, četnosti jejich využívání, vnímané významnosti a účelu používání. Zatímco 63 % z 387 respondentů uvedlo používání pracovního sešitu a považují ho za důležitý pro kvalitu výuky, využívání metodických příruček uvedlo pouze 24 % učitelů, přičemž 4 % uvedla časté využívání. Výsledky ukázaly, že pracovní sešity jsou nejvíce využívány během výuky nebo pro domácí přípravu žáků, nicméně významný podíl učitelů uvedl také využívání k přípravě výuky. Absence metodických příruček, potažmo neochota učitelů je využívat v případě, že dostupné jsou, ukazuje také na jejich přístup k přípravě výuky založené spíše na hledání vzdělávacího obsahu a konkrétních aktivit spíše než metodické podpory v širším smyslu.

Klíčová slova:
přírodovědné vzdělávání, základní škola, kurikulum.

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1 Introduction and theoretical background

The presented research directly follows its authors' previous work in the field of lower-secondary school chemistry textbook research. It is led by the presumption that knowledge of teachers' textbooks use sheds more light on the implemented curriculum. As far as research on textbooks is concerned, several authors' research worldwide surprisingly brings similar results. Teachers use textbooks as a primary source of instruction (Mullis et al., 2012). When preparing for their lessons, they consult textbooks as the primary source of information (Johansson, 2006; Sikorová, 2005). Whereas Sikorová (2010) reported over 30% of teachers using more than one textbook, Vojíř and Rusek (2021) found over 80% use even more textbooks. This could be explained by the teachers considering textbooks a convenient source of the materials they seek, nevertheless, Bakken (2019) found that some consider textbooks obligatory. This can even escalate to teachers feeling stressed and obliged to cover everything the textbook contains in their lesson (Perkkilä, 2002). In this case, textbooks structured according to a certain time frame, not according to topic needs, could further exacerbate this effect. More research of the textbooks' didactical equipment (Rusek et al., 2020) is therefore needed.

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With this strong position textbooks hold, their content, or more precisely, the way their content is didactically elaborated, affects the implemented curriculum's quality. Sikorová (2010 found that 26% of teachers followed textbooks systematically, with only 55% changing the way topics were presented in their own lesson preparations. Vojíř and Rusek (2021) proved that this approach is not influenced by the length of teachers' practice. Li (2013) as well as Orafi and Borg (2009) offered an explanation by arguing it is a combination of teachers' lack of confidence, experience or subject knowledge which makes them rely on textbooks this much. Borg (2015) even indicated this to be the reason lecturing, i.e. a teacher-centred approach based merely on a teacher's subject-matter presentation to students, is the prevalent method in contemporary education.

However, it is not only subject-matter teachers seek inspiration from. Lepik et al. (2015) and (Sikorová, 2005) found that teachers also seek methods to use in their lessons. As most textbooks are taken up with the explanatory texts (Červenková, 2010; Vojíř & Rusek, 2021), this could also be the reason for the prevailing transmissive teaching style. It is partly logical as textbooks are supposed to present the subject-matter, however, as shown in the paragraphs above, teachers prefer doing the reading themselves and then having the lecture.

In their previous study, Vojíř and Rusek (2021) discussed whether textbooks show teachers the trend or the other way round, teachers choose textbooks which fit their teaching style. One way or another, textbooks provide additional materials for teachers. It is a more detailed description of the course, additional didactical suggestions, and theoretical background knowledge (Steenbrugge et al., 2013). As far as the textbook components with the potential to activate students are concerned, workbooks as well as teachers' books need to be taken into account.

1.1 Use of workbooks and teacher's books

In spite of researchers' interest in science textbooks growing (Vojíř & Rusek, 2019b), information about other printed parts of textbook sets are rather fragmentary. Teachers' books are supposed to be structured in a way that guides the teacher through lessons planning towards educational goals. Researchers' interest was therefore targeted at particular teacher's book development with respect to their concrete focus (e.g. Fadilla & Usmeldi, 2020; Suhandi & Samsudin, 2019). Kendedes and Ratnawulan (2020) stressed specifical demands put on the teacher's books in the context of science education's conceptual change. Their role within changing state-driven educational goals was also stressed by Bayindir (2010). They gain significance as long as teachers see the proposed activities as the grounds of the intended curriculum (cf. Bayindir, 2010). Nevertheless, teacher's book's perception from only the expected activities' point of view could also lead to them being negatively assessed by teachers, as shown by (Güven, 2010): teachers criticised namely the activities' time-demandingness and teaching examples' attractiveness.

One of the variables, as far as workbooks are concerned, is their price. Compared to textbooks, they usually cannot be used repeatedly by several students. Mathematics workbook's efficiency was evaluated by Fleisch et al. (2011). Their research was built on the premise new(er) math workbooks developers aim at reducing wasted instructional time and the teacher's role associated with them writing the instructions on the board. In their research, they compared lessons where only a mathematics textbook was used with lessons where a textbook set (textbook + workbook) were used. The results showed no difference between the students' improvement in either of the groups. Erol's (2017) research on 7th graders on a social studies course in Turkey argued otherwise. Their research is interesting in particular compared with the Czech environment as it describes a shift in teaching conception at the exact time a new curriculum was introduced in Czechia. It represented a shift from an autocratic perspective of teacher-centred conception in which students were only passive receivers of information to a teacher-guided, student-centred constructive learning environment. Despite the author's positive assessment of the textbook and workbooks' use in education, the study showed over 75% of students considered a workbook a type of textbook. The reason was its use mostly just for students' home preparation, which made them use these materials unwillingly, not considering them an activating agent in education. Some teachers were even found to use the workbook exercises to grade the students, they used photocopies of different student-activating sources from different materials during their lessons.

A very special version of workbook was introduced by (Nainggolan et al., 2020) who used design-based research methods to prepare a student support for laboratory courses. Their work represents an example of a STEM-oriented goal employing an inquiry-based approach into students' work. In the Czech conditions, this can be parallel to Fiala's Inquiry-diary (see Fiala & Honskusová, 2020).

1.2 Czech perspective

The textbook tradition is very strong in Czechia. Primary and lower-secondary schools are obliged to provide every pupil or student with textbooks. Nevertheless, purchasing workbooks or teacher's books remains on each school's choice. Schools receive special funding for textbooks which are granted a so-called approval clause (a special certificate by the Ministry of Education which confirms the books' suitability for use in education, according to the curriculum, methods, ergonomic, etc.). A concrete textbook's choice is fully in schools' competence. Schools are also allowed to use textbooks which do not dispose of the clause, however, this possibility is being chosen only seldom. Most commonly, there are four sets of textbooks used in lower-secondary schools – see Tab. 1 (Vojíř & Rusek, 2021).

Tab. 1: The list of commonly used textbooks

Textbook title	Published*	Authors	Publisher	Reference in the text
Základy chemie 1; 2 [Basics of chemistry 1; 2]	1993	Beneš, P., Pumpr, V., Banýr, J.	Praha: Fortuna	ZCH
Základy praktické chemie 1; 2 [Basics of practical chemistry 1; 2]	1999, 2000	Beneš, P., Pumpr, V., Banýr, J.	Praha: Fortuna	PCH
Chemie 8; 9 [Chemistry 8; 9]	2006, 2007	Škoda, J., Doulík, P.	Plzeň: Fraus	FR
Chemie 8; 9 [Chemistry 8; 9]	2010, 2011	Mach, J., Plucková, I., Šibor, J.	Brno: Nová škola	NS

*Years of first publishing; the two records relate to the two books for 8th and 9th grade.

All the commonly used textbooks dispose of the approval clause. However, there are considerable differences in their elaboration. The textbooks ZCH and PCH were published within the previous curriculum. On the other hand, the textbooks FR and NŠ were published after the contemporary curriculum was approved which is also mirrored in their overall graphical design (Vojíř & Rusek, 2020). As far as the content's structure is concerned, the textbooks FR differ from the others as they do not follow the traditional consequence of chemistry topics (general chemistry, inorganic chemistry, organic chemistry, and biochemistry).

Teachers are rather satisfied with the textbooks they use. They consider them important for lesson preparation. The textbook set teachers expressed the highest satisfaction with are the NS textbooks, i.e. modern-looking textbooks following a traditional subject-matter's structure (Vojíř & Rusek, 2021).

The obligation for schools to provide students with textbooks does not concern workbooks and schools receive no funding primarily for their purchase. The other components of textbook sets (workbooks and teacher's books) are not available for every textbook set (the publication of materials depends on commercial publishers). The commonly used textbook sets, see Tab. 1, are accompanied by workbooks. Teacher's books, however, are available only for the PCH and FR textbooks.

2 Research goals

This research focused on understanding the way chemistry textbook projects are used in Czech lower-secondary schools. As the use of textbooks has already been covered (Vojíř & Rusek, 2021), attention was paid to the other printed materials that are part of the textbook projects.

With respect to previous research in this field, the following research questions were used:

1. What proportion of lower-secondary school teachers use workbooks and teacher's books for chemistry education?

2. How often do teachers use workbooks and teacher's books and how important they consider them for the quality of chemistry education?

3. For what purposes do teachers use workbooks in chemistry education?

3 Methodology

In order to answer the research questions and generalise the findings on the whole lower-secondary school chemistry teachers in Czechia, quantitative methods based on a questionnaire were used. The data were gathered from September to November 2018 on a randomly selected sample of lower-secondary school chemistry teachers. The data were analysed descriptively. Also, an explorative data analysis using datamining was used.

3.1 Research tool

An online version of a questionnaire was used. Its content validity was checked, and the tool was piloted (Vojíř & Rusek, 2019a). It consisted mainly of close-ended questions divided into the following categories:

- respondents' characteristics,
- the textbooks that are lent to students and used for teachers' preparation for teaching,
- textbook choice,
- teachers' satisfaction with the textbook,
- the perceived textbook importance for lesson preparation,
- using of workbook and teachers' book,
- perceived importance of workbook and teachers' book for quality of chemistry education and the purposes of the workbook's use.

Satisfaction, frequency of textbook use and their perceived importance, workbook or teachers' book were assessed using five-point Likert scales where only the limiting points (1, 5) were verbalised (1 – completely satisfied to 5 – completely dissatisfied; 1 – very significant to 5 – completely insignificant; 1 – I use very often (practically in every hour/preparation) up to 5 – not using). The method of workbook use was examined with the use of close-ended questions with options. The teachers explained their use of workbooks and teacher's books for lesson preparation, lesson realisation, with respect to their students' home preparations, as well as extension activities for individual students.

3.2 Research sample

The research sample selection emerged from the total number of lower-secondary schools in Czechia in 2017/2018 (MŠMT, 2018a). A minimum sample calculated on the 95% significance level was calculated using the Raosoft minimum-sample calculator (raosoft.com). The ratio of schools with lower-secondary level to the entire number of schools was considered. Moreover, the sample was extended due to the expected one third response-rate of online surveys (cf. Nulty, 2008). The schools were randomly chosen from the Czech Ministry of Education's school address book (MŠMT, 2018b). In the end, 1536 schools were addressed via email sent to these schools' headmasters. An explanation of the research's purpose, instructions and a link to the online questionnaire were included.

This resulted in the final sum of 387 teachers from 370 schools filling in the questionnaire. The 41% response rate of schools relevant for the research was calculated. As the number of participating schools exceeded the minimum sample, and they were selected randomly, the findings are considered generalisable to all lower-secondary schools in Czechia. As the previous research showed, there is only one chemistry teacher at 69% and two teachers at 22% of lower-secondary schools (Vojíř & Rusek, 2021), the results are also generalisable to the entire lower-secondary chemistry teacher population in Czechia. Moreover, as similar findings or trends were noted in papers from different countries, the results' international validity is also considerable.

3.3 Data analysis

An exploratory data analysis was performed using datamining. For this purpose, CRISP-DM methodology (Chapman et al., 2000) was followed (see Fig. 1). This methodology's principle builds on an analytical procedure's tasks' repeated entry and meaningful relations' evaluations being discovered.

Based on an initial understanding of the data and their specifics, their evaluation was prepared, i.e. grouping and entries' adjustments for computer evaluation. In the modelling phase, the implication relations which fulfil certain statistical measures were searched for in the data. These data rules can be described in an IF-THEN rules (antecedent ⇒ consequent) form (Fürnkranz & Kliegr, 2015, p. 55).

To analyse the data, a datamining tool, Easyminer, using the R-framework principle (Vojíř et al., 2018) was utilised. To evaluate the discovered data rules, the *confidence*, *support* and *lift* values were evaluated. *Support* indicates the frequency of an itemset's appearance in the dataset. *Confidence* shows how often a rule was found true. *Lift* shows the measure of an attribute's dependence. A *lift* > 1 confirms an implications' truth (Hahsler et al., 2005). Firstly, the search procedures minimum values were set as follows: confidence $= 0.7$, support $= 0.05$ and lift minimum value $= 1.1$. For interpretation's sake, a rule length limit was set to three variables.

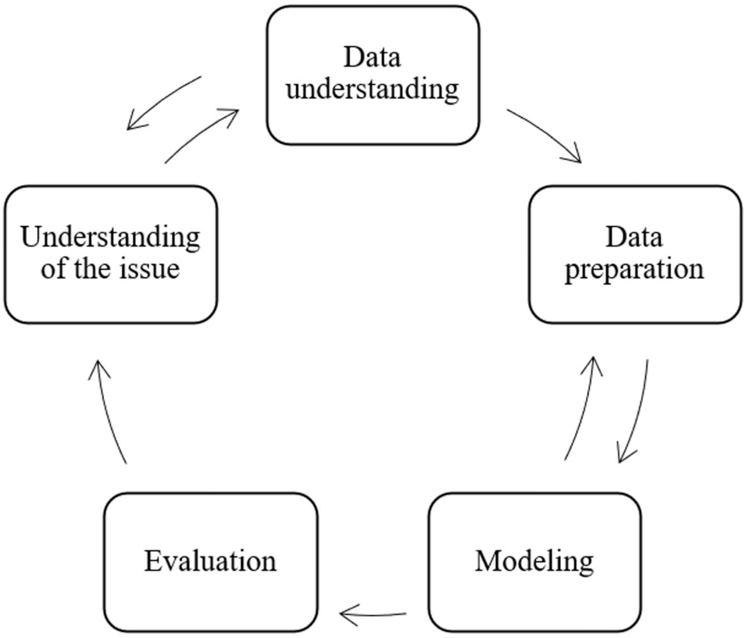

Fig. 1: Procedure of CRISP-DM

Within the modelling phase, interestingness with regards to the field of science education was evaluated for the discovered rules. Interesting rules were added into the final ruleset and interpreted later in other findings' context. In the following step, the mining procedure was in accordance with the methodology repeated with variables and rule parameters being changed in the modelling phase. The cycle of the procedure was repeated until no new rules were found.

4 Results and discussion

For transparency's sake, the results are further divided into workbooks and teacher's books parts.

4.1 Use of workbooks

The majority of the teachers (63%) answered that they use workbooks. 12% of the teachers admitted not using workbooks as they are not at their disposal or are unavailable for the textbook they use. 25% mentioned they do not use workbooks because they do not want it or do not need it (see Fig. 2). Altogether, the teachers rated the frequency of their workbook use in the middle of the scale (Med = 3). 26% mentioned they use workbooks *often* or *very often*. At the same time, the teachers who use workbooks consider them rather important for the quality of chemistry education (Med = 2).

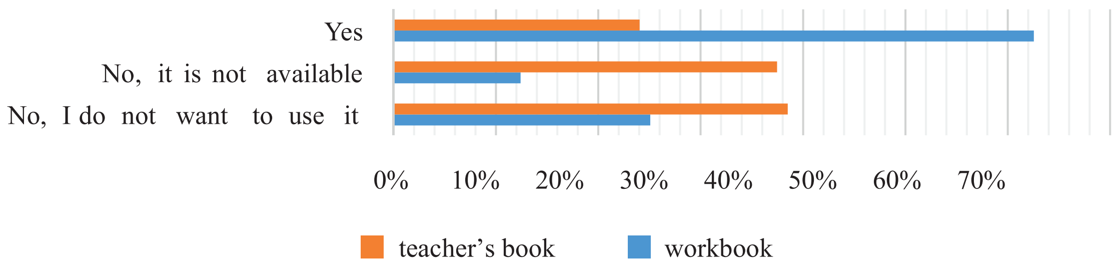

Fig. 2: Proportions of teachers using workbooks and teachers' books

These results showed the majority of the chemistry teachers consider the students' own activity when planning their lessons. This is a promising aspect towards students' scientific literacy development (Janoušková et al., 2019). Yet, a considerable amount of teachers showed in their teaching approach a strong teacher-driven transfer of information predominates (Vojíř & Rusek, 2021).

The results further showed workbooks are being used in all aspects of the educational process. The most frequent is their use directly during lessons (81%). 59% of the teachers use workbook tasks as extension activities, i.e. individualisation of education. On top of that, 40% of the teachers mentioned using workbook tasks for student preparation. The workbooks' influence on (chemistry) education was also shown as 28% of the teachers mentioned using them for their lesson preparation. This points to their well-considered inclusion in student-activating elements of their lessons.

This finding points to a considerable share of teachers' who use the entire textbook set's components to enrich their teaching by using material compatible with the conception of the textbook(s) they use. As this conception manifests mostly via a transfer of chemistry content knowledge (Vojíř & Rusek, 2020), using a workbook during lessons suggests these teachers' attention to knowledge fixation.

The teachers' attitude towards the entire textbook set proved to be an important factor. Teachers who are satisfied with the textbook they use are also more likely to use the workbook ($c = 0.687$, $s = 0.460$, $l = 1.099$). Similarly, teachers who chose the textbooks themselves are also more likely to use the workbooks ($c = 0.706$, $s = .297$, $l = 1.128$). This implication further increases if teachers chose the textbook set themselves and, at the same time, consider the textbook important for lesson preparation ($c = 0.805$, $s = 0.171$, $l = 1.287$). Similarly, teachers' satisfaction with the textbook plays a vital role. The teachers who chose the textbook set themselves and, at the same time, are satisfied with the textbook are more likely to use the workbook ($c = 0.725$, $s = 0.258$, $l = 1.159$).

These findings suggest a promising approach which could lead to chemistry teaching innovations. Having the opportunity to select a textbook they consider high-quality can identify with (cf. Laws & Horsley, 1992), and considering new teaching materials would also contain workbooks, seems to be a key towards teachers use of tasks.

Textbooks were found to play an important role in lesson preparation for the majority of teachers (Vojíř & Rusek, 2021). The results showed that a considerable proportion of teachers also prepare for their lessons using workbooks. Teachers' perceived importance of the textbook for lesson preparation seems to affect their use of the workbook. If teachers consider textbooks important for lesson preparation, they are more likely to use workbooks ($c = 0.712$, $s = 0.339$, $l = 1.139$). This result showed that the teachers who seek support in textbooks also consult workbooks as another material when preparing their lessons.

This link is strengthened for teachers who consider textbooks important for lesson preparation. More than 76% of the teachers who are satisfied with their textbooks use workbooks ($s = .276$, $l = 1.222$). The perceived importance of textbook for lesson preparation positively affects the use of workbook for almost 74% of the teachers with more than 10 year teaching practice ($s = 0.248$, $l = 1.181$). This finding could be explained by the experienced teachers' full exploitation of an offered textbook set.

The fact that the use of workbooks is especially frequent for the teachers who use the NS chemistry textbook set to prepare for education, further underlines the aforementioned findings. In this result, the teachers' highest satisfaction with this particular textbook set (Vojíř & Rusek, 2021) is reflected. Compared to the users of FR (52%, $s = 0.109$), ZCH (59%, $s = 0.165$), PCH (62%, $s = 0.109$), almost 74% of the teachers who use the NS chemistry textbooks also use workbooks ($s = 0.282$, $l = 1.139$). The lift values for other textbooks than those by NS are below 1 which suggests a below-average frequency for the implication validity. The lowest share of teachers was satisfied with the FR textbook (Vojíř & Rusek, 2021), which is again mirrored in their lowest use of the workbook. The more frequent use of workbooks is therefore likely to be associated with the overall perception of the textbook set, i.e. the extent to which a textbook project resonates with the teachers' conception of teaching. Teachers refusing a textbook set could then lead to them searching for alternative materials (cf. Laws & Horsley, 1992), including, e.g. an alternative workbook as expressed by the research's respondent: "The textbook ZCH does not contain enough subject-matter for practice. For this reason, I rather use the workbook by Taktik which contains many tasks and tips for a concrete subject-matter's mastery." This citation strongly suggests this teacher's teaching conception – attention to lower-order thinking and subject matter transfer – a phenomenon observed in a significant group of teachers.

A significant lift of a relation was found for teachers who studied a non-chemical educational program. If these teachers are satisfied with their textbook, they are likely to use the workbook too ($c = 0.77$, $s = 0.067$, $l = 1.223$). Moreover, this association rule applies for 70% of these teachers whose teaching practice is longer than 10 years ($s = 0.072$, $l = 1.119$). This finding suggests that workbooks support the teachers with a degree from another field of education than chemistry. They have educational know-how and are probably aware of the need to use activating techniques. They may feel insecure as far as the chemistry content knowledge, and its evaluation, is concerned. This idea can be further explored. In a period of a lack of (chemistry) teachers, when chemistry is being taught by people who did not study a chemistry education, it seems reasonable to consider workbooks a significant teacher support. They have not been, however, given attention in contemporary science education textbook research yet (Vojíř & Rusek, 2019b).

4.2 Use of teacher's books

Whereas most teachers use workbooks along with the textbook, teachers' books are being used only seldom (see Fig. 2). The results showed teacher's books are being used by only 24% of teachers. This is influenced by the teacher's books availability only for textbook sets PCH and FR. This state is undesirable as Heinonen (2005) found out teachers books are considered helpful by Finnish teachers, which either suggests their conception fits the teachers better, or the teachers seek methodical guidance instead of just structuring their lessons around subject-matter. Among Czech teachers, 39% of the respondents reported they either do not want to use a teacher's book nor do they need it. An additional 37% of the respondents mentioned its absence or unavailability as the reason for not using it.

Unwillingness to use a teacher's book was found to be more frequent for teachers who consider textbooks unimportant for their lesson preparation. Almost 62% of them claimed that they do not use the teacher's book because they do not want or do not need it ($s = 0.067$, $l = 1.608$). Similarly, 67% of the most experienced teachers in the sample (more than 10 years of teaching practice) chose this option ($s = 0.052$, $l = 1.732$). These teachers seem to be confident of their own experience and lesson preparation and do not feel the need for textbook support. With respect to the finding that the length of teaching practice does not significantly affect teachers' use of textbooks (Vojíř & Rusek, 2021), this finding shows that Czech chemistry teachers feel confident about their ability to prepare lessons only according to the textbook. This attitude was proven to strengthen with the increasing length of practice. However, this finding is in contrast with Finnish teachers, who express their satisfaction with the support provided by teacher's books (Heinonen, 2005).

The teachers' responses suggested the role of a teacher's book is being substituted by a textbook or a combination of textbooks. The teachers who mentioned they use a teacher's book consider it neither important nor unimportant for quality of chemistry education (Med = 3). They responded in the same way (Med = 3) about the frequency of a teacher's book's use. Only 4% mentioned they use it often or very often showing the marginality of this textbook set's element as far as its impact on teaching practice is concerned. This result then proves the majority of publishing houses' resolution not to publish teacher's books. From a didactical point of view, however, by excluding these, especially novice teachers' transfer into practice is made more difficult.

These findings only strengthen the conclusion that textbooks play an important role when teachers prepare their lessons (Vojíř & Rusek, 2021). This role is, however, not as expected – incorporating a textbook part into lesson instruction, but rather teachers drawing lesson structure, content, or even didactical transformation (order and method of teaching) of concepts from the textbooks. In this way, textbooks take over the role of teacher's books, despite the fact that their primary function targets a very different audience.

One finding seems to explain this state. Teacher's books are used by the teachers who use the chemistry textbooks by the FR publishing house ($c = 0.636$, $s = 0.127$, $l = 2.648$). This factor is even stronger with teachers who consider the use of a textbook important for lesson preparation ($c = 0.8$, $s = 0.072$, $l = 3.329$) or are satisfied with the textbooks ($c = 0.765$, $s = 0.067$, $l = 3.182$). This suggests a close link between the teachers' chemistry teaching conception and the elaboration of the chemistry textbook set. Also, the quality of the teacher's book could be mirrored in this finding.

Teachers' appreciation for textbook sets was shown not to be affected by the fact whether it contains a teacher's book or not. Although the textbooks by NS or ZCH do not dispose of teacher's books, the teachers expressed their satisfaction with them (Vojíř & Rusek, 2021). Out of these teachers, 43% (equally for both textbooks' users), expressed they do not want or do not need to use a teacher's book. The textbooks seem to fulfil their needs. However, considering the fact textbooks are originally a material designed for students, the results the structure and content suits teachers suggest students were not considered to be the primary recipients of these textbooks. This is in accordance with the results of textbooks' text-difficulty which showed text being too difficult, especially in these textbooks (Rusek et al., 2016; Rusek & Vojíř, 2019). Another explanation could be the teachers' experience and ability to construct lessons simply based on the lesson conception as suggested by textbook authors.

Although there is a teacher's book available for the PCH textbooks, teachers using them do not use the teacher's book ($c = 0.469$, $s = 0.078$, $l = 1.217$). The teachers who provide this textbook to their students and are satisfied with it especially responded that they do not want to use the teacher's book ($c = 0.625$, $s = 0.065$, $l = 1.623$). A possible explanation is in its didactical equipment (Rusek et al., 2020) as well as an overall elaboration derived from the earlier-published ZCH textbooks by the same authors (Vojíř & Rusek, 2020). Teachers' attitude towards the use of PCH and ZCH textbooks is then similar. There was no demand for a teacher's book by the ZCH users, therefore, also PCH users do not consider it important.

These findings point to the FR textbooks' rare standing. In this respect, two possible explanations come into question. First, the textbooks' unique conception probably required explanation. Second, at the time of their publishing, these textbooks represented a significant change and a positive deviation from a traditional chemistry textbook style (see Vojíř & Rusek, 2020). They might have been an option for innovative teachers seeking an alternative. Using a teacher's book explaining the ideas of the new conceptions in this case then seems logical.

Moreover, as the only one from the frequently used chemistry textbook series, it seems to keep the concept of student's "(text) book", whereas the others seem to aim at teachers too, possibly combining two different target groups' needs. In this respect, the use of a textbook series seems to reflect teachers' way of teaching and is an important indicator for lesson conception mapping.

5 Research limitations

The results of this research offer a deeper look into teachers' conception of education. One of potential limitations is in the sample selection. In spite of its size and randomised selection, online distribution via school headteachers could have resulted in less active or considerate teachers' absence in the sample. This frequent limitation is, however, reduced by the sample size.

Another possible limitation is the fact that only teachers' opinions were considered. Though teachers reveal a lot when talking about particular textbook set parts, their conception, perceived importance, (non)use, etc., only lesson observations and an analysis of their lesson preparation would bring a complete picture. Naturally, research of this scale requires a much larger project. However, it is the authors' intention to proceed in this direction too.

6 Conclusion

In this paper, attention was given to the missing piece of textbook sets – workbooks ad teacher's books. Workbooks accompany every Czech chemistry textbook contemporarily commonly used in lower-secondary schools. However, teacher's books are available only for two of the textbook sets. Compared to textbooks, these materials have not been given much attention by researchers. Teachers' conception of lesson preparation and realisation shows their perceived curriculum, which can then be compared to contemporary teaching paradigms. It is through knowledge about these textbook sets' parts a clearer picture about education can be drawn.

Unlike textbooks, workbooks are not provided to lower-secondary students by schools, and they have to purchase them in case their teacher requires this material, yet this research showed the majority of teachers use workbooks, with only about a fourth mentioning they would not like to use them.

Workbooks are being used for various purposes. Individual work in the lessons (subject-matter fixation) and homework suggest themselves. The biggest proportion of the research sample mentioned the workbook's use directly in lesson realisation. However, a considerable share of teachers consults workbooks when preparing for their lessons, which suggests their promising inclination towards activity-based teaching. Teachers' use of workbook depends mainly on their perception of the textbook set as a whole. Their identification with the teaching paradigm the textbook follows affects the use significantly too.

As opposed to this, teacher's books stay behind. The majority of chemistry teachers do not use them and/or do not want to. The research results suggest textbooks take over the teacher's books role in some cases. This claim was earlier confirmed in other research by Vojíř and Rusek (2021), who found that teachers even combine more textbooks to prepare for their lessons. Understandably, some teachers draw the subject-matter content, tasks, fun facts, pictures, etc. from their textbooks. Nevertheless, this only shows their conception of teaching builds mainly on the subject-matter and does not need methodical suggestions as far as the content's didactical transformation or methods are concerned.

Apart from the information about the use of another textbook sets' components, the possibility to use a data mining procedure was tested in this research. It is common e. g. in sociology or marketing, whereas (science) education research has typically used only classical statistical hypotheses testing. The used CRISP-DM methodology offers other hypotheses' evaluation and could, in many ways, expand contemporary knowledge in areas researchers would overlook.

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The Use of Eye-tracking in Science Textbook Analysis: A Literature Review

Použití eye-trackingu v analýze učebnic pro přírodovědné předměty: přehledová studie

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Contemporarily available technology has provided researchers with quite an accessible method to see through students' eyes. This offers researchers the chance to re-evaluate teaching materials in terms of their potential function, one that has been largely overlooked. This study presents a literature review drawing on science textbooks that use the eye-tracking method. Relevant journal articles or conference papers indexed in the Web of Science and Scopus databases were selected. From the original 112 papers, 18 were submitted to a thorough analysis after duplicate papers and papers not conforming to the topic were excluded. The studies' characteristics, topics (influence of textbook design on student learning, distribution of attention, textbook effect etc.) and used methods (the device and measurement, additional methods, methodological issues) are included in the review. (Novice) science education researchers, state officers responsible for textbook evaluation, textbook authors and even teachers can profit from this overview, as it clearly indicates the state of the art as well as potential research directions.

Key words:
textbooks, eye-tracking, science education, literature review.

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Aktuálně dostupná technologie poskytla výzkumníkům metodu, jak vidět očima žáků a studentů. To nabízí možnost přehodnotit potenciální funkci výukových materiálů z jejich dosud skrytého úhlu pohledu. V této studii je prezentována literární rešerše výzkumu v oblasti učebnic pro přírodovědné předměty pomocí metody sledování pohybu očí (eye-trackingu). Do studie byly zahrnuty relevantní články z časopisů nebo konferenčních sborníků indexovaných v databázích Web of Science a Scopus. Po odstranění duplicitních záznamů a článků nevyhovujících zkoumanému tématu, bylo z původních 112 prací 18 podrobeno důkladné analýze. Do přehledu publikovaných studií je zahrnuta jejich charakteristika, témata (vliv zpracování učebnice na učení žáků a studentů, rozložení pozornosti žáků a studentů, vliv formátu prezentace učebnice atd.) a použité metody (zařízení a metriky, další metody nebo metodické otázky). Příspěvek ukazuje současný stav zkoumané problematiky a naznačuje potenciální směry výzkumu. Je tak určen výzkumníkům v oblasti přírodovědného vzdělávání (včetně těch začínajících), státním úředníkům odpovědným za hodnocení učebnic, autorům učebnic nebo dokonce učitelům stojícím před výběrem nových učebnic.

Klíčová slova:
učebnice, eye-tracking, přírodovědné vzdělávání, literární rešerše.

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1 Introduction

Research on science textbooks has been growing in recent years (Vojíř & Rusek, 2019), gradually bringing more information about their unique standing in education. One group of research focused on the way textbooks are being perceived or the purpose of their use in education (Červenková, 2010; Lepik et al., 2015; Mullis et al., 2012; Sikorová, 2010; Vojíř & Rusek, 2021). Another group of research focused on the textbook content. Naturally, the ideas, concepts and/or their correctness were evaluated (e.g. Baptista et al., 2016; Gegios et al., 2017; Österlund et al., 2010). Within this group, textbooks' structural components (Rusek et al., 2020) or text-difficulty (e.g. Rusek et al., 2016; Šmídl, 2013) were analysed.

Contemporarily, more and more available new technology enabled, almost literally, researchers to see the books through students' eyes. Former endeavours to provide teachers with a rubric helpful for an informed textbook choice (e.g. Knecht & Weinhofer, 2006; Sikorová, 2007; van den Ham & Heinze, 2018) can thus be enhanced. Eye-tracking cameras or goggles are the cutting-edge gadgets in this respect. They offer a closer look into how textbook components are perceived with the use of more complicated and time-consuming methods, such as the already mentioned text-difficulty based on counting words and distinguishing terms (e.g. Rusek & Vojíř, 2019), categorizing visual components (e.g. Papageorgiou et al., 2017; van Eijck et al., 2011) or assessing visual components in relation to the text (e.g. Slough et al., 2010). Eye-tracking (ET) technology allows for students' eye-movement investigation including e.g. them looking at a textbook page. ET data visualisation includes e.g. scanpaths, or heat maps, the data can also be represented quantitatively, for example time fixation duration, mean fixation duration, fixation or saccade count. These measures are often detected in specific areas – identified prior to the research or after it according to research results (Lai et al., 2013).

In textbook research, this offers analysis of general layout, its overall ergonomics, different graphical components' fitness and function (Do students use particular textbook components as expected? Are contemporary textbooks useful for students?), or students' independent work with the textbook text (Do they read the entire paragraphs or skip them? Is the text structured enough? Do the included elements guide students when working with the book?). These can be summed up as testing whether the prepared, didactically transformed units suit the target group representatives.

2 Methodology

2.1 Aim

The aim of this review was to map trends in research focused on the use of the eye-tracking method in science textbooks' analysis. For this purpose, a literature review was performed. The following categories commonly used in corresponding reviews (e.g. Lai et al., 2013; Teo et al., 2014; Vojíř & Rusek, 2019) were identified:

- publication characteristics (continent, locality, authors, publication year)
- research characteristics (subject, topic, aim, results)
- methodological information (used device, sample size, reasons for excluding some participants, additional methods).

2.2 Procedure

With respect to paper quality, only papers published in journals and conference proceedings indexed on the Web of Science or SCOPUS databases were chosen for the review.

The search was realised with the use of the following keywords (TS[1] = eyetracking or "eye tracking" OR eye-tracking OR "eye gaze tracking" OR "eye-gaze tracking" OR "eye-based gaze tracking" OR "eyegaze tracking" OR "eye -movement" OR "eye movement" AND TS = textbook*) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article OR Early Access OR Proceedings Paper OR Review), in all WoS core collection databases and the SCOPUS database.

The assortment of articles followed the standard process of screening, identification, and eligibility assessment. Fig. 1 shows PRISMA flow diagram edited according to (Moher et al., 2009), including the numbers of all identified and discarded papers.

First, the papers' records including abstracts were exported to MS Excel. Next, duplications within papers indexed in both databases were eliminated. All records' abstracts were read to evaluate their suitability according to the previous criteria. Only papers corresponding to the review's topic were included for the full-text evaluation. Some papers were excluded based on the use of different methodology than eye-tracking or a different aim than science textbooks (1).

Information regarding the categories defined in the aim above were noted for each of the papers.

3 Results and discussion

A total of 18 studies using eye-tracking in science textbook research were identified. Although it is not as many as studies used ET in education in general (Lai et al., 2013) or in science education (Jarodzka et al., 2017), ET proved to be a promising asset in textbook evaluation too. With the trend of science education research focusing also on textbook research (Vojíř & Rusek, 2019), an increase in this area is expected. With respect to novice researchers in the field, this review then could serve as a basepoint.

3.1 Study characteristics

The number of papers which matched the research criteria does not, yet, follow a clear trend (see Tab. 1). Nevertheless, considering the time of the last database check, there still could be papers published in 2020 not yet indexed on the Web of Science, therefore not found on the search.

Tab. 1: Number of papers published in years

YEAR	1999	2013	2014	2015	2016	2017	2018	2019	2020
PAPERS PUBLISHED	1	1	3	1	3	2	3	3	1

[1] Topic, or abstract or keywords.

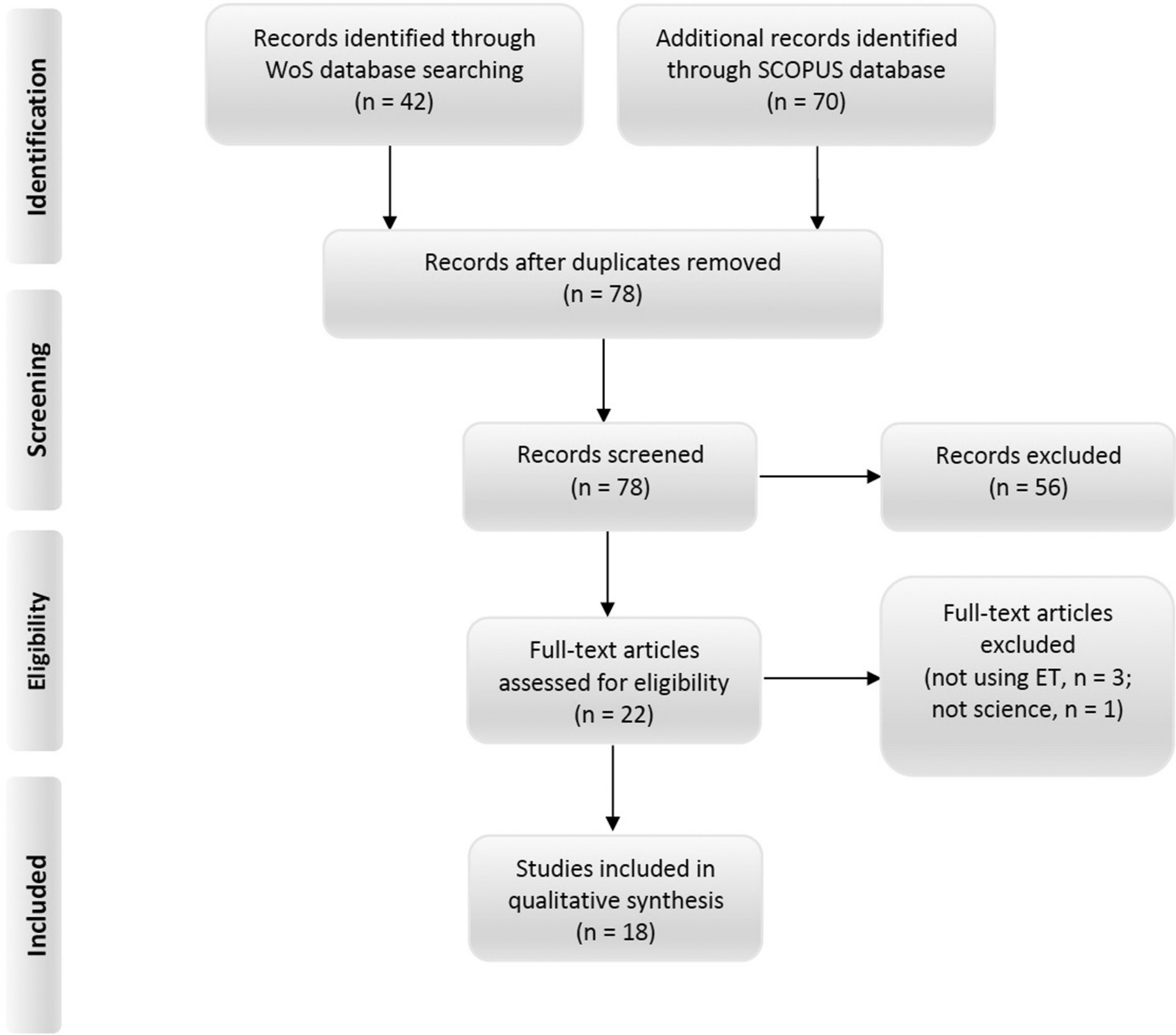

Fig. 1: PRISMA flow diagram describing the papers' selection for the analysis

The gap between the first and second published paper is surprising. Hannus and Hyönä (1999) have shown a very progressive approach to textbook research, which in 1999 already used ET to examine students' work with textbooks. The researchers investigated a still current problem of students' attention distribution between text and images. However, the gap between the first and second paper is surprising. This could be due to the insufficient technology at that time.

Since 2013, science textbook research using eye-tracking has been published every year. Although the search was updated to March 2021, only one research study on textbooks was identified in 2020. Given the trends of previous years, the reason may be due to the coronavirus pandemic and distance learning, in which students (research participants) were not personally present at schools and other institutions (Viner et al., 2020).

As far as its geographical use is concerned, eye-tracking has been used in textbook research mostly in Europe (12 studies), led by Germany (8), followed by the Czech Republic (2) and Finland (2). In Asia, three studies of such focus were identified in Taiwan, Korea and Qatar. In Africa there were two studies - both located in South Africa. There was another done in Australia.

From the level of education's point of view, the research focused on all levels (see Fig. 2). Research mostly focused on participants' comparisons. This included studies comparing student performance on related educational levels, e.g. lower and upper-secondary (Schnotz et al., 2014), but also completely different participant groups, e.g. elementary school students and adults (Jian, 2016; Kaakinen et al., 2015). A specific study in this category is represented by research focused on graduated respondents (Drexler et al., 2019). This study analysed teachers' reading textbooks. The specificity lies in the fact they use textbooks for a different purpose than students.

The studies used samples from 8 to 204 participants. The median was 20. The lower number of participants can be justified by the time-consuming nature of the research, which is often supplemented

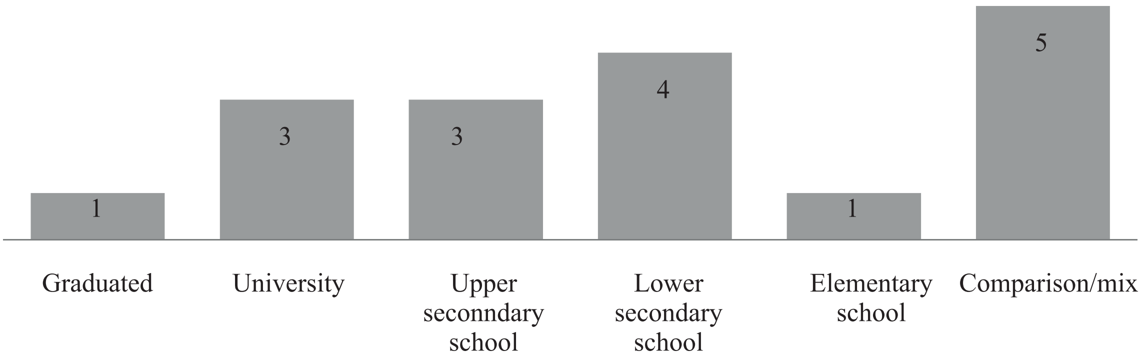

Fig. 2: Number of papers on different school level

by additional methods (e.g. interviews, questionnaires or tests (Gelderblom et al., 1993a; Kaakinen et al., 2015; Lim et al., 2014). On the contrary, studies using data from a higher number of participants work only with the eye-tracker data, analysing them quantitatively only (Schnotz et al., 2014).

Regarding scientific disciplines, eye-tracking for textbook analysis has not been used equally within science education (Fig. 3). The research on physics textbooks showed more focused attention by Ishimaru et al. (2016; 2017). The body of research grouped under the *Science* category included, besides science, also research integrating more school subjects (e.g. biology and geography). The *Other* category included research focused on an unspecified subject or research aimed at a platform or format (e.g. printed or digital) more than on subject-matter (Johnston & Ferguson, 2020; Johnston et al., 2016).

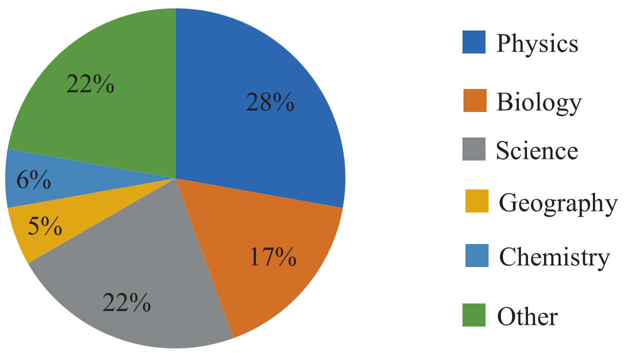

Fig. 3: Shares of studies focused on different science fields

3.2 Topics

The research studies were divided into five topics according to their focus. Analysed studies mostly focused on the *image's presence* (see Fig. 4). The study showed that the distribution of attention to individual parts (image and text) is influenced by many factors, including motivation, students' level (ability, age, type of education) (Hannus & Hyönä, 1999; Ishimaru et al., 2016; Schnotz & Wagner, 2018) and picture location (Drexler et al., 2019).

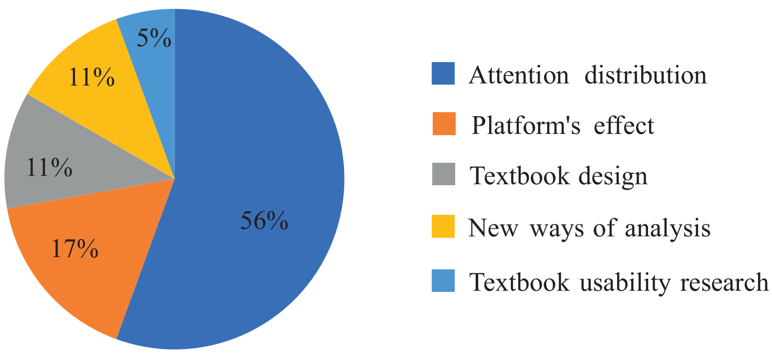

Fig. 4: Distributions of textbook analysis foci

Moreover, eye-tracking data proved to be a valuable source of information about the *effect of a used platform (printed, electronic, tablet, iPad etc.)*. Also, its importance proved the effect of *textbook design* (Kaakinen et al., 2015; Richter & Scheiter, 2019). The review also identified studies focused on *new ways of analysis* (Ishimaru & Dengel, 2017; Ishimaru et al., 2017) and also *usability research* (Gelderblom et al., 2019).

3.2.1 Textbook design

This type of research can bring the interested closer to an ideal textbook design. The influence of text processing has been investigated in chemistry and science textbooks for several years now. Richter and Scheiter (2019) analysed the different reading behaviour according to the presence of *multimedia integration signals* (MIS). They compared MIS +, a chapter which contained colour coding according to the picture, and MIS − chapter, including only text signals, e.g. bold face, headings or labels in the picture. Its use regarding eye-movements and previous knowledge was analysed. The results showed that MIS + improved the performance of students with low prior knowledge, also their visual behaviour changed. These students looked at the pictures earlier and started to read text later when MIS were present, while the high prior knowledge students' outcomes and eye-movements were not affected by MIS. Moreover, these students-perceived cognitive load increased when MIS were present.

Another part of the research focused on textbook design considered the form of chapter titles. In their study on reading tasks' influence on readers' eye-movements, Kaakinen et al. (2015) looked at title design's effect. They compared the difference between the title designed as a question or a statement. The results showed that questions such as "Why are forests important?" maintained readers' coherence better than titles such as "Importance of forests".

When encountering the question-design title, older students and adults went back in the text and formed concepts integrating information from the text. This minor change then seems to improve the reading approach, increasing the texts' educational effect even for inexperienced readers. On the contrary, the question-design forced the youngest pupils (elementary school) to concentrate more on the first visit (measured as their focus on the area of interest) to the text.

3.2.2 Image's presence

Research so far showed that students' use of textbook images was not as apparent as expected. Eye-movement measurement can clarify the difficulties of linking images and text. This was shown in research study on geography textbooks (Behnke, 2014). The heatmaps and scanpaths showed students mostly focused on the text in comparison to images while reading five textbook spreads.

The students' use of images turned out to be influenced by various factors. One of them is *motivation*. Lim et al. (2014) found that more motivated students spent the same amount of time (measured as time fixation duration) on the text and images. On the other hand, the less motivated preferred passive text reading and did not integrate the pictures in them. The reason could be found in their anxiety and demotivation

Another factor affecting students use of the textbook and its effect on students' learning proved to be their *level* – age, the already mentioned ability, or type of education. Research study on 10-year-old students (Hannus & Hyönä, 1999) showed the students with high intellectual ability were more strategic during textbook reading. They spent more time on the text as well as illustrations compared to the low intellectual ability students. Also, they did more back-and forth transitions. The ability to transition between individual textbook parts (text and image) also proved to be important in other studies. Jian (2016) compared adults' and 4th graders' reading behaviours. Whereas adult readers switched between text and illustration often, 4th graders transited in the text or illustration area, but rarely between text and illustrations.

Similar results were obtained in biological textbook research. Hochpöchler et al. (2013) investigated strategies students used while dealing with text and graphics to integrate these two sources of information to answer questions. The strategies were analysed using time fixation duration in text and picture. The results showed the text and images are associated with different student strategies. Texts are used in a coherence-formation strategy. Graphics are used on demand (information-selection strategy). The level of education proved to be an important factor in the use of these components as well. Students from higher track schools looked at the pictures when dealing with more difficult questions. They used the picture as scaffolding. On the other hand, lower track students looked at the picture even for the initial mental model construction but did not use them intensively afterwards. The attention to text and image with students at different levels of education was also studied by Schnotz and Wagner (2018) in biological and geographical textbook research. Senior students gathered more relevant information from pictures more easily (probably due to their higher intelligence. Besides the number of fixations, numbers of saccades between AOIs were analysed. The senior students switched more often between picture and text. These findings contradict the study in physics textbook by Ishimaru et al. (2016), who found that experts looked at graphics less compared to the novice and intermediate.

These results also showed the importance of an analysed phase. The high-attention parts were almost the same for the novice, intermediates and experts during the reading phase, the solving phase made a difference between these levels.

Moreover, the results revealed another factor that affects textbook text and image processing. It is *"when"*, i.e. particular phases of students' reading focused on different areas. With the students' fixations and saccades (transitions between text, picture and item) analysis, the use of text-image proved to be asymmetrical depending on the reading phase (Schnotz et al., 2014). The percentage of text–picture transitions decreased from the first phase to the last, whereas the percentage of picture–item transitions increased. According to this finding, texts showed to provide conceptual guidance, while images served as external cognitive tools used when needed (e.g. in the question part of the textbook). In their further research study, Schnotz and Wagner (2018) also confirmed that students focused on the image only during the second viewing, where the number of picture fixations was higher than the in-text fixations. Also, the between picture and item transitions were higher than between the text and item. Even in this study, the educational level proved to have an influence, as this characteristics are more valid for more competent learners.

The *location of the image* also showed to be a significant factor. While teachers were reading the textbook, they tended to skip the images. This was probably caused by their educational level, on which the pictures are no longer needed to understand the topic. When the textbook design was atypical (compared to classic textbooks), teachers paid the most attention to the central area of the textbook, even if there was a picture (Drexler et al., 2019).

Research on physics textbooks also showed students read the text from the beginning to the end. However, when there is a picture on the page, they looked at it, no matter where it was placed (Drexler et al., 2018). Students also read the image captions after observing the image (they found out what they had seen right after). This natural strategy can cause misunderstanding and should be included either into their instruction or be treated in the books' design.

As far as particular parts of a chapter are concerned, attention was paid mostly to the chapter's introduction and gradually decreased (Drexler et al., 2019). This calls for the use of special elements. Explaining new subject-matter was proven to have increased readers' attention even in the middle of the chapter (Drexler et al., 2018).

3.2.3 Platform's effect

The platform through which the textbook is presented also plays an important role. Beelders and du Plessis (2018) investigated IT students' reading according to the used presentation medium (Kindle, tablet, iPad, PC, paper). The results showed students read faster when reading on an iPad, which the students also indicated as the most pleasing to use for reading. The results showed paper was the least popular medium in this respect. On the other hand, students had to return to the textbook more on this device. From students' comprehension and concentration's point of view, a PC proved to be the best option, as they did not return to clarify the introduced concepts, as well as the fixations were longer and more numerous. These results, however, need to be read considering the students' specialization. Used to mostly working on a screen, this could have biased the result. For example (Johnston et al., 2016) and later Johnston and Ferguson (2020) found opposing results of students' preferences. For this reason, the topic of a medium needs to be considered with discretion. In studies students' scanpaths were analysed. Results showed students (among others also science students) skimmed and flipped more often and concentrated less on digital textbooks than traditional ones. They also made less notes and underlining than they did in printed versions. Students themselves also confirmed they learned best from a printed text.

3.2.4 Textbook usability research

Another aspect studied using ET in this respect by Gelderblom et al. (2019) was students' habit of working with an e-textbook. They analysed the problems students faced when using an e-textbook. The study compared students who used this textbook for one year with those who used it for the first time. Authors analysed students' gazepaths in a qualitative way to understand problems they faced while working with an e-textbook (scrolling pages, long searching for functionalities, e.g. searching box, etc.). The results showed some problems (e.g. finding the table of contents, creating a summary or highlighting) that arose regardless of the students group. The interviews also revealed the students emphasized the role of teachers in their ability to use the functionalities of these textbooks.

3.2.5 New ways of analysis

The use of eye-tracking in science textbook research, in comparison with the above-mentioned "classics", opened new ways of analysing or using gained information. Some papers included in this review bring a promising future to this method's use. Ishimaru et al. (2017) investigated the possibility of nasal temperature recording and its correlation with student concentration. The results showed potential for this method in students' work with a textbook. However, nose temperature change required a longer time, which could be the limit of its use. To use and process more data together, Ishimaru and Dengel (2017) and Ishimaru et al. (2017) proposed a system which can record natural eye-movements and convert them into valuable data. The data can be used in HyperMind – a system of customizable textbooks. It is built on a system recognizing the students' cognitive state through sensors (including eye-movement monitoring). According to the students' actual attention, the scope and layout of the textbook can change, a static text can be replaced by a video or representations can be changed according to a reader's age. This should improve student motivation and understanding by increasing the time they work with it. This, obviously, is an advantage over static textbooks.

3.3 Used methods

To address the second goal of this study, technical information was gathered to provide readers with an overview of the state of the art.

3.3.1 Eye-tracking device and used measurement

Most of the research used an eye-tracking device mounted on a PC or tablet that allowed for free head movement. The most used devices[2] were Eye Link (6), Tobii (6), SMI (5) and Applied Science Laboratories Model (1). The last one is especially interesting, as it was a model from 1994. In addition, four studies used eye-tracking glasses (Tobii or its combination with SMI). This allowed researchers to work with real (printed) textbooks, which at the same time brings methodological issues (see the chapter below).

Standard eye-tracking metrics were used in the analysed research. The researchers used fixation (count, mean, duration, frequency), saccades (mean, order, count), as well as less common metrics, such as pupil diameter. The Areas of Interest (AOI) were determined for individual stimuli. The quantities mentioned were related to individual AOIs then. Also, other metrics, such as visit count, or time to first visit of a particular AOI, were used. These quantities helped to determine when and to what extent the participants devoted their attention to individual parts of the textbook, therefore when a learning occasion occurred.

3.3.2 Additional methods

Eye-tracking allows where the participant looked to be observed but does not provide any information about why they looked there (Ishimaru & Dengel, 2017). This is why ET studies are often (all but three in this review) supplemented by additional methods. The most common method was a questionnaire (7). These were used to determine students' motivation or preferences. Tests (5) related to reading skills or intelligence (including spatial) were another additional method. Interviews were held in three cases. As mentioned above, a thermal camera was used in one study. Other devices in combination with ET were also used in other research besides textbook research (Cortes et al., 2018).

3.3.3 Methodological issues

The use of eye-tracking in research brings the undeniable benefits of seeing what research participants see. Nevertheless, the method is not universal, and several problems arise when using this method. First, most students with normal to corrected-to-normal vision problems can be tested with satisfactory results. Second, exclusion due to poor or unsuccessful device calibration (Jian, 2016; Kaakinen et al., 2015; Schnotz et al., 2014), quality of recorded data (Johnston & Ferguson, 2020; Richter & Scheiter, 2019) or incomplete or "dishonest" participants' work (Ishimaru et al., 2016) were faced. The number of excluded participants varied from 0 to 19 (med = 2). The authors themselves mentioned the research sample (size or selection) as a limit in their studies (Lim et al., 2014; Schnotz et al., 2014) which shows areas which should be addressed in the future. Third, a problem may occur when textbooks in real conditions (printed) are analysed. For this purpose, eye-tracking glasses are necessary. As experienced by Ishimaru et al. (2016) in a group of younger research participants, unused to the glasses, they often touched them which led to the accuracy loss.

[2]Some studies used multiple devices, so the numbers exceed the number of the analysed research papers.

4 Discussion

Five general topics emerged from the studies included in this review. As one of the selection criteria was the use of eye-tracking, focusing on the visual elements in textbook which are necessary for science education (Eilam & Gilbert, 2014) was natural. The most research attention was paid to the presence of images. Their presence in the text is usually considered beneficial for reader understanding (Carney & Levin, 2002). In addition, teachers were found to choose new textbooks based on their graphical shape (Vojíř & Rusek, 2021) which even increases relevance of this study area. Science disciplines use (graphical) representations of three types: macro-, micro- and symbolic (compare the evolution of the "chemistry triplet" in: Gabel, 1993; Johnstone, 1991; Taber, 2013; Talanquer, 2011) which carry the content/subject-matter. The problems with using images, found in above-mentioned studies, may therefore affect student's learning. In a positive way it offers i.e. showing multiple representations or promote students' learning of abstract topics. On the contrary, it can aggravate learning by increasing the cognitive load, distracting learners or simply (in case of less competent or novice readers) by confusing them. As shown in several studies in this review, motivation, level, quality of such graphics, its location in the text or even time of its appearance were studied. A special guidance could be provided to learners by their teacher in this matter. However, if textbooks were designed in an evidence-based manner, i.e. respecting corresponding research results, the textbook's structural components could be linked in a way which would support young readers to do the necessary transitions. Naturally, e-books or even adaptable e-books (e.g. Ishimaru & Dengel, 2017) could have this potential.

In contrast to the very traditional conception of Czech lower-secondary textbooks (Vojíř & Rusek, 2020) and their almost uniform component content (Rusek et al., 2020), these results could represent valuable evidence when new textbooks are prepared. Analysed studies showed, the use of MIS can improve low-prior knowledge students' performance.

With regards to the known textbooks' role in education in many countries (e.g. Lepik et al., 2015; Mullis et al., 2012; Vojíř & Rusek, 2021), this research seems to be a source of valuable remedy for students' learning results (Richter & Scheiter, 2019).

Apart from the presence of signals, another textbook design principle – the form of title – was studied. The question-designed title proved to enhance participants' understanding leading to a higher amount of back and forth eye-movements. This is usually a more experienced readers' characteristic (Jian & Ko, 2017), however, chances are this could work for other readers too eventually. To illustrate the current state, when Czech chemistry textbooks are evaluated in this criterium, the majority use traditional headings. Only one textbook series (Beneš et al., 1993a, 1993b) used questions in their main chapters' titles. Considering the fact the subchapters – particular lessons' titles are not formulated as questions, the effect found by Kaakinen et al. (2015) does not apply here either. Nonetheless, it can be considered a signal for teachers how to present their lessons goal, even what to write on the board at the beginning of a lesson.

With the increased use of e-books, the effect of a platform or format is currently also a hot research topic. Due to recently increased integration of digital technologies into teaching and households, digital materials gained on their importance (Scully et al., 2021). An attention to this learning materials area was paid even in studies which did not use an eye-tracker (e.g. Ross et al., 2017), nevertheless, eye-tracking data represent a valuable asset providing more detailed information about students' learning behaviour when using a learning material. Gelderblom et al.'s (2019) study showed paper was the least popular medium for students used to working with a computer. With ever developing technology, pandemics-forced shift to online teaching as well as increasingly more available technology such as tablets with stylus pens, e-textbook might soon take over. One way or another, for the time being, students' preferences need to be considered. Research shows most students still prefer traditional, printed textbooks (e.g. Johnston & Ferguson, 2020; Millar & Schrier, 2015).

These information help textbook authors, publishers, education researchers and mainly educators to better understand the functions of textbook together with their adoption. With expected more information from proliferating eye-tracking research, data could help both structure new and use existing textbooks in a way more suited to learners' needs.

5 Summary

In this study, research on science textbooks supported by eye-tracking was reviewed. The number of studies has been rising. It is therefore possible to assume more information to guide a more effective textbook use as well as development will soon be available.

The results showed there are many areas in which ET is used in textbook analysis. Mostly, *distribution of attention between text and image* was investigated. The results showed there are many factors influencing participants' attention to the text or images. These were: motivation, level, or reading phase. Also, the analysed studies discussed the *textbook design*. Research showed different title or chapter elaboration influenced student work. With respect to the *platform* on which the textbook was presented, students seemed to prefer printed textbooks to the digital, except for IT students used to digital resources. To evaluate the use of an e-book, *usability research* was found. The review also revealed promising innovative *ways of analysis* using ET. This could be used e.g. in designing an "intelligent"/adaptive textbook.

In this study, novice researchers find an overview of the state of the art and can get a head start. A strong message is being delivered to the state offices responsible for textbooks – their development or quality evaluation: there is an emerging, rapidly developing method which could be a gamechanger in this field. It should be supported on a national level so there would be a research group able to assist textbook authors evaluate their new books. Naturally, there are more ways to produce modern textbooks, nevertheless, there has never been such an opportunity to tune textbooks to their users' needs.

The authors of this review are aware of several *limitations*. First, the lower sample of analysed papers included in this study. Review paper samples are usually greater, but a standard methodology was used which resulted with this number of relevant studies. Second, eye-tracking measurements of any other material but textbooks provide similar results as the studies' participants' eye-gaze is not textbook-specific. Nevertheless, as textbooks hold a unique role within education tools, and as they have the potential to be the key agent in the contemporary endeavours to put students in the centre of education by diminishing the teacher's role, well-designed, evidence-based textbooks need to be produced.

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