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Making sense of journalistic COVID-19 data visualizations: An in-depth study of two adults' visual-numeric literacy

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Abstract

In 2020, the COVID-19 pandemic urged authorities to share quantitative information such as infection and death rates. One way of disseminating was through graphs, maps, and diagrams. Such data visualizations communicate numeric data in compact ways, but also require a particular mathematical literacy from readers. We conceptualized this particular mathematical literacy as *visual-numeric literacy*. To study it, we interviewed two young adults with higher education but low confidence in mathematics and asked them to make sense of COVID-19 data visualizations from journalistic digital media. An in-depth analysis of their visual-numeric literacy revealed that the two participants had developed various sense-making strategies. Their lived experience in the pandemic assisted them to overcome obstacles in mathematical sense-making, and gain insights from the data visualizations. We discuss out-of-school mathematics learning and provide recommendations for improving adults' visual-numeric literacy.

Keywords: data visualizations, visual-numeric literacy, out-of-school learning (of mathematics), sensemaking, COVID-19 pandemic, mathematical literacy, numeracy.

Introduction and literature review

The COVID-19 pandemic affected people all over the world. Governments and journalistic media tried to inform citizens of risks and the spread of the pandemic, among others through a wide range of visual representations of public health statistics. These were based on quantitative data and mathematical models. In this paper, we describe a study, carried out during the COVID-19 pandemic, on how adults read these data visualizations (DVs).

DVs such as graphs, diagrams and maps have become important in public discourses (Engebretsen & Kennedy, 2020), as illustrated by the many COVID-19 DVs. DVs are visual representations of quantitative data. They are compact and useful to communicate messages, to convince readers, to explore data, to see patterns that other formats render invisible, and to explain connections between phenomena (Kirk, 2019; Li & Molder, 2021). Despite the usefulness of DVs, there are also pitfalls. DVs can be misleading through irregular scaling and incorrect proportions (Kwon et al., 2021) and some design conventions, such as logarithmic scales, are less readily understood (Romano et al., 2020). Reading DVs is a complex skill that is influenced by the design of the DVs, the readers' knowledge of DVs, as well as the readers' knowledge and expectations about the data (Shah & Hoeffner, 2002). Further, researchers have identified several aspects of DV reading, including extracting information, finding relationships

in the data, and making judgements or extrapolations that go beyond the visualized data (Friel et al., 2001). In the case of the COVID-19 pandemic, the mathematical literacy[1] demanded by the media coverage was a complex blend of mathematical, statistical, linguistic, demographic, and critical skills (Aguilar & Castaneda, 2021; Gal & Geiger, 2022). Due to the high stakes involved, Da Silva et al. (2021) suggested that COVID-19 DVs can be used for critical discussions of the relationships between DVs, policy and inequality.

The capability to read DVs was measured in several large-scale international surveys. According to two of them, IALS and PIAAC, all OECD countries have a significant number of people who perform at a problematically low level of reading documents that contain DVs, tables, diagrams and so forth. The IALS study indicated that the scores of adults in Norway, where the present study was conducted, were generally above the OECD average. However, an estimated 30% can only deal with simple, clearly laid out materials and will struggle with demands of everyday life and in work in a complex, advanced society (OECD, 2000). The more recent PIAAC survey indicated that an estimated 40% of Norwegian adults may have struggled with journalistic COVID-19 DVs (OECD, 2019), which is the theme of this paper.

According to Evans (2018), the advanced state of modern statistics has created a boundary between experts and the general public. When statistics are used in public policy debates, the gap between experts and the general public constitutes an "overt crisis of statistics" (p. 38) because the interpretation of statistical data is shielded from criticism by its complexity, lack of transparency, and assumed authority. On the other hand, Gal and Geiger (2022) investigated the use of statistics and mathematics in the media coverage of COVID-19 and found examples of news items that *invite* readers to critically scrutinize statistical and mathematical issues. This was realized in various ways, for example by pointing out issues of data quality, dissent among experts, or results of fact checking.

Jackson et al. (2018) reviewed research on numeracy practices at work and in private life. They found that the mathematics that people use in everyday situations is (1) contextual, that is, interrelated with personal, social, and cultural surroundings, and (2) unstable, that is, variable over time and circumstances. Everyday numeracy practices change in response to changes in the surroundings such as a new job, a new tool, or a significant event such as a pandemic. Jackson et al. (2018) caution that this connectedness between numeracy practices and their situatedness creates a challenge for survey research, such as PIAAC and IALS. To meet high statistical standards, these studies transform literacy and numeracy practices into competence categories, levels, and scores, and they zoom out *across* personal, social, and cultural surroundings. Jackson et al. (2018) recommend large-scale studies to be complemented by qualitative research on practices *within* different personal, social, and cultural contexts. With the present study, we want to contribute to the latter.

Researchers have provided advice on guiding learning processes towards developing effective and efficient DV reading skills (e.g., Friel et al., 2001; Shah & Hoeffner, 2002; Glazer, 2011). However, these studies focus mostly on compulsory education and do not consider adults or lifelong learning. Studies on adults' mathematical practices in out-of-school contexts have found that such practices are strongly connected to the social contexts in which these occur (e.g., Curdt et al., 2022; Jackson et al., 2018) and that school-learnt mathematics is not a guarantee of success in out-of-school mathematics (Heyd-Metzuyanim et al., 2021).

[1] The capability to use mathematics in diverse contexts has many definitions and names. In this paper, we generally use the term *mathematical literacy* as an umbrella term, but we also use the term *numeracy* when this is the preferred term in referenced papers.

To study mathematical literacy practices embedded in lived experiences (Curdt et al., 2022; Jackson et al., 2018), the media coverage of the COVID-19 pandemic offered a rich opportunity for research. There were studies using digital surveys (Heyd-Metzuyanim et al., 2021) and studies on how imagined readers encounter demands and opportunities when reading COVID-19 media artefacts (Aguilar & Castaneda, 2021; Da Silva et al., 2021; Gal & Geiger, 2022; Kwon et al., 2021; Stephan et al., 2021). These studies were constrained by social distancing measures and lockdowns. For the present study, we made use of a window between lockdowns when it was allowed to meet people. We carried out interviews with young adults face-to-face to study their actual engagement with COVID-19 DVs from popular news media. So, the pandemic timing directly impacted our study. Hence, our method was different from digital surveys and video interviews. In this way, our study validates and complements findings from the other studies mentioned.

Theoretical framework

For our in-depth analysis, we needed a framework that accounts for the many aspects of DV reading and the role of lived experience in sense-making processes that were highlighted in the literature review (e.g., Jackson et al., 2018). A frequently used framework for graph reading is from Friel et al. (2001), which distinguishes between reading the data, reading between the data, and reading beyond the data in a DV. This framework focuses entirely on the artifacts' characteristics and does not account for the readers and their lived experience.

The framework used for the IALS study is named Document Literacy. It describes "the knowledge and skills needed to locate and use information contained in various formats, including job applications, payroll forms, transportation schedules, maps, tables and charts" (OECD, 2000, p. x). This framework highlights the cognitive underpinnings of how people locate and use information in DVs (Kirsch & Lennon, 2017), but does not consider how people read DVs differently according to how the information in the DVs affect their lives (Jackson et al., 2018).

We needed a framework that considers reading and making sense of DVs as a multi-faceted skill (Gal & Geiger, 2022; Tout et al., 2021) that includes aspects such as making sense of mathematical models (Aguilar & Castaneda, 2021; Gal & Geiger, 2022) and critically and reflectively use quantitative information to inform actions and judgements and reflect on their sociopolitical implications (Da Silva et al., 2021; Gal, 2002; Gal & Geiger, 2022; Geiger et al., 2015; Stephan et al., 2021; Tout et al., 2021; Weiland, 2017). Also, the framework should capture interrelations between mathematical literacy practices with personal, social, and cultural surroundings.

We found that the framework *visual-numeric literacy* (Tønnessen, 2020) met these needs. Visual-numeric literacy is the capability needed for getting information from texts when reading newspapers, websites, guidelines, and so forth, that include visual representations of quantitative data such as graphs, diagrams, and maps. This framework is inspired by research in language learning (Hasan, 1996) and is grounded in the theoretical perspective of social semiotics (Van Leeuwen, 2005), which casts an eye on practices in specific social and cultural circumstances. We regard visual-numeric literacy as a specific form of mathematical literacy. It is similar to Document Literacy but has a special focus on the readers' social contexts. Key to the social context is the role of lived experience. The framework is composed of three different aspects that together cover the nuances highlighted above. Below, we explain the three aspects, the relevant contexts, and how we used them in this study.

First, the *recognition* aspect concerns the recognition of the sign systems used for meaning making, and for decoding the signs in order to connect them to the meaning intended by the designer. In the case of verbal language literacy, the main sign system is the alphabet. In the case of DVs, the sign system contains dots, lines, axes, numerals, colors and so forth. Second, the *action* aspect of literacy pertains to using texts – in this case DVs – to reach personal goals. It can entail using DVs to inform actions and decisions, such as finding a good time for visiting elderly relatives during the pandemic. Finally, the *reflection* aspect pertains to exploring and challenging the boundaries of DV practices and conventions through reflection, critique, analysis and enquiry. Reflection literacy drives development.

Hasan (1996) distinguished between two relevant contexts when people engage with texts, and we have applied this distinction to our analysis of interaction with DVs. First, a DV can be understood within the context of its sign system, that is, the repertoire of available signs and codes. It is this kind of meaning making that yields statements like "infection rates are higher in Alta than in Kristiansand" when interpreting Figure 3 because this statement can be inferred from the DV alone. Second, the social context is also a rich source for meaning making. The social context entails the readers' lived experience, history, aspirations, and environment – family, friends, identity and so on. When the readers' social context is used for meaning making, statements will go beyond information inferred from the DV, for example "I need to be extra careful around my elderly parents now that the infection rates are so high". By combining the three aspects with the two contexts, we created a framework consisting of six labels (Table 1) that we used for our analysis. The research question for this paper is:

What characterizes adults' visual-numeric literacy when reading and making sense of journalistic COVID-19-related DVs?

Table 1. Aspects and labels used for analysis of visual-numeric literacy.

Aspect	Label	Example of utterance
Recognition literacy	Context of sign systems: Decoding without relating it to the experienced world	When I look at the numbers, I see that the increase is even more here.
	Context of the readers' social situation: Decoding while relating it to their experienced world	Here in the graph, the infections are going up. I remember that happened.
Action literacy	Context of sign systems: Action within the DV	I move the mouse over the graph.
	Context of the readers' social situation: Action beyond the DV	I cancelled a trip to my parents after I saw these types of graphs.
Reflection literacy	Context of sign systems: Reflection on the DV	The logarithmic scale on the vertical axis makes the graph misleading.
	Context of the readers' social situation: Reflection on the socio-political impact of the DV	DVs do not show how people experience the pandemic.

Methods

Research context, design and participants

We held interviews in the spring of 2021, when infection rates in Norway were high but relatively low in the municipality of the study (FHI, 2021). For the interviews, we used VG (Verdens Gang), the most used online newspaper in Norway (Mediebedriftene, 2021). When the first infections occurred in Norway, VG developed a web page showing health data related to the COVID-19 pandemic (www.vg.no/special/corona). The web page contained little text and a wide range of DVs of infections, mortality, vaccinations and so forth for Norway and the World. The DVs were displayed in different formats, such as line graphs (see Figures 1 and 5), and choropleth maps (see Figure 3). There were interactive features, such as mouseovers to show exact data, like the infection rate for a specific date or a specific city (see Figures 2 and 5).

Also, readers could change certain details in some of the DVs, for example between daily and cumulative numbers or between linear and logarithmic scales. Below each DV, there were clickable help-buttons that offered text boxes with legends and explanations of key concepts. The webpage was frequently updated with new data. The webpage contained examples of what Gal and Geiger (2022, p. 19) have called *embedded criticality*, that is, cues directing the readers' attention towards "statistical and mathematical issues that require critical scrutiny". Examples of this include a log of changes and errors, and mention of missing or incomplete data. This web page attracted much traffic. Therefore, it was an important part of the media coverage of the pandemic in Norway and an authentic arena for investigating adults' visual-numeric literacy.

For the data to be rich, we needed participants who were able verbalizers of their thoughts. Also, we wanted them to be in the lower ranges of the PIAAC numeracy levels because that would reveal more of the struggles to make sense of DVs, and it would make them more representative of an 'average' reader. Therefore, we approached people on the campus of a Norwegian university asking them whether they were a student, but not in a discipline with high mathematical entrance requirements (e.g., natural sciences, engineering, mathematics, economics). The interviews lasted roughly one hour, and the participants received a 200 NOK gift card. The interviews consisted of two parts: The first part was an unstructured interview where the participants were asked to explore at their own pace and comment as they read. Thereafter, each participant was asked open-ended questions about their reading. We chose to start with an unstructured interview to get an impression of how they would engage with the page with minimal interference from the researchers (Bryman, 2016).

Because the unstructured first part of the interview did not ensure comparability and coverage of all the aspects of the framework, the second part of the interview followed a semi-structured design (Bryman, 2016). In this second part, the interviewer asked questions that targeted each aspect of their visual-numeric literacy, as well as relevant background questions. The participants were asked the same main questions, but follow-up questions varied depending on their answers. Among the questions asked in this part of the interview were questions about the DV shown in Figure 2. Here, the interviewer asked them to elaborate on the information they get from the DV, followed up by probing questions that targets the logarithmic scale such as "when is the increase in the number of infected the greatest?" and "what happens if you switch to a linear display?" Towards the end of the interview, the participants were asked questions about their experience with school mathematics.

The two participants, hereafter anonymized as Abe and Bea, had a similar background in that they both reported a negative experience with school mathematics. However, their experience with COVID-19 DVs was very different: Abe reported that he avoided numerical content in general and had never seen a DV related to COVID-19. By contrast, Bea had a strong interest in COVID-19 DVs and had visited the web page used for the interviews many times already.

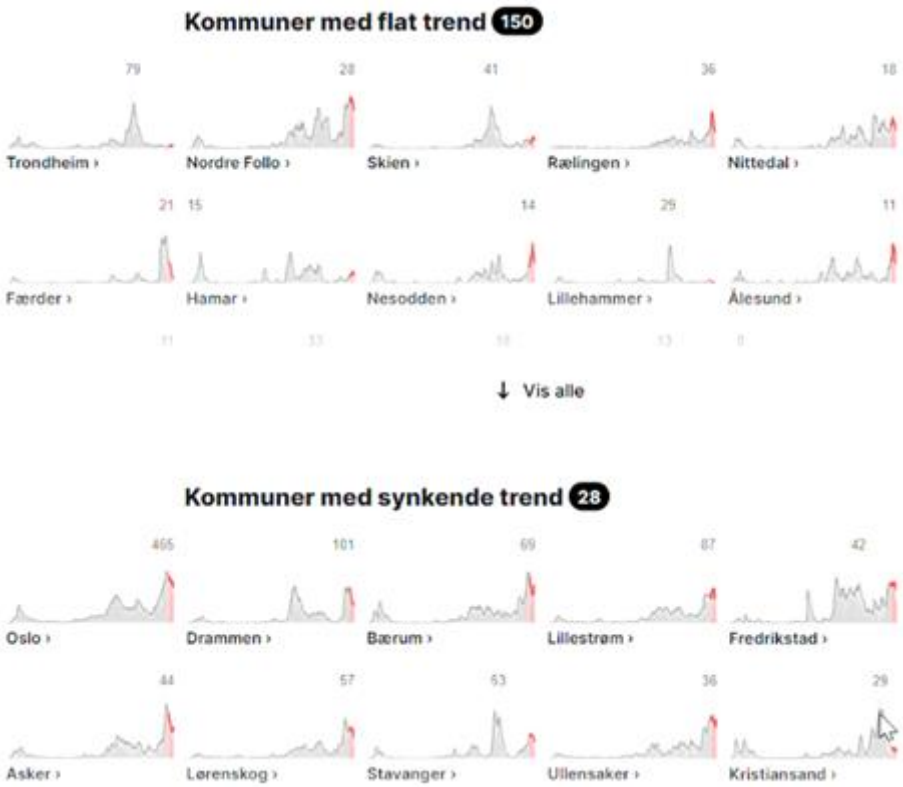

Figure 1. Miniature line graphs of infection trends per municipality, grouped according to rising, flat or sinking trends. Downloaded from vg.no 07.04.2021.

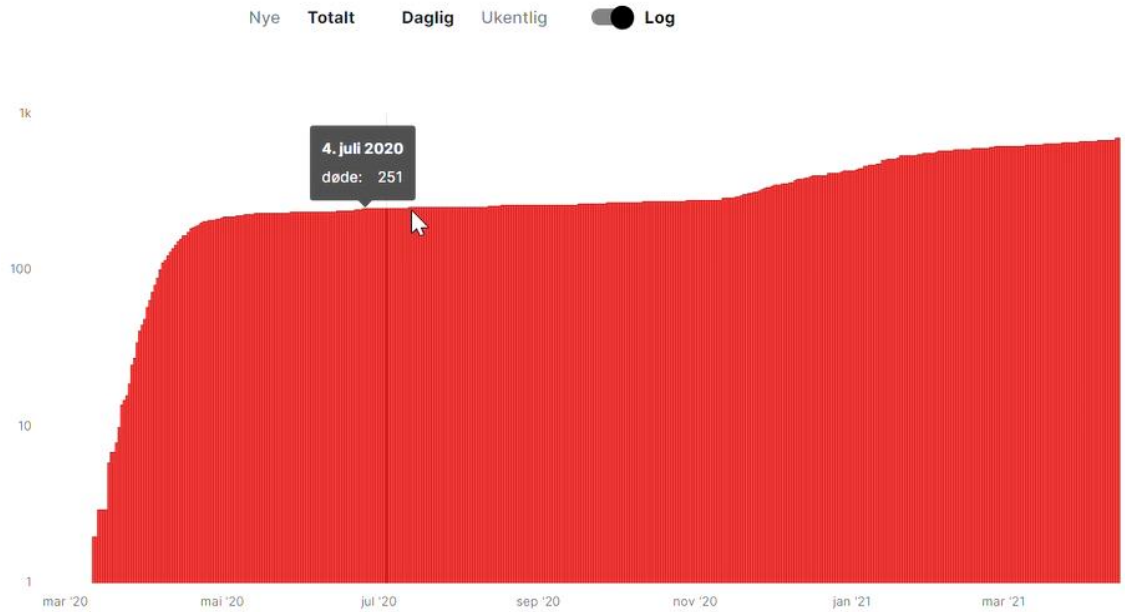

Figure 2. Histogram of cumulative deaths in Norway with logarithmic vertical scale and mouseover showing 251 deaths on 4 July 2020. Downloaded from vg.no 07.04.2021.

Figure 3. Choropleth map showing infection rates in Norwegian municipalities. Downloaded from vg.no 07.04.2021.

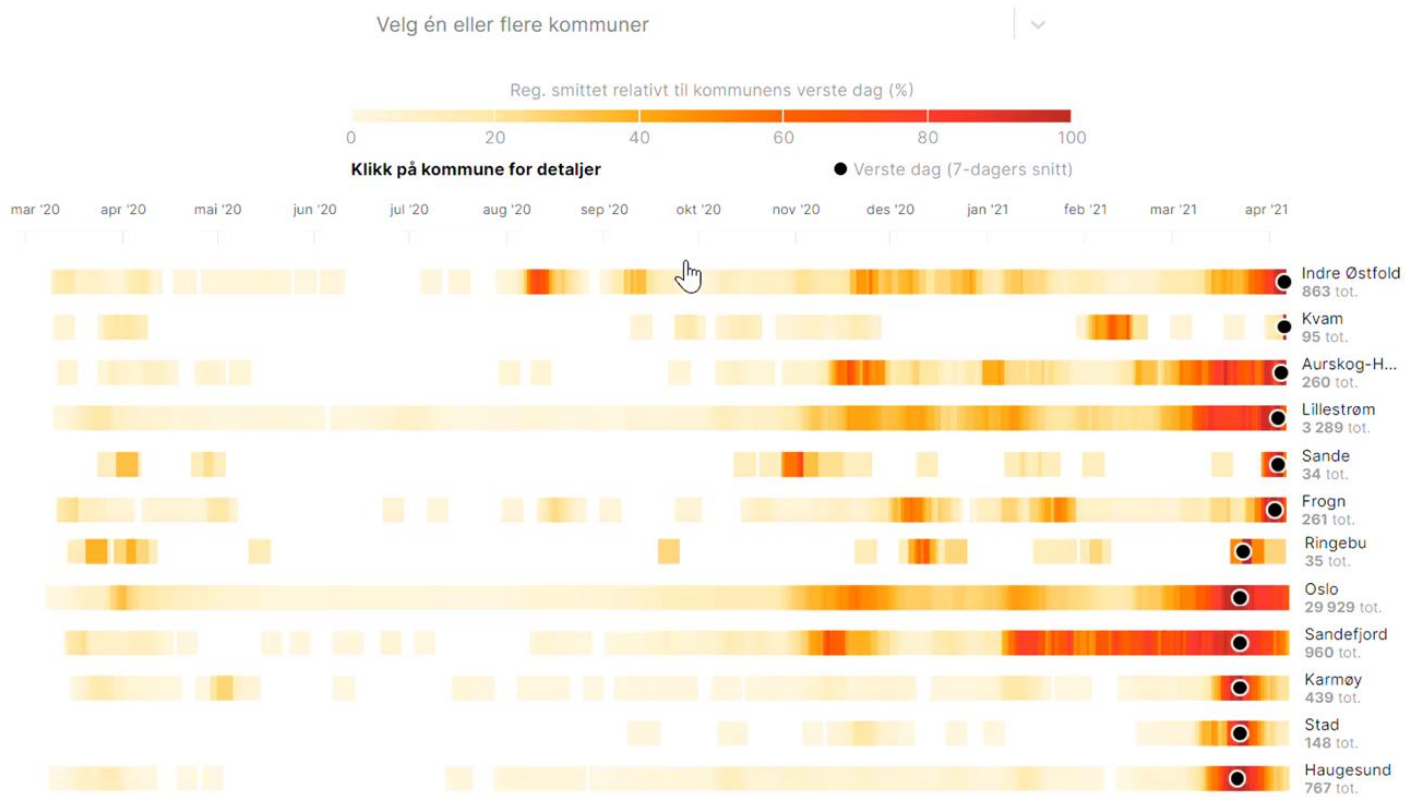

Figure 4. Barcode plot ranking municipalities by the date of the highest number of infected. Downloaded from vg.no 07.04.2021.

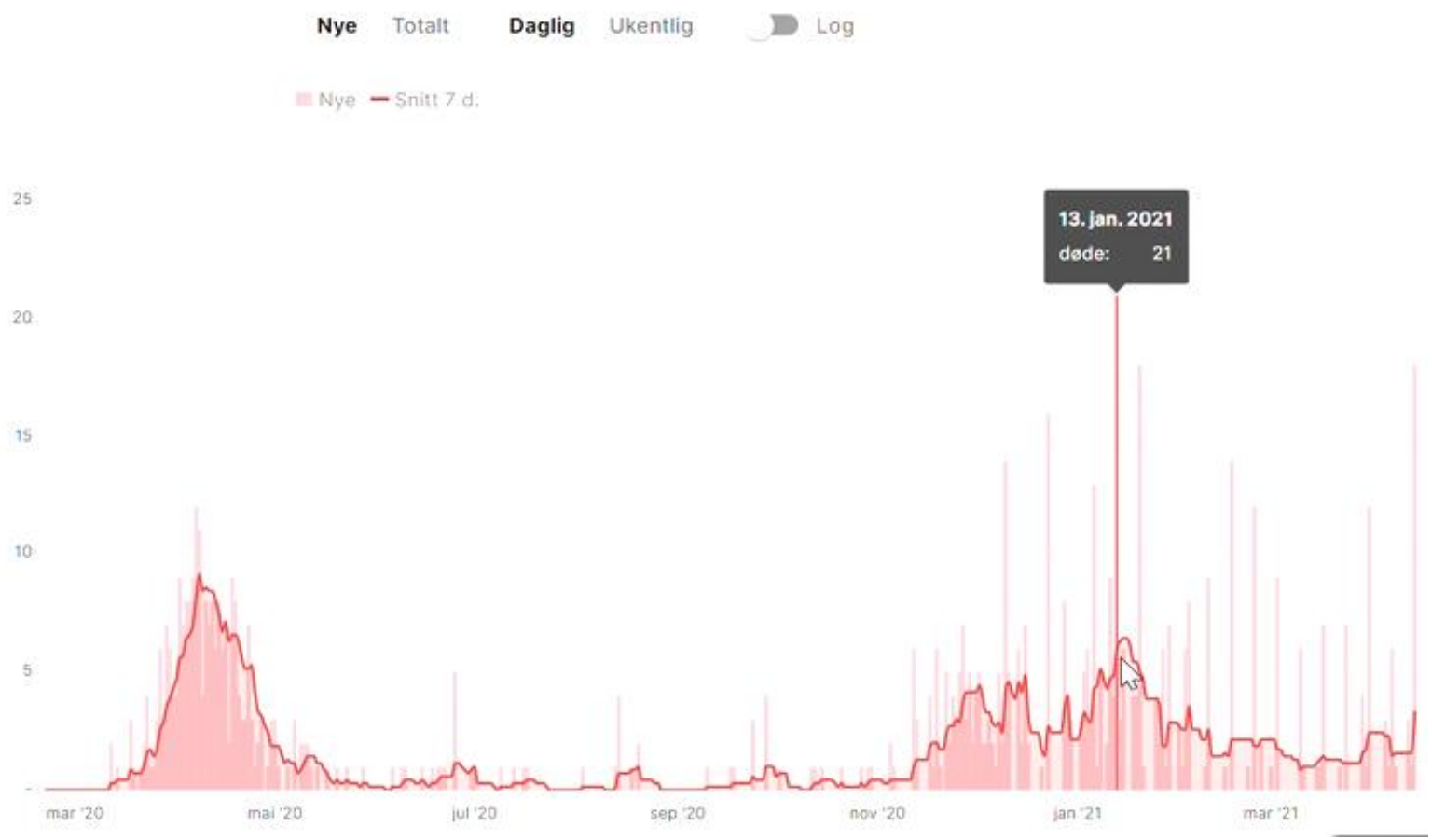

Figure 5. Combined histogram and line graph showing daily and 7-day average deaths in Norway with mouseover showing 21 deaths for 13 January 2021. Downloaded from vg.no 07.04.2021.

Data and analysis

After transcribing and anonymizing the data, the analysis consisted of three rounds. First, the transcripts were read thoroughly to get an overview. Second, each statement was labeled as explained below. Third, for both participants, all statements were rearranged according to the labels, which enabled us to characterize the three aspects of each participants' visual-numeric literacy.

The analysis was based on six labels (Table 1). For each of the three aspects of literacy, recognition, action, and reflection, we distinguished between two contexts. When the reading was turned towards the DVs themselves, we labeled them 'sign system context'. When the reading was explicitly turned towards the DVs' role or impact on the social context, we labeled it as 'social context'. The label 'recognition literacy in the sign system context' was used when a participant directly decoded a DV (e.g., decoding values from graphs). The label 'recognition literacy in the social context' was used when decoding was supported by social context. And so forth for action literacy and reflection literacy.

After initial analysis, both participants were sent the transcripts and a summary of the analysis. Both agreed that they were accurately represented.

Results

In this section, we first present key findings for Abe and Bea separately. A summary of the characteristics for each participant is provided at the end of this paragraph. This will then be synthesized across the participants in the Discussion paragraph.

Abe

Abe was a 22-year-old male university student of Music and English. In upper secondary school, he specialized in Music and took the lowest course in Mathematics (1P). He disliked mathematics and statistics but considered them useful. When asked about experiences in the COVID-19 pandemic, he highlighted feelings of loneliness, but he had a circle of close friends to socialize with. His sources of pandemic information were popular social media, Google, and an Instagram account from the local municipality that posted about mitigation measures. He claimed that he never saw graphs about the pandemic before the interview.

Abe's recognition literacy

To analyze Abe's recognition literacy, we looked for instances where he decoded DVs, and we were interested in which relevant contexts he used (the sign system or the social context). For instance, when Abe looked at a DV where the Norwegian municipalities were grouped according to their trend in infections (rising, flat, sinking) and represented by small line graphs (Figure 1), he commented:

> 96 Abe: Flat trend, Trondheim has been good recently. Sinking trend, Kristiansand. … [pointing at the peak in the curve for Kristiansand] That's when everything was closing. Otherwise, it has been sinking in Kristiansand. What is amusing is that I work out at the gym almost every day, while everything is shut down. … They started shutting down everywhere except Kristiansand.

His comment on Trondheim was probably based on recent news about that municipality. Next, he looked at the headlines, and found his university town Kristiansand in the cluster under the headline "sinking trend". He pointed with the cursor to a peak in infection rates in February 2021, about six weeks before the interview. Here, he pointed at the tension that whilst society was closing down at this point, Kristiansand remained open, which he concretized by his habit of going to the gym every day. This instance illustrates several

characteristics of Abe's reading and sense-making. First, he often relied on cues from the textual part of the DVs such as headlines, and not the numerical part, to make sense of the DVs. Second, he used his pandemic knowledge and experiences from his social context to make sense of the DVs and validate his interpretations.

When he discussed a DV that incorporated a histogram, showing daily COVID-19 mortality, and a line graph showing seven-day averages of the same data (Figure 5), he was asked to explain the difference between the bars and the line. This question was aimed at probing his recognition literacy in the context of the sign system. He said:

302 Abe: I think the dark red line is general.
303 Int: Yes, what does that mean?
304 Abe: I'm thinking … when I say general, I'm thinking of the number of infections we get in that time, you know, rather than exact numbers we have this … you know … as long as we stay below zero cases or percent, then infection rates go down.

Although he struggled to verbalize what he meant by 'general', this dialogue showed that he understood that the red line shows something that differs from the 'exact' (absolute) numbers. His statement about negative numbers points at a hurdle for Abe in expressing decreasing infections in mathematical terms. After studying the DV further, he concluded that the line is an average of the bars, and as he said this, he also realized that there was a legend explaining that the curve is a seven-day average of daily deaths, and that the bars show daily deaths. This shows that he had an intuitive and informal understanding of graphs and, through discussion, enquiry and finding legends, was able to decode a number of signs in the DV, in particular the difference between the bars and line graph.

When asked to explain the concept 'per 100 000' used in the choropleth map (Figure 3), Abe used the terms "percentwise", "large perspective" and "average perspective", showing untechnical and informal understanding of relative numbers in the DV. When discussing further, Abe expressed that infection rates per 100 000 in municipalities with fewer than 100 000 inhabitants were "nonsensical and inaccurate". He stated that rates per 100 000 could not be applied for cities like Bodø with fewer than 100 000 inhabitants (lines 361, 363). This showed a deficient capability to decode relative numbers. Nevertheless, he was able to accurately make sense of the map by decoding the colors, where he could read darker shades of red showing worse intensities of the pandemic. In this way, the map allowed him to avoid numbers. Thus, his recognition literacy was functional and non-formal. With each DV he used a narrative of experiences from his own social context to support his decoding.

When Abe was challenged to make sense of Figure 2, which shows deaths in a diagram with a logarithmic vertical scale, his initial impression was that "a lot of people have died" (line 200). However, after studying the concrete numbers from the mouseovers, he realized that the graph showed cumulative numbers. Initially, he claimed that the greatest increase was when the curve was steepest, even after studying the concrete numbers through mouseovers. It was only when he and the interviewer toggled between the logarithmic and linear scale that he realized that there was an even larger increase in the winter 2020/21. This shows that he had difficulties with the formal numerical codes.

Abe claimed several times that the graphs repeated themselves. This was elaborated:

290 Abe: It [Figure 2 and 5] is even more repetition because it shows that it was like I thought that there was a lot of infections in the [Christmas] holidays.

Hence, Abe interpreted the DVs holistically as telling a story of how the pandemic developed in waves and disregarded the concrete numeric information underlying each DV.

Abe's action literacy

First, we focus on Abe's action literacy in the context of the sign system, that is, his actions with the DVs only. While exploring the page, he scrolled up and down a lot and would often continue talking about a DV while scrolling further and making mouseovers. Unless prompted, he never opened expandable information boxes or switched toggles. His scrolling and use of mouseovers supported him in finding relevant information, although he did not utilize the full potential in information boxes and toggles.

When looking at Abe's action literacy in the social context, we analyze how he used DVs to inform actions and decisions, and how he saw the DVs as reflecting events happening around him. Talking about the page in general, he said:

> 176 Abe: It [the content of the page] shows … where it is worst … at the same time it shows what we have to do, we must be more careful when we are in large cities. At the same time, the cities must think clearly and not lose the grip only because the virus is spreading in one place.

Thus, to Abe the contents of the page called for certain forms of action by authorities. He also said that:

> 462 Abe: [I must be careful] on behalf of myself, others, and so forth. And if I go and visit my family, then I must take them into account.

Thus, by finding relevant information, Abe felt ready to act and be extra careful about visiting areas with high infection rates on behalf of himself and others.

When asked why a peak in a graph for infections occurred roughly two weeks before a peak in a mortality graph, he reasoned:

> 385 Abe: They may have been fighting for their lives and died after some time.

So, when prompted, he was able to reason causally across the DVs, and for this he used his pandemic knowledge. This reasoning supported by the social context was a central feature in both his recognition and action literacy.

Abe's reflection literacy

First, we present findings about how Abe reflected on the DVs themselves, that is, reflection literacy in the context of the sign system. While discussing a DV showing infection peaks in Norwegian municipalities (Figure 4), Abe initiated a discussion on the limitations of using relative numbers. In this DV, the municipalities were ranked by the most recent date of the highest infection rate. Thus, small and large municipalities were mixed. The DV used a color code where the hue varied according to the infection rate, and the total of infected was given in numerals. Kvam, a rural municipality, was ranked second because they just experienced a large outbreak. Oslo, the capital and largest city in Norway, was ranked much lower despite having a higher absolute number of infected.

> 102 Abe: These are very small numbers when you look closer.
> 103 Int: Are Oslo's numbers also small? You just found Oslo.
> 104 Abe: They [Oslo] have 29 000 [infected]. A lot more than the 95 [infected] that are in Kvam. That's a little unclear. But still …
> 105 Int: Yes. What do you mean by unclear?
> 106 Abe: I think that you can perfectly well look in terms of percentages that, all right, now there are 95 percent infected, oh my! But then you see that only two out of three are infected. That's a little unclear in my opinion.

In this instance, Abe pointed at the complexity of him reading this DV. He indicated that the ordering contradicted the ordering he knew. Then he pointed out that it was the use of relative numbers that created this tension. The change of 95 infections to 95 percent and his

ratio “two out of three” in line 106 were constructed for his argument. His perception of unclarity seemed to stem from his mixing of relative and absolute numbers.

He also reflected on the opportunities offered by DVs:

258: Abe: Just now, it was new to me that it [the latest wave of infections] started in November and not in February.

He considered the DVs as a helpful and trustworthy addition to other means of reporting about the pandemic because they illuminate patterns.

Now we turn to findings about Abe’s reflection literacy in the social context. Abe gave his opinion on news media:

268 Abe: [the degree to which the media exaggerate] varies of course, but that’s why I like to look at multiple perspectives.
269 Int: And that means through social media?
270 Abe: Yes.

Although he thought that news media tend to exaggerate and used social media as his main source of information instead, he still considered the page to be trustworthy because of the richness of perspectives it provided and because he considered the Norwegian Institute of Public Health (FHI, the data source) reliable. He commented that the page offered him new information. Despite spending a considerable amount of time exploring the page, he did not attend to the instances of embedded criticality.

Summary of Abe’s visual-numeric literacy

Abe relied to a large extent on his knowledge and experience of the pandemic to make sense of the DVs.

- *Recognition literacy*: He decoded DVs functionally, non-formally and in a way that was dependent on concrete interpretations of the social context of the data. He had a limited understanding of mathematical concepts such as relative numbers. Unless prompted, he did not fine-read DVs and often interpreted them based on general impressions and headers. He decoded the particular meanings only when there were absolute numbers given, which he used to create narratives (e.g., telling personal memories from his gym, or visiting his family). While avoiding quantities, he interpreted the DVs qualitatively, which led him to interpret the DVs as telling the same story even though they show different data sets.
- *Action literacy*: He avoided DVs in his everyday media habits and preferred non-numeric content. When looking at DVs in the interview, he actively scrolled and looked for mouseovers, which helped him find relevant information. When he encountered contradictory interpretations of the DVs, he did not look for resolutions. When prompted, he could see causal relations in the data. He saw how actions and events such as Christmas holidays left an imprint in the data, and how data can inform action.
- *Reflection literacy*: He was critical of some design choices when the DVs did not reflect his impression of reality. Nevertheless, he considered the page as a whole as trustworthy, and it could offer him new insights into the pandemic.
- *Cross-aspect*: We observed that in the context of the sign system, Abe’s action literacy (mouseovers, toggles) supported his recognition literacy. For each of the aspects of literacy (recognition, action and reflection), his lived experience of the pandemic helped him give meaning to the sign system.

Bea

Bea was a 23-year-old female university student of Gender Studies, with a bachelors’ degree in Global Development. In upper secondary school, she chose the theoretical stream, specialized in

Social Sciences and took the lowest course in Mathematics (1P). She had negative experiences with school mathematics, she said she knew the basic concepts such as plus or minus, and beyond these she said to have low confidence. When asked about her pandemic experiences, she answered that it had caused some strain on her studies, work and social life, but she considered herself relatively unaffected by the pandemic. She regularly consulted a wide array of sources about the pandemic, and she was a regular reader of VGs COVID-19 webpage. In the beginning of the pandemic, she visited the page several times a day. At the time of the interview, she visited it 2-3 times a week. She regularly encountered statistics and DVs in her studies and in social media.

Bea's recognition literacy

As with Abe, we looked for instances where Bea decoded DVs, and were interested in which relevant contexts she used (the sign system or the social context). When she first explored the page, she did so very quickly because she was already familiar with the content and did not need much time to get an overview. This shows that her familiarity with the page enabled her to decode many of the DVs quickly and effortlessly. When she was challenged to make sense of the DV in Figure 2 which shows cumulative numbers of deaths in a logarithmic vertical scale, she started by looking up the headline. Her first impression was that "it looks like a lot", adding that the red area under the graph increased the overwhelmingness. However, she proceeded to decode data values through mouseovers showing the concrete numbers, which changed her impression:

58 Bea: … it is not quite so overwhelming after all when you look at the numbers, I think.

Here, she used her action literacy in the sign system to support her recognition literacy in the sign system by looking up numbers in mouseovers. To further probe her decoding of the logarithmic scale, she was asked to identify when the number of deaths grew fastest. First, she answered March and April 2020 when the curve was steepest. When she then was asked to compare the increase in this period with the increase in the most recent period, she concluded:

68 Bea: … when I look at the numbers, I see that it [the number of deaths] is even more here [in winter/spring of 2021] even though the curve is flatter.

This contradiction between the visual shape and numerical information prompted a search for a resolution. After considering time intervals, she looked at the vertical axis:

74 Bea: It goes straight from 10 to 100 here and from 100 to 1000. And 1 to 10. So, it makes sense that it is steep here [in March and April 2020]. But, if you don't look at the numbers, only the shape, you may not get that.

By pointing at the characteristic of the logarithmic scale, she inferred that this design feature had misled her initial decoding of the shape of the curve. Hence, aided by a prompt from the researcher and quality control of her own decoding, she developed an understanding of diagrams with logarithmic scales. This shows that she was capable of learning to decode new signs related to DVs through reflection and enquiry into her own decoding. Hence, she used her reflection literacy to expand her recognition literacy. Her decoding of Figure 2 relied consistently on signs in or surrounding the DV, and there were no explicit references to the social context during this sense-making process.

Later, Bea discussed the concepts 'per cent' and 'per 100 000', used in some DVs. Elaborating on the meaning of 'per 100 000' in a world map showing the countries, which were colored according to infection rates per 100 000 inhabitants, she explained:

116 Bea: I understand it as something used to make it easier to understand percentwise how many infected there are. So, it's not right to say that if we are 700 infected then … it can be that they have equally many infected in a country percentwise, but twice the number of inhabitants.

Her mention of "percentwise" suggests that her understanding of 'per 100 000' was modeled on an understanding of percent and useful for comparing across, for example, countries of different size.

117 Int: Is it possible to talk about number of infected per 100 000 inhabitants in a country with less than 100 000 inhabitants?
118 Bea: Yes, they just need to calculate it.
119 Int: Yes. Can you elaborate on that? Take for example a fictitious country with 10 000 inhabitants.
120 Bea: Yeah, then they need to calculate from 10 000. They have to, kind of, multiply their number of infected by 10.

And somewhat later, she discussed differences between percent and 'per 100 000':

146 Bea: The difference is that 10 percent is a lot more [than 10 per 100 000].

With this, she showed to have understood the concepts of 'per 100 000' and percent, their mutual relation, and their usefulness for comparisons. She uses an example from the social context, Norway versus the US, to elaborate her understanding of 'per 100 000', but there was no indication that she depends on the social context to decode these numbers. Thus, while she was able to connect the signs to the social context, she did not depend on the social context to decode the DVs.

Bea's action literacy

First, we focus on Bea's action literacy in the context of the sign system. While exploring the DVs, she often used mouseovers, which she described like this:

98 Bea: [To find the number of infected] I go in here and it says registered infected. Then I take the cursor over and see how many there are.
102 Bea: … for positive tests and such, which I don't really look at, it's the same thing. You just take the cursor over and kind of look at the date and number of infected, and the same for the other categories.

Using mouseovers to extract numbers was a crucial component of her reading habits. The quote from line 102 also suggests that she habitually checked infection rates and skipped content that she deemed less relevant. This was elaborated later:

106 Bea: The number of people on respirator isn't crucial to me. It is of course sad that it happens, but it is not something that I … yeah.
236 Bea: [When I don't immediately understand something] I move on rather than spend time trying to understand it.

Thus, from her extensive experience with the page, she selected information based on pertinence and how readily she understood the content. When asked to explain the difference between the pale pink bars and the red line in Figure 5, she demonstrated how she found explanations:

284 Bea: The thick red line is, it's written here and when I hold the cursor over, it explains what it is. It is the average over seven days. So, it's the average. The pale pink [bars] are the number of new cases per day. So even though some of them [bars] are very high, they don't reflect the averages.

Thus, she had developed effective reading habits that involved interactive features and content filtering that enabled her to efficiently find relevant content and make sense of the DVs. In other words, her action literacy supported her recognition literacy.

Now we turn to Bea's action literacy in the social context. Related to this, she said:

18 Bea: … It has been a lot about [COVID-19] in everyday life, casual conversations and when I'm at work and with friends. It has been a lot of talk about it. Now, the numbers are falling.

In this quote, Bea connected her knowledge of statistics on infection rates to her personal life and mitigation policies. She indicated that the falling numbers could lead to less invasive mitigation policies in the near future. This shows that she was capable of connecting the information from the DVs to her social context.

Bea's reflection literacy

First, we present findings about Bea's reflection literacy in the context of the sign system. After the exploration, Bea shared her thoughts on the limitations of DVs and statistics:

> 40 Bea: It shows a lot of statistics. But it is … a lot of numbers, and numbers don't always represent reality the way we experience it.

While looking at Figure 2, she reflected on how DVs can be misleading:

> 58 Bea: It looks like a lot. First, it's entirely red and you don't usually associate red with something good. […] The first impression is like 'wow it looks like a lot'. But then you look closer and it's not so overwhelming when you look at the numbers. I think.
> 74 Bea: […] If you look at the shape and not the numbers, you may not understand it.

Here, she reflected on impressions based on salient visual features such as the color red and the steepness of graphs. She described the logarithmic scale as misleading and not as wrong. This suggests that she understood that the logarithmic scale did not change the data themselves, only their visual representation. Hence, she reflected on how challenging design choices such as logarithmic scales can mislead readers.

Next, we present findings relating to her reflection literacy in the social context. Discussing a bar chart of registered infected in Norwegian municipalities, she said:

> 100 Bea: For today it [the number of registered infected] says zero but it's certainly not updated because for yesterday it says 421.

Here, she concluded that an anomalous value was due to lags in the updating of data. Thus, she showed how she could critically analyze a DV and use her understanding of the processes behind the data collection to understand anomalies.

She generally trusted the page to be accurate but would often compare it with other sources. She did not attend to the instances of embedded criticality on the page, but her use of multiple sources to validate the data suggests that she is aware of the possibility of missing, inaccurate or incomplete data. She suggested that the use of DVs can make webpages appear more scientific, but that DVs can be confusing for people who do not understand them. Further,

> 42 Bea: Thinking about the next few days and the coming week, when we just had a large breakout here earlier this week and they are opening up this weekend. I don't think it adds up when the numbers are high but we are opening up instead of staying locked down.

This quote shows how she sees connections between statistics and events and how she can critically reflect on the relationship between policies and statistics. Thus, her judgment of appropriate actions, which pertains to her action literacy in the social context, triggered her reflection literacy.

Summary of Bea's visual-numeric literacy

Bea was able to decode DVs without explicit reference to her knowledge and experience of the pandemic.

- *Recognition literacy*: She decoded DVs functionally, effectively and formally. For relative numbers, she had an accurate understanding that involved definitions, calculation procedures as well as meta-knowledge of their usefulness. She showed a flexible and open attitude towards logarithmic scales, which she learned to decode during the interview. She

was capable of decoding DVs within the context of the sign system with minimal reference to the social context. She was able to use the social context to explain the usefulness of relative numbers.

- *Action literacy*: Before the interview, she already had developed an extensive familiarity with the page, and reading habits that helped her select and locate desired content such as legends and explanations. This helped her to make sense of DVs quickly and effortlessly. She used mouseovers, scrolling and visual searches for legends and explanatory text to explore DVs analytically and systematically. She could see how actions and events such as vaccinations and holidays could leave an imprint in the data, and how data can be used to inform actions and decisions.
- *Reflection literacy*: She was critical of some design choices. Her criticism was based on the impressions that the DVs gave her, potentials for misunderstanding, and the validity and accuracy of the data. She was aware of limitations of DVs. Through critical analysis, she could perform quality control of her own reading and when encountering contradictions, she was able to resolve these.
- *Cross-aspect*: We observed that her reflection literacy supported her recognition and action literacy; that her action literacy triggered her reflection literacy; and that she could fluently translate between the sign system context and her social context literacy.

Discussion and conclusion

The research question for this paper was "what characterizes adults' visual-numeric literacy when reading and making sense of COVID-19 data visualizations?". Visual-numeric literacy is the form of mathematical literacy that is specific to getting information from/making sense of DVs, and our answer is framed by the framework of Hasan (1996) and Tønnessen (2020) that distinguishes between recognition, action, and reflection literacy, and between the contexts of the sign system and the readers' social context (Table 1).

A first characteristic of visual-numeric literacy was that the three aspects (recognition, action and reflection literacy) and the two contexts (the context of the sign system and the social context) all interacted and were mutually reinforcing. Hasan (1996) and Tønnessen (2020) suggested that action literacy builds on recognition literacy and that reflection literacy builds on action literacy, and not the other way around. Our study contradicts this hierarchy. For example, action literacy (e.g., using interactive features to look up legends) supported recognition literacy, and knowledge of the depicted social context through lived experience supported recognition of signs. These interactions between different aspects of literacy are not captured by frameworks that are useful for large-scale surveys such as IALS and PIAAC (OECD, 2000, 2019). There, standardized tasks are administered to participants across countries and cultures and are therefore unlikely to capture themes that are deeply connected with the participants' social context. For example, IALS applied a task about firework related injuries (Kirsch, 2001), which could be comprehensible to many participants. However, it is unlikely that such a social context is really significantly impacting the participants' social lives, in the same way as the COVID-19 pandemic impacted the participants in our study. Therefore, our qualitative study could capture the role of the social context in making sense of DVs. This demonstrates how qualitative research can complement quantitative research such as IALS and PIAAC (OECD, 2000, 2019).

What also characterized visual-numeric literacy was that it interacts with other forms of literacy. For example, when the participants scrolled and used toggles, they used their digital media literacy. The interaction between visual-numeric literacy and digital literacy was also

observed by Tønnessen (2020). We also observed that visual-numeric literacy interacted with a more general mathematical literacy when making sense of relative numbers and logarithmic scales. A limited understanding of these concepts was a hurdle for the sensemaking process. However, with some guidance, participants were able to develop this understanding. Visual-numeric literacy also interacted with media literacy, when participants showed skills in filtering and organizing the web page. Neither of our participants explicitly attended to the instances of embedded criticality (Gal & Geiger, 2022), but one participant showed a critical awareness of the data quality. The fact that they did not critique or enquire into the underlying data infrastructures supports Evans' (2018) concerns about the non-transparent boundary between lay people and people with statistical expertise. The interaction between multiple forms of literacy agrees well with Gal and Geiger's (2022) call for blended knowledge where mathematical and statistical knowledge are integrated with other forms of knowledge such as language, contextual knowledge and critical demands.

A further characteristic of visual-numeric literacy relates to the diversity and design of DVs. We observed a diverse range of DV formats including a line graph with missing vertical axis (Figure 1), bar charts, choropleth maps and a barcode plot (Figure 4). These illustrate how media (1) continuously introduce new formats and (2) break conventions taught in schools. This diversity and unconventionality mean that readers need to continually and flexibly adapt and develop their visual-numeric literacy to account for new formats and new contexts. At the same time, we also observed that the DVs were designed with journalistic insight that supported readers. For example, the use of colours to express danger (red) or calm (white), the inclusion of legends and explanatory text to guide readers, and the use of headings to create structure and coherence, were helpful cues and lowered demands to visual-numeric literacy.

In addition, we found two characteristics of how readers can approach their visual-numeric literacy. The first can be characterized as *avoiding DVs* and consequently not using opportunities to develop visual-numeric literacy. The second approach can be characterized as *being interested in social phenomena depicted by DVs*, whereby a need for information leads to frequently visiting DV-filled media pages that are regularly updated and relevant to a reader's life. One case in our study shows that this second approach can lead to the development of a sophisticated visual-numeric literacy.

Of course, our study has limitations through the selection of DVs and the low number of participants. However, the low number of participants enabled an in-depth analysis. Further, the research setting, where a participant reads DVs under the watching eyes of a researcher, is artificial and does not match the circumstances under which readers typically interact with digital DVs. A further limitation in this study is the theoretical framework; it is well suited for describing the participants' capacity to read and make sense of the DVs as well as describing the sense-making processes, but it does not reveal how visual-numeric literacy can be developed.

Our study sheds light on the need to think of graph reading as a practice that is deeply connected to the readers' social context. Therefore, we recommend mathematics educators to go beyond teaching graph reading as a mechanical decoding of signs, and to connect signs to events that are authentic and relevant to the students' lives. The DVs that people encounter in everyday life are constantly changing. Therefore, readers must constantly adapt their visual-numeric literacy to new demands. Lifelong learning of visual-numeric literacy can start in schools but must be reinforced by regular participation in activities that involve DVs, such as reading the news. Also, DV designers should be aware of and attend to the challenges that readers face when reading DVs. These challenges depend on the readership and the social context visualized (e.g., COVID-19, climate issues). We recommend that DV designers consider further developing appropriate reader guidance by offering explanations of key

concepts, clear structure and guidelines for how to read DVs, as well as meta-information about the data (sources, methods for handling, etc.).

In terms of recommendations for theory and research, this study sheds light on the need for researchers to use theoretical frameworks with a broad scope that can capture the many facets of reading and making sense of DVs. In particular, the role of lived experience was found to be significant and is easily overlooked in frameworks that focus on cognitive skills. We encourage future research to focus on why some people productively engage with everyday mathematics while others avoid it. We also encourage future research on finding ways of teaching mathematics in mandatory, vocational, and adult education that can promote participation and lifelong learning in everyday mathematics activities. In this regard, we expect that teaching approaches that involve practical and relevant activities can be beneficial, and that emotions play a vital role.

DVs are ubiquitous in contemporary society, and are used to offer information of democratic, social and economic relevance (Engebretsen & Kennedy, 2020). People who are unable to make sense of DVs can therefore have problems participating in important discourses. The high number of people who perform poorly on surveys of relevant skills are worrying (OECD, 2000, 2019), and the present study adds to the concern by showing how one participant, who habitually avoided DVs and other numerical content in everyday life, struggled to make sense of many DVs. As with other mathematical practices in everyday life, DV reading is context dependent and in constant development (Jackson et al., 2018). Therefore, we encourage efforts to make school mathematics more socially relevant with the aim of preparing students for lifelong participation and lifelong learning in adult life.

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