Mapping the Landscape of Data Visualizations in Schools and Educational Resources

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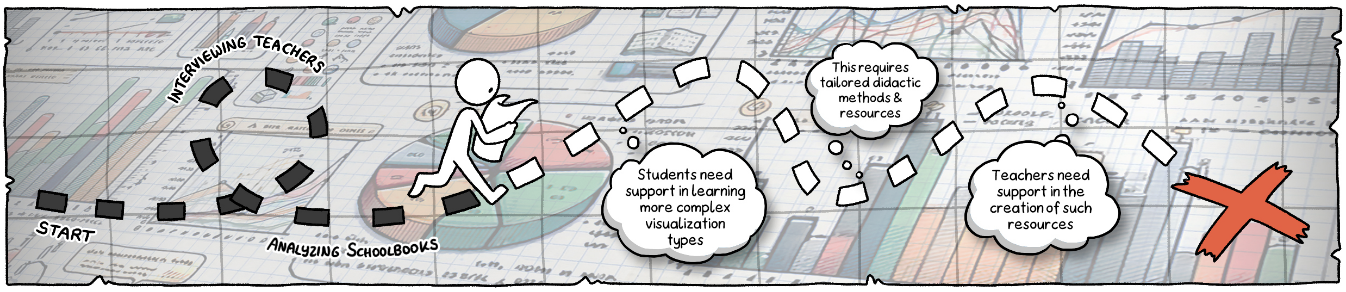

Figure 1: *The metaphorical voyage of this character mirrors the research aim of the work presented in this paper; mapping out the landscape of data visualizations in schools and educational resources. Future work lies ahead to uncover the full picture of visualization literacy in schools and explore implications on learning materials and methods to effectively teach visualization in schools.*

Abstract

This study explores the use of data visualizations in school education, examining how they are integrated into teaching practices and materials. By conducting semi-structured interviews with 15 teachers across Austria and Slovakia, coupled with a thorough classification of 5,655 data visualizations in 54 Austrian school textbooks, we gained insights into the landscape of visualization types used in educational settings. Despite the discovery of a wide array of visualization types, our analysis reveals a predominant reliance on simple business charts, highlighting a gap in the variety of methods and resources available for effectively teaching a wider range of visualizations. From our research, we derive lessons learned that pave the way for future development of educational methods and materials to enhance visualization literacy in schools.

CCS Concepts

• ***Computing methodologies*** → *Collision detection;* • ***Hardware*** → *Sensors and actuators; PCB design and layout;*

1. Introduction

In the past few decades, we have witnessed extraordinary growth in both the volume and the complexity of available data, the significance of which is increasingly evident in various domains such as industry, medicine, and science. However, developments in data collection and storage have largely outpaced our ability to effectively educate the public on skills required for comprehensive data analysis and informed decision-making [KL16]. This results in a low level of *visualization literacy* [BMBH16], which Boy et al. [BRBF14] describe as *"the ability to use well-established data visualizations to handle information in an effective, efficient, and confident manner"*. In a society heavily influenced by media, where information is often presented with intentional or unintentional biases, limited visualization literacy skills are a serious handicap preventing people from accessing valuable information necessary for critical thinking and making informed decisions.

Recognizing the urgency of education in this context, the European Commission has identified digital literacy as a key competence, devising a Digital Education Action Plan to support the adaptation of education in Member States [Eur21]. Additionally, many points in Austrian curricula of different subjects [Fed23] are specifically related to visualization literacy. For example, the curriculum of Algebra mentions *"analysis of graphical representations such as time-distance and time-space diagrams, temperature curves or*

DOI: 10.2312/eved.20241052

price indices over time; retrieving values, explaining changes in the data, detecting abnormalities; and representation of coherence based on tabular data". The Biology curriculum mentions *"representing and explaining processes and phenomena in various forms (table, graphic, diagram, ...) and communicating them appropriately to the target group"* (translated from German to English).

While some research does exist on visualization education in schools (e.g., [ARC*17, CRA*18, BBG19, BZP*20, NP16]), there is a lack of methods and concepts for learning materials that support students in learning and that effectively integrate interpreting and constructing visualizations in the educational framework of schools. Addressing this gap requires understanding the current landscape, i.e., the didactical methods employed and the types of visualizations currently encountered by students.

Therefore, our work followed the main research question ***RQ:*** *"How are data visualizations integrated into current teaching methods and existing educational resources in high schools?"* and explores two main aspects in the sub-questions: ***SQ1:*** *"Which materials and educational methods do school teachers currently use to teach data visualizations?"*, and ***SQ2:*** *"Which kinds of data visualizations appear in school books and are therefore likely to be encountered by students?"* Our contributions are an in-depth discussion of semi-structured interviews with 15 teachers of various subjects in middle and high schools in Austria and Slovakia (see Section 4) and a systematic analysis of data visualizations in 54 school books for high school grades (see Section 5).

Our research evaluates the present state of visualization literacy within educational settings, serving as important groundwork for future efforts in designing didactic approaches that enhance visualization literacy in schools, and subsequently, the general public.

2. Related Work & Background

Although the topic of visualization literacy has been identified as a future challenge by the Visual Analytics (VA) community (e.g., in [KKEM10, BBG19, GTS10]), it has not received much attention for a long time, with efforts only having increased in recent years [BBG19, BKR*24]. Previous research on teaching data visualization in schools includes a study from [BCK01], which examined how K12 (primary and secondary education) students interpret and generate data visualizations. More recent work by Alper et al. [ARC*17] has further explored current practices and challenges in teaching and learning data visualization in early education. They developed *C'est la Vis*, a tablet tool to teach and use pictographs and bar charts in early school grades. In the follow-up publication [CRA*18], researchers reflect on visualization literacy in early education and provide lessons learned and directions for future research. Börner et al. [BBG19] introduced a data visualization literacy framework developed to define, teach, and assess data visualization literacy. Recently, [BZP*20] developed a tablet-based tool called Construct-A-Vis, which supports elementary school children in creating visualizations based on free-form activities. The tool uses scaffolding [HC06] as a pedagogical method and integrates feedback mechanisms that show if the visual mapping was correct.

It should be noted that several of the aforementioned studies on visualization literacy in school settings ([ARC*17, BZP*20, CRA*18]) advocate for the incorporation of games or gamified approaches as effective pedagogical tools, hinting at a wider range of methods suitable for teaching data visualization. Huron et al. [HCBF16] also stress the effectiveness of hands-on and playful approaches to learning data visualization and provide interactive and tangible tools to foster a collaborative learning experience.

Another alternative teaching medium is comics, which has recently found its way into data visualization contexts [BRCP17]. Numerous studies have demonstrated the efficacy of comics in enhancing memorability and engagement for school subjects and science communication [Tru21, Far18], and current studies in the data visualization community highlight their potential for teaching visualization concepts in general [BBS*23, WDB19].

The abundance of diverse learning media supports the consensus among researchers that data visualization is best taught through interactive, hands-on methods. Such approaches, however, need to account for many different contexts of data visualizations, depending on the underlying data. Therefore, we also asked teachers about other learning media they incorporate into their teaching.

3. Methodology

We employed a mixed-method approach comprising qualitative and quantitative analysis [Cre99]. To explore the aspect **SQ1**, we conducted semi-structured, in-depth interviews with 15 teachers (9 Austrian and 6 Slovak teaching various subjects and in different school types). The interviews were conducted, recorded, and transcribed in accordance with data protection and ethical regulations, which all interviewees were informed of and gave their written consent. Following the interviews, we performed a qualitative content analysis [Sch12], which we report on in Section 4.4.

Based on the aspects of the interviews, we selected a set of official school books, which we systematically analyzed to answer **SQ2** [MF19]. We examined every page of the school books, counted and documented every instance of data visualizations, and classified them based on metrics described in Section 5.1.

4. Semi-structured Interviews with Teachers

The main aims of the semi-structured interviews were to understand to what extent teachers use data visualizations in their lessons, in which contexts they encounter them, and to obtain a holistic overview of the materials they currently use in their classes.

4.1. Study Design & Procedure

We structured our interview guide as follows: The first part covered an introduction in which we briefly explained the purpose of the interview and collected demographic data. Next, we asked interviewees to explain "data visualization" in their own words to ensure a common wording and definition of the term. The second part of the interview identified general teaching materials and didactic methods (beyond just the topic of visualization) they currently use. In the third part, we concentrated on investigating teachers' expectations and needs regarding the application of alternative learning media, such as comics, storytelling, and games. In the fourth part, we collected which topics within the interviewees' taught subject(s) already contained or would benefit from data visualizations. Lastly, we asked participants to report on the tools and methods they might need to teach these topics mentioned above. All interviews were held online using Microsoft Teams and lasted 38 minutes on average. There were three interviewers in total; two interviewers for each of the nine sessions with Austrian teachers, and one for each of the six sessions with Slovak teachers. The interviews were recorded, fully transcribed and merged with the interviewers' notes before proceeding with the analysis.

4.2. Participants

We aimed to select teachers from a broad demographic sample regarding age, educational background, and teaching experience, spanning both general education and technical high schools. We made use of our network of partner schools of the research project to identify and approach teachers for the interviews. In total, 15 teachers, nine from Austria and six from Slovakia participated in the interviews. Ten identified as female and five as male, their age ranged from 22 to 60 years (Mean: 42.7, SD: 13.6), and their teaching experience from 1 to 47 years (Mean: 12.7, SD: 13.5, Median: 8.5) in the subjects Informatics, Mathematics, Physics, Geography, Chemistry, History, Biology, Languages (German, Slovak, Russian, Latin), Music, and Psychology.

4.3. Data Analysis

To systematically answer SQ1, we analyzed the interviews using the method of qualitative content analysis [Sch12]. This approach involved creating a category system, which we then used to process and evaluate the transcripts. The category system consisted of 11 main categories and 17 subcategories, which we extracted from the answers from the interviewees [MF19]. The full categorization is available in our supplementary material (last accessed: Apr 15, 2024). After a pilot test, we refined the category system and used the finalized version to code the interviews and find patterns.

- **C1 – Term definition and interpretation:** Teachers' understanding of the term "data visualization"
- **C2 – Visualizations in subjects:** In which subjects do data visualizations occur (C2.1 - C2.14: Biology, Chemistry, Mathematics, Physics, Russian, Informatics, Latin, History, Electrical Engineering, Geography, German, Music, Psychology, Slovak).
- **C3 – Types of visualizations** Specific visualization types that are used in teaching.
- **C4 – Used textbooks:** Textbooks including name and ISBN (subcategory C4.1 - Textbook ID).
- **C5 – Types of learning materials** Other learning materials and/or tools used to teach content with visualizations, for example, YouTube videos, school books, and online resources.
- **C6 – Expected type of engagement with visualizations:** Since we expected less granular visualization learning goals at this level of education, we decided to broadly categorize the types of tasks into interpreting and constructing, simplifying the categorizations used for higher visualization education (e.g., [AL21]).
- **C7 – Didactic methods:** Which didactic methods are applied to convey data visualization knowledge to students?
- **C8 – Educational games in teaching**: Teachers' stance on incorporating games and gamified strategies, and whether they integrate them as supplementary elements to other techniques or as a primary instructional approach for certain topics.
- **C9 – Storytelling (e.g., comics) in teaching:** Similar to C8.
- **C10 – Topics taught using visualizations:** Exploring potential topics that could benefit from incorporating visualizations.
- **C11 – Additional ideas and comments.**

4.4. Results

The participants generally interpreted the term "data visualization" **(C1)** as "visual depiction of information". Their understanding spanned from conventional graphs and diagrams that simplify extensive data sets to more advanced visual representations such as animations, videos, slideshows, and even tangible objects.

Subjects: The utilization of data visualizations **(C2)** varied across subjects. Mathematics, Physics, Geography, Informatics, and Biology showed a higher reliance on data visualizations to exemplify learning content, which is not surprising given the nature of the subjects. Nevertheless, teachers reported varying degrees of data visualization usage. Some primarily utilized basic diagrams like bar charts, while others also emphasized their dependence on visualizations for simplifying complex concepts. For example, a Biology teacher highlighted the additional value visualizations bring when explaining body structures, reproduction cycles, or other complex processes. Physics also exhibited diverse visualizations, from representations of mechanical processes to graphs depicting time-dependent signals. Geography teachers reported using maps and statistical diagrams, and Mathematics teachers also repeatedly highlighted the importance of visualizations for statistical data and mathematical functions. In contrast, subjects like History, Latin, German, Slovak, Music, and Psychology showed a rather low use of data visualizations. History teachers reported that diagrams and tables do appear in textbooks, although they are less integral to the content than in other subjects. In Music, one teacher noted that sometimes a series of illustrations is used to "visualize" music (e.g., an image of a thunderstorm would represent a loud drum beat); however, this does not strictly fall under data visualization. Two teachers of the subjects with lower use of data visualizations remarked that they acknowledged their importance but mentioned a lack of relevance and time constraints in the curriculum.

Type of Visualization: Concerning category **C3**, "type of visualizations" distinct patterns emerged in the data visualizations employed in interviewees' teaching methodologies. The most frequently mentioned types of visualizations included Line Graphs, Bar Charts, Pie Charts, and Scatterplots. These were used across multiple subjects, although the application varied depending on the topic and nature of the data used. All Mathematics teachers mentioned subject-specific visualizations like Function Graphs, while Concept- and Mind Maps stood out in Humanities courses.

Types of Teaching Materials: Responding to category **C4**, "types of textbooks", teachers mentioned that subject-specific textbooks, such as Mathematics or Biology, do contain data visualizations. Such textbooks are the main resource for teachers due to the integration of a wide variety of visual learning aids. Teachers of lan-

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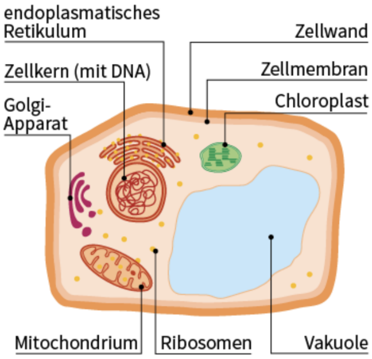

Figure 2: *An example of an Illustration Diagram, labeling parts of a plant cell. Note that in some Austrian high schools, "natural sciences" subjects share a single textbook, explaining its inclusion in our "physics" book list. © Hölzel Verlag. Used with permission.*

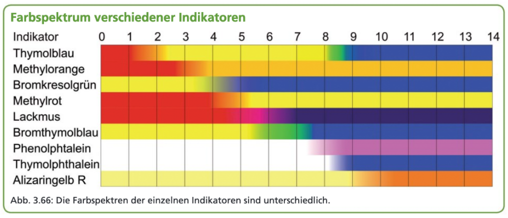

Figure 3: *Example of a visualization we classified as "Other", as it does not fit into any category in the DataVis Catalogue [Rib20]. It shows the colors different chemical indicators assume at different pH values. © Hölzel Verlag. Used with permission.*

guages also agreed that textbooks are their main educational resource, even though visualizations are not very common in their subjects. For the subject of Informatics, however, teachers reported that they exclusively use online learning materials instead of traditional textbooks. Teachers were also asked about additional learning materials and/or tools they use regarding visualizations (**C5**). Additional textbooks (13 mentions) and printed materials (5) with visualizations were commonly mentioned. Digital materials were quite prevalent, such as PowerPoint presentations (4) or additional online tools, specifically LEIFIPhysik [SU24] (1), PhET Interactive Simulations [Oli24] (1), Kahoot! (1), Leto (1), and GeoGebra [Geo24] (5) were mentioned. One teacher also mentioned that they used the online shared workspace tool Trello (1) to create burndown charts. Five teachers noted that they prefer easy-to-use and intuitive tools that facilitate quick understanding. Other software for specific subjects that were mentioned were Desmos [PBC24] and Tracker [DWR24] for Physics (1), the MS Office Package (4), or Excel (3) for Informatics and Mathematics.

Types of Engagement with Visualizations: Responses on students' engagement with visualizations (i.e., the tasks associated with them; such as just interpreting or also constructing their own visualizations, **C6**) showed that both interpretation and construction of visualizations are common learning activities. Many teachers (10 out of 15) noted that their students have to do both. Some mentioned specific activities that highlighted interpretation (3), and a few teachers emphasized that their students did not have to create visualizations yet (2). One teacher stated that younger students only interpret visualizations, while older ones also have to construct their own. Two teachers mentioned that visualization construction is mainly done with tools like GeoGebra or Excel.

Didactic Methods: Regarding didactic methods employed for teaching data visualization topics (C7), various techniques were mentioned. Practical and interactive approaches were especially emphasized. Teachers frequently mentioned adopting a blended approach (10 out of 15), consisting of traditional lecturing, group activities, class discussions, and individual tasks. Especially group work (5) and class discussions (4) were recurring themes, with the latter often centered around contemporary events such as election outcomes or COVID-19 statistics. Some teachers mentioned individual assignments (4) where students have to generate statistics based on personal interests. They underscored that the active involvement of students in data collection was an integral aspect of the learning experience. Additionally, the use of multimedia elements such as videos, animations, and games was also mentioned (3), suggesting a broader spectrum of interactive teaching tools.

Educational Games: Based on the teachers' responses, the integration of educational games as a pedagogical tool (**C8**) stands out as a promising approach. A majority of teachers (15) either expressed their willingness to, or were already incorporating educational games into their teaching. However, the extent and regularity of implementation varied. Some respondents (5) only cited sporadic use due to logistical constraints. The inclusion of games appeared to be more prevalent among younger students and for less complex subjects. Educators stated (11) that they used gamified approaches mainly as a bonus to traditional teaching techniques. However, two teachers mentioned that games could be the main instruction method for certain topics. Additionally, two respondents highlighted potential challenges, such as designing games tailored to high-school curricula or addressing occasional student reluctance to participate. Overall, factors like topic complexity, student age, and individual educators' comfort and enthusiasm for gamified learning influence whether they use such teaching methods.

Comics: The question of using comics or storytelling in teaching (**C9**) evoked a range of responses from the interviewees. Many teachers (8) reported having previously used storytelling or comics in their classes or having displayed a willingness to explore these approaches. These teachers mentioned using comics as a tool for students to engage with and present content and that this approach was valuable in making the theory-practice connection stronger. Seven educators indicated that they had not used such methods yet, and one teacher expressed skepticism, noting concerns that their teenage students might perceive it as "uncool" from an older teacher. Five teachers also mentioned the difficulties of envisioning using this method for complex subjects such as Mathematics and Informatics. Like educational games, comics, and storytelling were mostly cited as complements to traditional teaching methods.

Further Topics: When asked about other topics that could benefit from the introduction or increased use of visualizations (**C10**), one teacher highlighted the potential in helping to understand com-

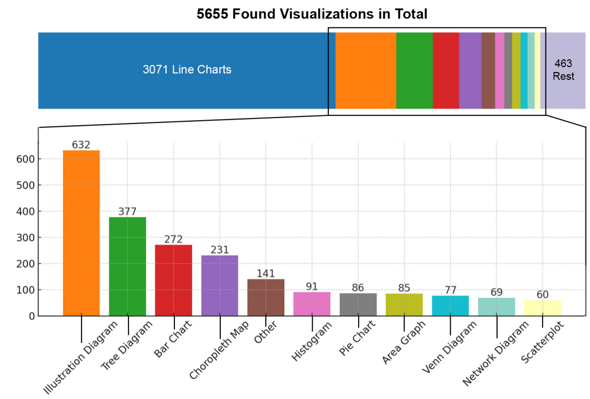

Figure 4: *This chart shows how often different types of visualizations were found across all school books. Note that it excludes Line Graphs, which were the most common type of visualization (3071 instances), and 33 rarer types (463 instances) each accounting for less than 1% of all visualizations, to preserve readability.*

plex concepts in Chemistry. Others suggested that visualizations could prove valuable in supporting high school students during the writing of their mandatory high school research papers, aiding in organizing thoughts or the structure of their work, and creating more convincing arguments. A geography teacher named global processes as a topic that would profit from more data visualizations, such as migration and trade flows. Mathematics teachers (4) identified numerous opportunities for visualizations in their subject, specifically citing function plotting, geometry, probability calculations, and descriptive geometry. One teacher mentioned that nearly every topic in Physics would benefit from visualizations. Three educators expressed similar views on Biology and Informatics, although one noted possible impediments because of differences in students' abilities to interpret visualizations.

Additional ideas, Expectations, and General Comments: In the final category (**C11**), interviewees shared additional ideas, expectations, or general comments. Teachers expressed various desires, including the need for "user-friendly" applications that enable students to create their visualizations easily (2). They also emphasized the importance of pre-made visual teaching materials that alleviate long preparation times (3) and proposed the development of lesson templates that incorporate visualization techniques (1). Additionally, some teachers (3) highlighted the significance of resource accessibility, expressing the need for improved technical facilities in the classroom. They mentioned using mobile phones inside and outside of the class, given their widespread ownership among students. However, the challenge of offline accessibility was also acknowledged, as not every student has consistent internet access. Furthermore, some educators (3) expressed a desire for teaching resources to be more student-friendly and comprehensive and suggested that incorporating visuals or playful methods like games could enhance students' engagement and understanding.

Summary of Main Insights:

1. **Varying Degrees of Application in Different Subjects (C2)**: The use of data visualizations varied considerably between subjects. Mathematics, Physics, Geography, Informatics, and Biology had a higher tendency to include data visualization topics, due to the inherent characteristics of their content. In contrast, subjects like History, Languages, Music, and Psychology showed lower to moderate utilization of data visualizations.
2. **Prevalence of Standard Business Charts (C3)**: Visualization types mentioned by teachers included Line Graphs, Bar Charts, and Pie Charts, but some also mentioned Scatterplots.
3. **Books and Materials Used (C4 & C5)**: Teachers primarily rely on textbooks that sometimes contain data visualizations, and complement them with a variety of digital tools and materials. However, Informatics teachers reported that they hardly used textbooks and instead relied on digital tools such as PowerPoint, GeoGebra [Geo24], and online platforms. Consequently, the next step of our analysis involved evaluating occurrences of data visualizations within existing school textbooks.
4. **Types of Engagement (C6):** Both interpretation and construction of data visualizations play a role in class. The latter is mainly achieved in tools like GeoGebra and Excel.
5. **Diverse Didactic Methods (C7)**: Teachers employ various teaching methods, combining traditional lecturing with group work, class discussions, and individual tasks.
6. **Openness to Alternative Didactic Methods (C8, C9)**: The use of educational games as a pedagogical tool was considered promising, with many teachers already using or expressing openness to use games in teaching, especially with younger students. Some teachers use storytelling or comics to strengthen theory-practice connections, while others find their application challenging, especially in subjects like Mathematics.

5. School Book Analysis

To address sub-question **SQ2**: "Which kinds of data visualizations appear in school books and are therefore likely to be encountered by students?", we carried out a systematic analysis of school textbooks (see Section 3). In the preceding interviews, STEM subjects and Geography emerged as the main subjects which frequently emoployed data visualizations. Consequently, we directed our analysis towards textbooks within these subjects. We also combed through the latest (2023) version of the Austrian school curriculum [Fed23] to compile a list of explicitly mentioned visualization types and found the following: Line Graph, Bar Chart, 100% Stacked Bar Chart, Pie Chart, Histogram, Scatterplot, Boxplot, Pictogram Chart, Tree Graph, and "Maps and map-related depictions". Consequently, we anticipated to encounter these specific visualization types more frequently in textbooks as well.

5.1. Method

Initially, we asked the Austrian Ministry of Education for a list of the most widely used school books in our selected subjects. However, we were informed that such statistics do not exist, as each school independently determines its book selection. Therefore, we contacted major school book publishers in Austria to gather a comprehensive selection of school books on the aforementioned subjects. We obtained 54 school books (29 mathematics, 14 physics, three informatics, and eight geography), which were designed for students in Austrian school grades nine and above, spanning ages

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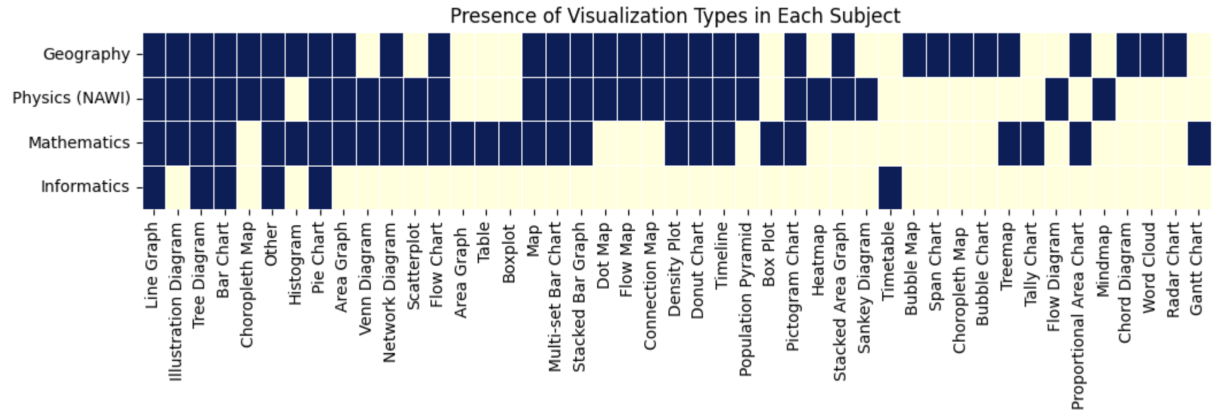

Figure 5: *This binary heat map shows which types of visualizations appeared in books on different subjects. Geography had the highest variety of types (32 types in 8 books, entropy H = 2.6), followed by Physics (28 in 14 books, H = 1.67) and Mathematics (28 in 29 books, H = 1.05), then Informatics (6 in 8 books, H = 1.55). The columns are ordered by how often a visualization type appears in the dataset.*

14 to 19. For an exact list of books, please refer to our supplementary material. Although our interviews with teachers included educators from Slovakia, we were unable to acquire Slovak school books as no publisher responded to our requests.

We examined every page of the acquired books, counting and documenting every instance of data visualizations and systematically classifying them based on the following metrics:

- **Type of Visualization** – The type of visualization according to the Data Visualization Catalogue [Rib20], which lists 60 types of graphs, diagrams, tables, maps, and other visualizations. This was the most important aspect to determine the variety of visualizations students are likely familiar with.
- **Scale** – Whether the data is *qualitative* or *quantitative*, which goes hand in hand with the visualization type.
- **Number of Variables** – *Univariate* or *multivariate* data.
- **Frame of Reference** – Whether the data is *temporal* [AMST23], *spatial* [AA06], or *spatio-temporal* [AA06]. We classified all other miscellaneous data as "*abstract*" [AMST23].
- **Dimensionality** – Whether the visualization is drawn *2D* or *3D*. Expecting mostly 2D, we were interested if we could also find visualizations whose complexity required 3D representation.
- **Expected Type of Engagement** – What kind of engagement the context of the visualization affords: Do students merely have to *interpret* the visualization, do they have to *construct* (a part of) the visualization themselves, or is it used in an *onboarding* or tutorial context, where the exact anatomy and use cases of the visualization technique are explained? We chose this metric to understand the importance attributed to the use of data visualizations in the books.

Overall, five researchers were responsible for the school book reviews, with two of them assuming the role of primary reviewers aiming to maintain the consistency of our metric application. All identified instances of data visualizations were recorded in a shared Google spreadsheet, and any instances where reviewers encountered uncertainties in the classification were separately documented on individual lists. These lists were discussed during regular meetings to achieve a unified approach to the classification.

5.2. Results of the Book Analysis

Across all school books, we identified 5,655 visualizations, with 5,192 representing types that make up at least 1% of the total. Figures 4 and 5 show an overview of the amounts and distributions of found visualizations.

Type of Visualization – We found 45 different types across all books. The predominant type was *line graphs*, which accounted for 3,071 of all 5,655 visualizations (54.3%). This high number results from the fact that graphical representations of functions in coordinate systems are a recurring topic, with many examples in math books. Physics books also feature many diagrams that illustrate the relationship between distance, time, velocity, and acceleration. However, 2,795 (91.01%) of all found line graphs can be attributed to math books alone. The second most common type of visualization we identified was *illustration diagrams* (see Figure 2), which make up 11.2% of all visualizations. Even though illustration diagrams are not strictly considered *data* visualizations, they are a distinct category in the Data Visualization Catalogue [Rib20], which is why we included them in our analysis. *Tree diagrams* closely follow with 6.7%, and some other significant visualization types include *Bar Charts* (4.8%), *Choropleth Maps* (4.1%), *Histograms* (1.6%), *Pie Charts* (1.5%) and *Area Graphs* (1.5%), *Venn Diagrams* (1.4%), *Network Diagrams* (1.2%), and *Scatterplots* (1.1%). All other found types of visualizations were either types that are not listed in the Data Visualization Catalogue [Rib20] (see Figure 3) or hybrid forms (e.g., a Choropleth Map annotating regions with Bar Charts), both of which we classified as *Other* (2.5%). A visualization of these numbers can be seen in Figure 4. The remaining visualizations each accounted for less than 1% of the dataset (some examples include Flow Charts, Area Graphs, or Boxplots, which all appeared less than 50 times). Generally, our analysis revealed a broad variety of visualization types, although the degrees of variety differ across subjects. Interestingly, Geography showed the highest diversity (see Figure 5), which is likely attributed to the wide range of topics that belong to the subject, such as landscapes and climate, economy and politics, and the prevalence of spatial data in general. For detailed metrics, please see our supplementary material.

Scale – In terms of qualitative vs. quantitative data, our results show that 70.9% of found visualizations represent quantitative data, 28.6% qualitative data, and 0.5% both.

Number of Variables – Most visualizations showed multivariate data (78%), while univariate data are less common (22%).

Frame of Reference – Most of the data behind the visualizations found were abstract (82%). 9.2% were temporal, 7.7% spatial, and 1.1% spatio-temporal. It should be noted that we decided to classify all visualizations of mathematical functions (i.e., line graphs without any "data" per se) as abstract, although some of them were accompanied by an introductory text such as "The function $B(t) = 210 \cdot 1,12^t$ describes the growth of a bacteria culture.", which would technically suggest a temporal frame of reference.

Dimensionality – Almost all visualizations found were 2D (99.6%). Since 3D visualizations presuppose more complex underlying data and interpretation possibilities are rather limited in printed form, this result was to be expected.

Expected Type of Engagement – The main purpose of most of the visualizations in the school books was for the students to read and interpret them (68.8%). They often illustrated facts presented in accompanying text but sometimes required students to perform interpretation tasks such as identifying trends, locating points of interest, or recognizing patterns. Exercises prompting students to complete partially finished visualizations or construct them from the ground up, using data tables or given functions as a basis, were less common (9.32%). Instances where visualizations were explicitly explained ("onboarding") were the least common (0.9%). Among the types of visualizations that received such distinctive attention were line graphs, bar charts, network diagrams, and, interestingly, scatterplots, boxplots, and flow charts, despite constituting less than 1% of all found visualizations overall. Looking at individual subjects, Physics and Geography mainly used visualizations for illustrative purposes or for students to interpret data, while Mathematics and Informatics had more exercises where students were expected to construct or complete visualizations themselves (see Figure 6). In the case of Mathematics, however, the number of instances where students were required to construct graphs might be even greater, as we only scanned the text around visualization figures during our analysis instead of reading every page in detail. While we reviewed exercise solution sections, which would have unveiled construction tasks hidden in purely text-based instructions, there remains the possibility that some were overlooked.

6. Discussion, Limitations, and Lessons Learned

The semi-structured interview and the systematic analysis of school books revealed some insights into the landscape of teaching data visualizations in schools. In the following, we answer the research questions raised in Section 1.

RQ: "How are data visualizations integrated into current teaching methods and existing educational resources in high schools?" Both interpretation and construction are recognized as vital aspects of teaching visualization-related aspects in schools. This was visible in the official curriculum [Fed23], strongly echoed by teachers during the interviews (see Section 4), and further evidenced in the results of our analysis of the school books (see Section 5). However, more emphasis is attributed to the interpretation of data visualizations. This observation aligns with the existing research on data visualization education, where established models such as Bloom's Taxonomy frequently serve as foundational frameworks for course design [AL21]. Within these models, learning objectives regarding interpretation constitute fundamental knowledge and provide the groundwork for any learning objectives related to construction. Consequently, the dominance of interpretation tasks we saw in our studies is understandable, especially given that students at this level are still in the process of grasping the fundamental concepts of data visualization.

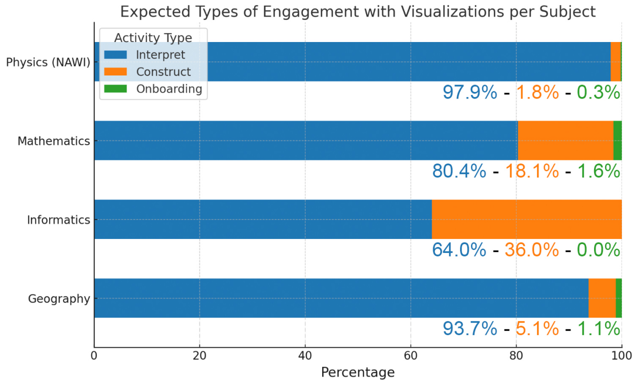

Figure 6: *The ratio of how many visualizations within each subject were expected to be interpreted (blue), constructed (orange), or received dedicated explanations on the visualization technique, similar to an onboarding (green).*

SQ1: "Which materials and educational methods do school teachers currently use to teach data visualizations?" Teachers use a variety of materials and methods in their classes. Subject-specific textbooks form the common ground, but they are generally augmented through digital materials and online tools which cater to more individual teaching goals. While, for example, language and music teachers acknowledged the importance of data visualizations for skills such as scientific writing and digital literacy, they only serve a minor function in their own subjects, whereas they play a more significant role in STEM subjects and Geography. Another insight of our study is that both our interviews and the availability of school books for the subject in general revealed that Informatics hardly uses textbooks and instead exclusively relies on digital tools and individual resources, suggesting a high potential for alternative didactic methods to teach data visualization knowledge. Our interviewed teachers also expressed their positive experiences with using alternative didactic methods like playful approaches or primarily visual media like comics, to support younger students and strengthen theory-practice connections (see Section 4.4). Recent studies have shown that playful methods take advantage of the

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inherent nature of play, which is characterized by curiosity, motivation [dKVSvDvG14], experimentation, and enjoyment [IGL*13]. In a previous workshop where middle school students constructed visualizations using LEGO® and plastic tokens, we also saw that such playful methods lead to more sophisticated and creative visual encodings [KSB*23]. Therefore, educators should create an environment that encourages students to explore, manipulate, and create visual representations by introducing playful or more alternative elements into visualization education. Further research may focus on developing such innovative methods by using serious games or comics to improve the visualization literacy of students.

SQ2: "Which kinds of data visualizations appear in school books and are therefore likely to be encountered by students?" Generally, there is a wide variety of visualization types, although the frequency and focus are less balanced. Although slightly more complex visualizations such as Scatterplots and Boxplots are explicitly mentioned in school curricula and receive special attention in the form of dedicated explanation chapters in textbooks, for example, they are overshadowed by the overwhelming presence of more straightforward business charts like Line Graphs and Bar Charts as well as Tree Diagrams (see Figure 4).

In their research on the development of the VLAT-Test, Lee et al. [LKK17] explored the types of visualizations present in K-12 curricula, data visualization authoring tools, and news outlets. Our findings regarding school curricula align with their research, with our list of visualization types expanding to include Pictogram Charts, Tree Graphs, and "various maps". In news outlets, Lee et al. [LKK17] identified the frequent use of simple business charts such as Line Graphs, Bar Charts, but also saw frequent use of Choropleth Maps and Bubble Charts. Comparing these with our analysis suggests that school education covers many types of visualization encountered in everyday life. The only exception between both studies are Bubble Charts, of which we found only four instances (0.007%) in our analysis.

In contrast, interviews conducted with journalists revealed their desire to employ more complex charts to convey detailed data insights. However, they often refrain from doing so, as they fear that such complex visualizations might not be understood by their general audience [SRG*23]. Similarly, other studies have highlighted that the limited visualization literacy of the public when it comes to reading and interpreting visualizations beyond simple charts is a hindrance when conveying data to the public, e.g., in museums [BMBH16]. Our analysis results also reflect this lack of exposure to more complex visualizations during the average school education. For instance, network visualizations (excluding tree graphs) remain largely absent from the curriculum. As a result, people tend to encounter and attempt to comprehend much more complex visualizations later in life, often leading to difficulties in understanding and interpretation [ASSB*22]. However, this absence is likely attributed to the fact that advanced visualizations are mostly used for very specific contexts and unique characteristics, which makes their integration into general education challenging.

Limitations: A limitation of this study is its geographical scope, as our analysis was restricted to Austrian school textbooks because its encompassing research project was based in Austria and focused on its educational landscape. While connections with an international colleague allowed us to include Slovak teachers to expand our perspective, our findings may not be fully generalizable to international contexts.

7. Conclusion & Future work

In this paper, we present the results of interviews with 15 teachers and an extensive analysis of 54 school textbooks, classifying 5,655 instances of data visualizations. Our study revealed a predominance of Line Graphs, with other common visualizations including Illustration Diagrams, Tree Diagrams, Bar Charts, and Choropleth Maps. Although more complex visualization types like Scatterplots and Boxplots are granted dedicated explanation sections in school books, they still receive less emphasis compared to simpler types. Generally, our analysis showed that students encounter a broad spectrum of data visualization types throughout their education, contrasting with the generally low level of visualization literacy observed in the general public, possibly because only a select few are given explicit focus in school.

Therefore, we derive several **lessons learned** that inform the design of future educational materials aimed at enhancing visualization literacy: **(1)** Students need support in learning **more complex visualization types** beyond the standard business charts. To enhance visualization literacy, more active focus needs to be put on the variety of data visualization types, as well as their explanation and onboarding techniques. **(2)** This requires **tailored didactic methods** and resources. Teachers have reported positive experiences with playful and alternative didactic methods, such as **serious games** and **comics**; not only in practical construction tasks but also to facilitate a more hands-on, memorable way of grasping the theory. However, they note the significant lack of time to prepare such content. **(3)** Hence, there is also a clear need to support teachers in the **creation of such resources** or facilitate access, potentially through the use of customizable templates.

Similar to the character charting a course through the landscape of teaching data visualization in Figure 1, future research needs to assess the actual level of students' visualization literacy and explore possible differences between countries. This knowledge and our current findings will serve as a robust foundation for developing effective didactic materials and methods. Such efforts are essential for effectively teaching data visualization in schools and contributing to enhancing visualization skills among the general public.

Acknowledgments

We want to thank the publishers *Trauner Verlag + Buchservice GmbH* and *Österreichischer Bundesverlag Schulbuch GmbH & Co. KG* for providing us with copies of their school books free of charge. We would also like to thank the teachers for participating in our interviews. This work was funded by the Austrian Science Fund (I 5622-N) and Czech Science Foundation (No. 22-06357L) as part of the Vis4Schools project and by the GFF NÖ as part of the dissertation project VisToon (SC20 - 014). For the purpose of open access, the author has applied a CC BY public copyright license to any Author Accepted Manuscript version arising from this submission.

References

[AA06] ANDRIENKO N., ANDRIENKO G.: *Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach*. Springer, 2006. doi:10.1007/3-540-31190-4. 6

[AL21] ADAR E., LEE E.: Communicative Visualizations as a Learning Problem. *IEEE TVCG 27*, 2 (2021). doi:10.1109/TVCG.2020.3030375. 3, 7

[AMST23] AIGNER W., MIKSCH S., SCHUMANN H., TOMINSKI C.: *Visualization of Time-Oriented Data*. Human–Computer Interaction Series. Springer, 2023. doi:10.1007/978-1-4471-7527-8. 6

[ARC*17] ALPER B., RICHE N. H., CHEVALIER F., BOY J., SEZGIN M.: Visualization literacy at elementary school. In *Proc. of CHI* (2017), ACM. doi:10.1145/3025453.3025877. 2

[ASSB*22] ALKADI M., SERRANO V., SCOTT-BROWN J., PLAISANT C., FEKETE J.-D., HINRICHS U., BACH B.: Understanding barriers to network exploration with visualization: A report from the trenches. *IEEE TVCG* (2022). doi:10.1109/TVCG.2022.3209487. 8

[BBG19] BÖRNER K., BUECKLE A., GINDA M.: Data visualization literacy: Definitions, conceptual frameworks, exercises, and assessments. *Proc. of the National Academy of Sciences 116*, 6 (2019). doi:10.1073/pnas.1807180116. 2

[BBS*23] BOUCHER M., BACH B., STOIBER C., WANG Z., AIGNER W.: Educational Data Comics: What can Comics do for Education in Visualization? In *2023 IEEE VIS EduVis Workshop* (2023), IEEE. doi:10.1109/EduVis60792.2023.00012. 2

[BCK01] BAKER R. S., COREBETT A. T., KOEDINGER K. R.: Toward a model of learning data representations. *Proc. of CogSci 23*, 23 (2001). doi:10.1184/R1/6470567.v1. 2

[BKR*24] BACH B., KECK M., RAJABIYAZDI F., LOSEV T., MEIRELLES I., DYKES J., LARAMEE R. S., ALKADI M., STOIBER C., HURON S., PERIN C., MORAIS L., AIGNER W., KOSMINSKY D., BOUCHER M., KNUDSEN S., MANATAKI A., AERTS J., HINRICHS U., ROBERTS J. C., CARPENDALE S.: Challenges and opportunities in data visualization education: A call to action. *IEEE TVCG 30*, 01 (2024). doi:10.1109/TVCG.2023.3327378. 2

[BMBH16] BÖRNER K., MALTESE A., BALLIET R. N., HEIMLICH J.: Investigating aspects of data visualization literacy using 20 information visualizations and 273 science museum visitors. *Information Visualization 15*, 3 (2016). doi:10.1177/1473871615594652. 1, 8

[BRBF14] BOY J., RENSINK R. A., BERTINI E., FEKETE J. D.: A principled way of assessing visualization literacy. *IEEE TVCG 20*, 12 (2014). doi:10.1109/TVCG.2014.2346984. 1

[BRCP17] BACH B., RICHE N. H., CARPENDALE S., PFISTER H.: The emerging genre of data comics. *IEEE CG&A 37*, 3 (2017). doi:10.1109/MCG.2017.33. 2

[BZP*20] BISHOP F., ZAGERMANN J., PFEIL U., SANDERSON G., REITERER H., HINRICHS U.: Construct-a-vis: Exploring the free-form visualization processes of children. *IEEE TVCG 26*, 1 (2020). doi:10.1109/TVCG.2019.2934804. 2

[CRA*18] CHEVALIER F., RICHE N. H., ALPER B., PLAISANT C., BOY J., ELMQVIST N.: Observations and reflections on visualization literacy in elementary school. *IEEE CG&A 38*, 3 (2018). doi:10.1109/MCG.2018.032421650. 2

[Cre99] CRESWELL J. W.: Chapter 18 - mixed-method research: Introduction and application. In *Handbook of Educational Policy*, Cizek G. J., (Ed.), Educational Psychology. Academic Press, 1999. doi:https://doi.org/10.1016/B978-012174698-8/50045-X. 2

[dKVSvDvG14] DE KONING-VEENSTRA B., STEENBEEK H. W., VAN DIJK M. W., VAN GEERT P. L.: Learning through movement: A comparison of learning fraction skills on a digital playful learning environment with a sedentary computer-task. *Learning and Individual Differences 36* (2014). 8

[DWR24] DOUGLAS B., WOLFGANG C., ROBERT M. H.: Desmos. https://physlets.org/tracker/, 2024. Accessed: 2024-02. 4

[Eur21] EUROPEAN COMMISSION: Digital Education Action Plan. https://education.ec.europa.eu/focus-topics/digital-education/action-plan, 2021. Accessed: 2024-02-15. 1

[Far18] FARINELLA M.: The potential of comics in science communication. *Journal of Science Communication 17*, 01 (2018). 2

[Fed23] FEDERAL MINISTRY REPUBLIC OF AUSTRIA: Curriculum general secondary schools austria. https://www.bmbwf.gv.at/Themen/schule/schulpraxis/lp/lp_ahs.html, 2023. Accessed: 2023-12-22. 1, 5, 7

[Geo24] GEOGEBRA®: Geogebra. https://www.geogebra.org/?lang=de-AT, 2024. Accessed: 2024-02-09. 4, 5

[GTS10] GRAMMEL L., TORY M., STOREY M.: How information visualization novices construct visualizations. *IEEE TVCG 16*, 6 (2010). doi:10.1109/TVCG.2010.164. 2

[HC06] HOLTON D., CLARKE D.: Scaffolding and metacognition. *International Journal of Mathematical Education in Science and Technology 37*, 2 (2006). doi:10.1080/00207390500285818. 2

[HCBF16] HURON S., CARPENDALE S., BOY J., FEKETE J.-D.: Using viskit: A manual for running a constructive visualization workshop. In *Pedagogy of Data Visualization Workshop at IEEE VIS* (2016), HAL. 2

[IGL*13] ITO M., GUTIÉRREZ K., LIVINGSTONE S., PENUEL B., RHODES J., SALEN K., SCHOR J., SEFTON-GREEN J., WATKINS S. C.: *Connected learning: An agenda for research and design*. Digital Media and Learning Research Hub, 2013. 8

[KKEM10] KEIM D., KOHLHAMMER J., ELLIS G., MANSMANN F. (Eds.): *Mastering The Information Age – Solving Problems with Visual Analytics*. Eurographics, 2010. 2

[KL16] KWON B. C., LEE B.: A comparative evaluation on online learning approaches using parallel coordinate visualization. In *Proc. of CHI '16* (2016), ACM. doi:10.1145/2858036.2858101. 1

[KSB*23] KEJSTOVÁ M., STOIBER C., BOUCHER M., KANDLHOFER M., KRIGLSTEIN S., AIGNER W.: Construct and play: Engaging students with visualizations through playful methods. In *CHI PLAY Companion* (2023), ACM. doi:10.1145/3573382.3616082. 8

[LKK17] LEE S., KIM S. H., KWON B. C.: VLAT: Development of a Visualization Literacy Assessment Test. *IEEE TVCG 23*, 1 (2017). doi:10.1109/TVCG.2016.2598920. 8

[MF19] MAYRING P., FENZL T.: *Qualitative Inhaltsanalyse*. Springer, 2019. doi:10.1007/978-3-658-21308-4_42. 2, 3

[NP16] NOLAN D., PERRETT J.: Teaching and Learning Data Visualization: Ideas and Assignments. *The American Statistician 70*, 3 (2016). doi:10.1080/00031305.2015.1123651. 2

[Oli24] OLIVER N.: The phet project. https://phet.colorado.edu/, 2024. Accessed: 2024-02-09. 4

[PBC24] PBC D. S.: Desmos. https://www.desmos.com/?lang=de, 2024. Accessed: 2024-02-09. 4

[Rib20] RIBECCA S.: The data visualisation catalogue. https://datavizcatalogue.com/, 2020. Accessed: 2024-01-12. 4, 6

[Sch12] SCHREIER M.: *Qualitative content analysis in practice*. Sage publications, 2012. 2, 3

[SRG*23] STOIBER C., RADKOHL S., GRASSINGER F., MOITZI D., STITZ H., GOLDGRUBER E., GIRARDI D., AIGNER W.: Authoring tool for Data Journalists integrating Self-Explanatory Visualization Onboarding Concept for a Treemap Visualization. In *Proc. of CHItaly 2023* (2023), ACM. doi:doi.org/10.1145/3605390.3605394. 8

[SU24] SABINE K., ULRICH M.: Leifiphysik. https://www.leifiphysik.de/, 2024. Accessed: 2024-02-09. 4

[Tru21] TRUȘCAN M.-S.: How to successfully integrate the multi-modal learning in english classes using comics. http://tinyurl.com/learning-comics-english, 2021. Accessed: 2024-02-09. 2

[WDB19] WANG Z., DINGWALL H., BACH B.: Teaching Data Visualization and Storytelling with Data Comic Workshops. In *Extended Abstracts of CHI* (2019), CHI EA '19, ACM. 2