European Proceedings of
International Conference on Education & Educational Psychology
EpICEEPSY

www.europeanproceedings.com

e-ISSN: 2672-8141

DOI: 10.15405/epiceepsy.22123.15

ICEEPSY 2022
13th International Conference on Education and Educational Psychology

AN ANALYSIS OF GRAPHICAL REPRESENTATION OF DATA IN ELEMENTARY SCHOOL MATHEMATICS TEXTBOOKS

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Abstract

The paper aims to present the research on the frequency and prevalence of graphical representations of data in Czech elementary education mathematic textbooks. Textbooks were selected based on the presence of a note of approval granted by The Ministry of Education, Youth and Sports of the Czech Republic. Eighty-four textbooks (and workbooks where available) were analysed, with 2760 graphical representations of data identified. These representations were coded into seven types and 14 subtypes with a combination of apriori and emergent coding. Graphical representations of data are affluent in local mathematics textbooks. They follow logical routes of introduction, with pictorial unit graphics common in the early grades, taking the form of proto-graphs later. Bar graphs and pie graphs are the most common types of fully developed graphs identified in the source materials. The outputs will serve as a base for further study in the area, as the ways of building data visualisation literacy are not yet sufficiently explored and described in the local context of elementary education.

Keywords: Primary education, mathematics, data visualisation literacy, graphs, Czech Republic

https://doi.org/10.15405/epiceepsy.22123.15
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Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2672-8141

1. Introduction

Visual representations of data play a crucial role in our civic lives. Recent global covid-19 pandemics went hand-in-hand with a flood of visualised data, as the emergency asked for fast and reliable ways to report and communicate up-to-date numbers. The recent geopolitical situation in Europe is also unravelling during the times when the topic of disinformation gains its spotlight – and data visualisation can be misused to fuel disinformation and manipulate its readers (McNutt et al., 2021) while exploiting our inbuilt trust in data. In light of these events, we stress the need for data visualisation literacy (DVL). DVL is defined as "*the ability and skill to read and interpret visually represented data in and to extract information from data visualisation*" (Lee et al., 2017, p. 552; for more definitions, see Börner, 2019) and can be seen as a part of broader data literacy and an extension of more established visual literacy.

The need to develop the ability to interpret and generalise from data graphics has already been discussed for decades (see Curcio, 1987), and visual data comprehension is a long-standing topic in the education area (already discussed in Strickland, 1938). Still, a high portion of the population performs low on critical aspects of data visualisation literacy and has difficulties interpreting graphical representations of data in media or textbooks (Börner et al., 2016).

1.1. Problem Statement

While some attention already has been paid to the research and development of instructions for strengthening visualisation literacy among the adult public, the topic has not yet been addressed much in primary education. DVL in the context of primary education receives meagre attention and is currently dealt with by only a handful of researchers (e.g., Alper et al., 2017; Chevalier et al., 2018; Shreiner, 2020). Visual literacy shows no better treatment (as noted by Guo et al., 2018). Primary education is where the fundamentals of our data visualisation skills should be built. By the fourth grade, children should have all the knowledge and skills necessary for reading graphs (Curcio, 1987). However, we are not even sure how and in what forms data visualisations are present in our educational materials. Graphics are ubiquitous in textbooks (Fingeret, 2012; Roberts et al., 2013) and "*a lot is known about the impact of graphics on comprehension and learning. Despite this, very little is known about what types of graphics appear in these texts*" (Fingeret, 2012, p. 2) and this also applies to graphical representations of quantitative data.

Although some content analysis studies already focus on graphical data representations in elementary education textbooks (e.g., Alper et al., 2017; Fingeret, 2012; Shreiner, 2017), there are no studies conducted in the local context of Czech educational materials. Data visualisation literacy is not even a topic yet in Czechia, even though broader data literacy is currently a prominent theme amid recent curricular developments in the country. Currently, state standards in the Czech Republic mention data visualisation and the ability to interpret and create data graphics as an essential skill that should be developed (MŠMT, 2022), but they do not provide any guidance (same as reported for US standards by Shreiner, 2020).

The research presented here will constitute a first step in understanding the current state of primary-level DVL development in the local context of the Czech formal education system. It will serve as a base for further inquiry into the area. Our primary research questions for this analysis are as follows: what types

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of graphical representations of data are present in Czech elementary mathematics textbooks? How common are they? In what chronology do they familiarise students with visual representations of data? Furthermore, what terminology is used for data visualisation objects in these textbooks?

2. Research Methods

To answer these questions, we conducted a content analysis of primary education mathematics textbooks. The method was selected as a first step in deepening our understanding in this area because, as Coleman (2016) reported, teachers' most frequently used instructional practices while working with graphical representations (including data visualisations) were to point to or refer to graphical representations in textbooks. Textbooks are also regarded as materials with the highest influence on what happens in classrooms (Son & Diletti, 2017). This chapter will present the stages of our research in detail.

2.1. Selecting textbooks for analysis

We decided to analyse mathematics textbooks because "*certain aspects of visualisation literacy are taught as early as at elementary school, where children learn to read basic charts and graphs in mathematics and science classes*" (Alper et al., 2017, p. 5485). Furthermore, based on local state standards for elementary education and relevant curricular documents, mathematics is the area that should lead children to educational outcomes in data visualisation skills. Our focus was on the most neglected grades in terms of data visualisation research: grades 1 to 5 of elementary school.

We chose complete series of textbooks, together with workbooks where available. Only materials validated by *The Ministry of Education, Youth and Sports of the Czech Republic* (editions with a valid note of approval granted by the ministry at the time of the analysis) were selected and analysed. Five complete textbook series from four different publishers were also chosen based on our consultation with professional subject librarians, physical availability and local usage. Eighty-four textbooks and workbooks were analysed, with 5528 pages total (see Table 1).

Table 1. Selected textbook series with amounts of books by grade (G) and totals of pages per series

Textbook series	G1	G2	G3	G4	G5	**Total**	**Total of pages**
Matematika pro ZŠ *(DIDAKTIS)*	3	3	2	2	2	12	1044
Matematika se Čtyřlístkem *(FRAUS)*	2	3	3	3	3	14	998
Matýskova matematika *(Nová škola)*	5	6	6	6	6	29	1620
Matematika a její aplikace *(Prodos)*	3	3	3	3	3	15	945
Matematika dle prof. Hejného *(FRAUS)*	2	3	3	3	3	14	921
Total	15	18	17	17	17	84	5528

2.2. Defining graphical representations of data

Not all visuals used in textbooks are graphical representations of data. For our research, graphical representations of data are visual displays of quantitative information, e.g., any graphic that shows quantitive data and its visual variables are influenced by numerical inputs. These graphics could also be called *data-driven*, as used by Chevalier et al. (2018). Visual variables influenced by input data are a crucial

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part of the definition because data visualisation terminology is famously inconsistent. Different sources use the terms *chart*, *diagram*, *graph*, or *plot* quite freely, and the situation is the same in the Czech language: '*diagram*' and '*graf*' can be used interchangeably. Furthermore, '*graph'* (in Czech '*graf*') is a term from graph theory, making the terminological landscape even foggier. For different approaches to defining charts, graphs and data visualisations, see Friel et al. (2001).

This variety can be counterproductive when creating a classification of graphical data representations for the sake of content analysis: for example, Fingeret (2012) developed a class named *Graphs*, which contains pie, bar and line *graphs* together with a "*pyramid diagram*" (p. 29), which is traditionally used as a visual metaphor of a hierarchy and its visual variables are usually not directly influenced by quantitative data. On the other hand, a pyramid *chart* (sometimes referred to as a sorted two-way histogram) is a type where individual steps of the pyramid change their height or weight based on input data (see Harris, 1999). Discerning between those terms is often complicated and can lead to many confusions. This fact also led us to one of our research questions: while analysing the frequency and prevalence of different types of graphical representations of data, we also wanted to look into what terms are used to describe them.

During the analysis, we marked some graphics as '*fully-developed graphs'* – meaning they work as graphical devices as defined by Roberts et al. (2013): "*Graphical devices that illustrate the relationship between two or more variables using points, lines, or differentiated parts of a whole (e.g., pie graph, line graph, bar graph).*" (p. 17), i.e., they are fully developed statistical graphics with all the components that usually constitute it. This notation enables us to further differentiate between more advanced graphical representations of data and simpler data-driven graphics that may utilise the same visual variables while serving as proto-graphs.

2.3. Classification and rules for coding

First, a small and various exploratory sample of textbooks from selected series and grades was chosen, pre-analysed and validated with a fellow reviewer to clarify ambiguous items. Based on this pre-sample, the priori classification of visual data representations was created while being informed by existing classifications used in analysis up-to-now (esp. Alper et al., 2017; Burrows & Cooper, 1987; Shreiner, 2017) and while consulting the leading reference guides from the domain (mainly Harris, 1999). This classification created a base for our analysis with definitions and examples for each data graphic type. When a new type of graphical representation emerged later during the data collection, the classification was updated to encompass the complex reality of graphics used in Czech elementary mathematics textbooks and workbooks. Graphical representations of data were coded into seven main types, including a total of 14 specific subtypes (for a complete list of types and subtypes, see *Table 2*).

The rules were developed for coding. For every object, we noted its type, page, terminology, level of visual abstraction, and role. As noted in Burrows and Cooper (1987), both interpretation and construction of graphs are essential, and the necessity to focus on both is stressed. That is why we also decided to code the role of graphical data representations in textbooks. We noted where textbooks asked children to complete a graphic, such as drawing in a series of symbols to represent data or filling a part of an empty pie graph with colour. These visuals were listed as *constructional*. In cases where data graphics were used

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solely to present data for an exercise and were intended to be read rather than visually altered or completed, we labelled them *interpretative*. They were labelled as *presentational* when used in explanation sections (presenting the subject matter, not part of an exercise). The level of visual abstraction was adopted from Alper et al. (2017) and Burrows & Cooper (1987) and also noted during coding as well, i.e., whether the graphical object used pictures of real-life entities, illustrations or abstract shapes to represent numerical data.

3. Results and analysis

In total, 2760 graphical representations of data were logged during our analysis, together with their observed properties. Frequencies were calculated for all the types. Frequencies were then split by grades to analyse the prevalence of different types in different levels of primary education (*see Table 2*).

Table 2. Absolute frequencies of types and subtypes by grades (G) and relative frequency by all types

Types and *subtypes*	G1	G2	G3	G4	G5	**Total of types**	**% from all**
Pictorial units	635	353	177	116	48	1329	**48.15%**
Free-form pictographs	*331*	*122*	*26*	*29*	*9*	*517*	*18.73%*
Structured pictographs	*304*	*230*	*125*	*81*	*29*	*769*	*27.86%*
Abacus pictographs		*1*	*26*	*6*	*10*	*43*	*1.56%*
Numbered lines	111	150	193	98	124	676	**24.49%**
Regular numbered lines	*110*	*148*	*191*	*96*	*121*	*666*	*24.13%*
Thermometers	*1*	*2*	*2*	*2*	*3*	*10*	*0.36%*
Part-whole (PW) graphics	50	143	92	125	116	526	**19.06%**
Regular PW graphic	*50*	*132*	*38*	*45*	*58*	*323*	*11.70%*
Bar models		*1*	*18*	*9*	*9*	*37*	*1.34%*
Pie graphs		*10*	*36*	*71*	*49*	*166*	*6.01%*
Bar graphs	2	35	11	19	67	134	**4.86%**
Regular bar graph	*2*	*35*	*9*	*17*	*67*	*130*	*4.71%*
Histogram			*2*	*2*		*4*	*0.14%*
Line graphs		1	2	6	40	49	**1.78%**
Point graphs		1	4	9	31	45	**1.63%**
Dot plots		*1*		*1*	*8*	*10*	*0.36%*
Scatterplots			*4*	*8*	*23*	*35*	*1.27%*
Specific types		1				1	**0.04%**
Gauge graph		*1*				*1*	*0.04%*
Totals	798	684	479	373	426	2760	100.00%

3.1. Pictorial units

Pictorial units present data with pictographs, which can be unstructured (free-form pictographs, 18.73 % of all graphical representations of data), or they can be organised non-randomly (structured pictographs, 27 % of all graphical representations). There were 517 free-form pictographs (FP) in the

https://doi.org/10.15405/epiceepsy.22123.15
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sample, peaking in presence in G1 (64.02 % of all FP) and then gradually leaving the textbooks as grade progressed, with 23.60 % of all FP present in G2 and <2% in G5. In G1, free-form pictographs are the most salient type, with 41.48% of all the data graphics used in G1 textbooks and workbooks. Structured pictographs are common even in higher grades, peaking also in G1 (38.10 % of all representations in G1), but only slowly declining in presence till G4 (21.72 % of all G4 graphics). In Czech mathematics textbooks, we identified a particular type of illustrated structured pictograph that we traced separately: abacus, primarily used to visually represent place values when working with bigger numbers (thus peaking in presence in grade 3 (5.43 % of all G3 graphics).

3.2. Numbered lines

Numbered lines are a common simple way of visualising data, being steadily present through all five grades while being the most salient visual representation in G4 (40.29 % of all G4 representations). Most of the numbered lines are used in a constructional way (44.08 % of all numbered lines), followed by interpretative usage (32.10 %) – see *Table 3*. In our classification, we defined a specific subtype, *thermometer*, that is, in fact, an illustrated numbered line. This visual metaphor was present as a small number of cases (0.36 % of all graphics).

Table 3. Relative frequencies by roles for every type of graphical representation

Types	**Interpretation**	**Construction**	**Presentation**	**Total**
Bar graphs	47.76%	47.76%	4.48%	100.00%
Line graphs	53.06%	40.82%	6.12%	100.00%
Numbered lines	32.10%	44.08%	23.82%	100.00%
Part-whole graphics	41.25%	43.92%	14.83%	100.00%
Pictorial units	53.27%	33.48%	13.24%	100.00%
Point graphs	35.56%	53.33%	11.11%	100.00%
Specific types	0.00%	100.00%	0.00%	100.00%
Total	**45.22%**	**39.24%**	**15.54%**	**100.00%**

3.3. Part-whole graphics

There were 526 part-whole (PW) graphics in our sample. PW graphics can often be seen as a preparatory stage to understand more abstract and developed part-whole data visualisations (such as treemaps), with pie graphs being the most interesting sub-type here. Regular PW graphics (mostly rectangular data graphics; namely fraction diagrams and other part-whole items, such as area models and decimal area models) were the most common subtypes (*see Tab. 2*). Separately, we noted a specific type of PW graphic that was in the end quite rarely used in Czech textbooks: bar models (only 1.34 % of all graphics, peaking in G3 with 3.76 % of all graphics used in this grade).

There were 166 pie graphs in total, mainly used when presenting and practising fractions. First pie graphs are presented as early as G2, peaking in G4 (19.03 % of all data graphics in G4). Out of all pies, there were only 12.05 % of *fully-developed* pie graphs; 45 % of those were used interpretatively and 40 % in *constructional* exercises (where n_{pie} = 20). In analysed textbooks, pie graphs were addressed as *circular diagrams* or *circular graphs* (*'kruhový diagram* or *'kruhový graf'*, but never as *pie*, *'koláčový' in Czech*).

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3.4. Bar graphs

There were 134 bar graphs in our sample, including four histograms (i.e., particular type of joined column graph), classified as a subtype here with regard to Harris (1999). As the Czech language does not differentiate between *bar* graphs and *column* graphs, we were tracking them under the joined type of *regular bar graph*. Bar graphs are the second most prevalent subtype in G5 (with 15.73 % of all G5 data graphics scoring second after numbered lines in this grade). Out of 130 regular bar graphs, there were 125 *fully-developed* ones, of which 50.40 % were used constructionally. Even here, the words *'graf'* and *'diagram'* are used freely, with the attribute 'sloupcový' or 'sloupkový' (Czech variants of *bar*). Interesting was the use of *illustration* level of abstraction: pictorial proportional bar graphs (e.g., using differently sized trees in place of bars) were present in five cases. In three cases, these illustrated graphs were called *figural diagrams* (*'figurální diagramy'*). Two out of four recorded histogram cases were also called *'histogram'* in textbooks.

3.5. Line graphs

Line graphs are gradually introduced into the textbooks: we traced first line graphs as early as G2, but they are most prevalent in G5 (making 9.39 % of all G5 data graphics). All identified line graphs were *fully-developed* ones. 40.82 % of line graphs were used interpretatively, 53.06 % were used constructionally, and 6.12 % were used as part of explanation sections of textbooks. Same as with other types, words *'graf'* and *'diagram'* are used indiscriminately here, with attribution *'spojnicový'* used where specified (translated freely as with join line between two points). In two cases, the term *'grafikon'* was used as the graphical representation dealt with timetable data.

3.6. Point graphs

Point graphs are a specific type of data visualisation that utilises points (or dots) to visualise data. In this category, we classified dot plots (functionally similar to bar graphs, with the difference being the visual variable of position used instead of length) and scatterplots. Scatterplots are marginally present in our sample since G3, peaking in G5 (5.40 % of all G5 representations), where they are utilised to work with coordinates. They were never called *scatterplots* or *correlation diagrams* in our sample, same as dot plots – those were addressed solely as *'graf'* or *'diagram'*.

4. Discussion

Our analysis showed that various graphical representations of data are affluently present in Czech elementary mathematics textbooks and workbooks. Children in G5 can be already familiar with pie graphs, line graphs, bar graphs, point graphs, and in some cases, even specific subtypes such as histograms. As Coleman (2016) discovered, "*the most widely* [and frequently] *used types of graphical representations were bar graphs*" (p. 209). She was analysing teachers' reported overall use of graphical representations, and bar graphs were approached solely as fully-developed graphs, but we can agree that situation in our sample is similar: out of 228 fully-developed graphs of various types, there were 129 bar graphs (56.58 %).

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The introduction of different types of graphical representations follows the recommendation by Burrows and Cooper (1987). They state that representations should be established in logical sequence from simple to more complex, e.g., starting with simple pictorial units, then using structured pictographs and later moving to bar graphs and more developed graphs. Indeed, graphical representations follow a logical path in our sample, starting with free-form pictographs in early grades, then becoming more structured and fully developed later on. This logical sequence can be illustrated with bar graphs, where children are gradually prepared to understand them by structured pictographs, which are also common in Czech mathematics textbooks during early grades (as reported in *Chap. 3.1*). Terms used for fully-developed graphs are varied, as it reflects the messy reality of the field. There is no clear distinction between *'graf'* and *'diagram'* in the analysed textbooks, and we believe this lack of distinction is constrictive. However, that is not the fault of textbooks, as it is a known issue in our domain.

4.1. Further inquiry

The sole presence of a graph is essential in familiarising the children with such a visual form but building a robust DVL is a much more varied task. The critical part is the context and the process: we argue that data visualisation skills are useless without grasping the data literacy preceding it. Even from the point of view of a reader: when I do not understand the fabric of data behind the visuals and when I am not familiar with data collection and transformation processes and their limitations, I cannot ever fully assess and critically evaluate the graph I am looking at. This is even more apparent from the point of view of a creator.

The first step is to develop DVL in a real context – Shah and Hoeffner (2002) included in their implications for teaching graphical literacy skills the goal to teach them *in the context*, as teaching them abstractly may not make students able to apply them later in the real context of science (or any other context). In our sample, we found several cases where instructions utilised abstract data in graphs without any context (e.g., read *values* from a graph, draw in *values* into a graph), but the situation will have to be further analysed. In future studies, it will be beneficial to focus more closely on fully-developed graphs and their functions in textbook exercises, together with what type of data they are utilising and in what ways.

Curricular developments in the Czech republic's education system are an opportunity for interconnecting classes and fields, which means more opportunities for graphical representations of data in other fields than mathematics. In further studies, it will also be beneficial to broaden the analysis to textbooks in other elementary subjects, i.e., widen the scope into science and social studies textbooks, and compare the findings between disciplines.

Another step will be to analyse data-driven graphics as a part of a broader data literacy teaching process. There are examples in our sample that could be marked as interesting in terms of introducing children to data processes. One notable example is a pie graph used for a complex process of data collection, abstraction and data transformation. The task begins with making a timetable of a regular day in terms of picking the most salient regular activity for every hour. These activities are assigned colours and then filled into a stripe of paper divided into 24 squares (data can be grouped by activity), forming a stacked bar graph. The stripe is then glued into a paper loop, and a circle is drawn with the same diameter as the paper one. Marks on the circle are drawn based on the data on the paper loop. This way, the base for a pie chart is

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created, and a fully-developed graph can now be constructed by connecting marks on the circle with its centre point. The presented process includes data collection, transformation, and choosing a relevant visual metaphor to present the data. Further deeper qualitative content analysis of fully-developed graphs in textbooks would contribute to understanding how data literacy and connected DVL are developed in primary education. As Brugar and Roberts (2017) implies, the final goal is to find fruitful ways to guide teachers in cultivating visual literacy and data visualisation literacy in children effectively.

Acknowledgments

The presented results are a part of a specific project called Content analysis of textbooks for the first level of elementary school with a focus on the development of skills in visualisation literacy with financial support from the University of Hradec Králové.

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