The role of context knowledge for middle school students' development of critical statistical literacy

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Context knowledge generally plays an important role for learning statistics, but insights are needed into its role for the development of statistical literacy. This study reports on a design research project in which a digital learning environment was developed to foster middle school students' critical statistical literacy. Design principles include a focus on building context knowledge and scaffolding reflections of statistical arguments. The qualitative analysis shows that students use context knowledge to reflect on limitations, relevance, and consequences of statistical arguments. It also reveals that this context knowledge is often taken from phenomena which are outside the current learning environment in a subjective and metaphorical use of context.

Keywords: Statistics education research, statistical literacy, critical literacy, design research, middle school.

Introduction

The development of statistical literacy is a growing concern in mathematics education research. In the wake of the global covid pandemic, recent studies have illustrated the complex demands posed by media items that report on aspects of the pandemic using mathematical and statistical representations and argumentations (e.g. Gal & Geiger, 2022). However, whereas the critical statistical literacy demands are relatively well-elaborated in research (e.g. Weiland, 2017), there exists a need for studies that illustrate learning trajectories towards critical statistical literacy or empirical accounts of students' development of critical statistical literacy. Some existing studies show that context knowledge might play a central role for this development (Vahey et al., 2012; Stephan et al., 2021). This study aims to provide insights into the mechanisms through which context knowledge influences the development of critical statistical literacy. The theoretical background will illustrate a theoretical model for conceptualizing the demands of critical statistical literacy and the role of context. Afterwards, a design research study is introduced that uses a developed digital learning environment to foster statistical literacy by placing special importance on a climate change context. The empirical analysis will show how students' knowledge of contexts surrounding climate change influences their reflections on statistical arguments.

Theoretical background

Analysis and reflection of statistical argumentations

Recent studies show the complex demands posed by media items using "statistical and mathematical products" (Gal & Geiger, 2022). For example, Aguilar and Castaneda (2021) illustrate the mathematical competencies needed to understand the Mexican government's sometimes highly

technical official information on the covid pandemic. To this *analytic* perspective of understanding statistical information, a *reflective* perspective is added by other authors. Gal and Geiger (2022) show that citizens need to evaluate the strength of evidence of the reported information and even need to critically evaluate the "embedded criticality" of the media item by identifying the perspectivity of the media item itself. Kollosche & Meyerhöfer (2021) highlight the role of models in the use of numbers in argumentation. Their analysis of indicators used in communicating the dangers of COVID-19, they show that while on the surface, the mathematical concepts often are simple (e.g. the fraction of deaths per infected person), the statistical procedures and modelling assumptions behind the calculations are extremely complex (e.g. defining what counts as 'dying of covid' and estimating a number of infected persons based on test availability and test characteristics).

This study uses a theoretical model to specify the learning content of critical statistical literacy (Figure 1, adapted from Büscher, 2022). In this model, statistical argumentations create connections between four domains of argumentation: a *phenomenon* about which the argumentation aims to justify a claim, *data* which quantifies the phenomenon, a *model* that highlights specific relations within the data, and the *text* of the actual argumentation at hand – where 'text' means a general form of information consisting not only of words, but also images, graphs, and other forms. A statistically literate reader of an argumentation should be able to engage in *analysis* to separate the rhetoric and visualization of an argumentation from its contents, to distinguish between contextual interpretation and the reported model, and to identify the dataset on which the argumentation builds. Building on such an analysis, a step of *reflection* can uncover missing information and critical blind spots of the argumentation. The text might engage in unfair rhetoric, and alternative formulations of visualizations would paint a different picture. The argumentation might be influenced by the choice of model, and a different model using the same data might produce a different result. The choice of data or sampling method might have influenced the conclusion. And finally, the argumentation might ignore critical aspects of the phenomenon. Thus, a statistically literate and critical reader needs to engage in two very different types of activities: whereas analysis identifies the given content of an argumentation, reflection identifies the content that is missing.

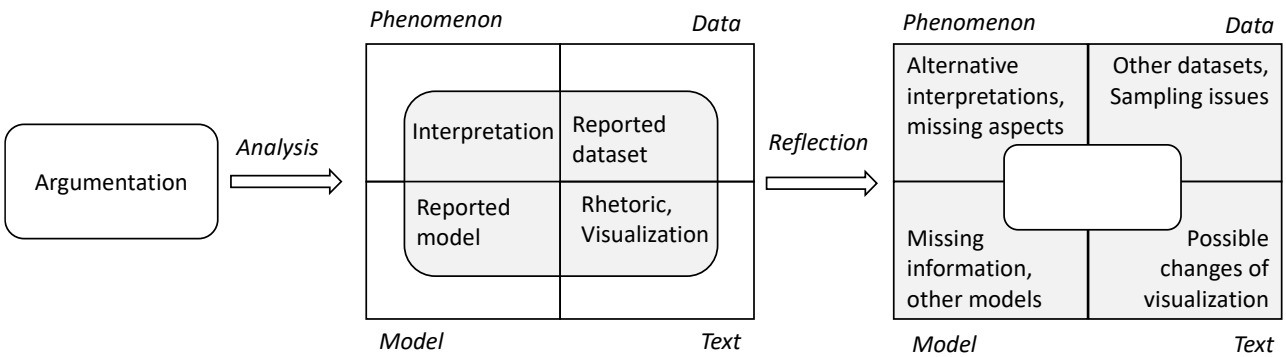

Figure 1: Analysis and reflection of four domains of a statistical argumentation

Context knowledge and statistical literacy

The model of analysis and reflection of statistical argumentations shows that context knowledge of the phenomenon that the argumentation aims for is central. This central role of context knowledge has also been observed by other researchers. Skovsmose (1998) distinguishes four different types of reflection on mathematics, one of which is the context-oriented reflection. This type of reflection is characterized by asking about purpose, the "political and social function of applying mathematics to a certain situation" (Skovsmose, 1998 p. 199). Thus, a reflection on the phenomenon of an argumentation uncovers the larger context in which the single interpretation at hand in the argumentation is situated. Missing context knowledge can then hinder a thorough reflection of the argumentation. One example is illustrated by a study of Stephan and colleagues (2021) about students' sociopolitical awareness about different statistical argumentations. Here, students showed stronger critical awareness when the task was focused on a context with which students had direct experiences (the corona crisis) than when the task used a context with which most of the participating students had only indirect contact (structural racism and police brutality).

This opens the question how to support students in developing the required context knowledge for reflecting on statistical argumentations. One approach used by Vahey and colleagues (2012) is to develop interdisciplinary courses on data literacy. In their study, different lessons in different school subjects provided contributions: social studies provided knowledge of the phenomenon of geography and justice in water allocation, mathematics provided knowledge of data analysis and models, and English arts provided textual knowledge of argumentations. The results show that an interdisciplinary approach provides many benefits, but also poses hard challenges (Vahey et al., 2012).

The problem remains how to provide more focused learning opportunities within mathematics classrooms for developing the knowledge necessary to engage in analysis and reflection of statistical argumentations. For this, more insights are needed into the ways in which students' context knowledge influences their development of critical statistical literacy. Therefore, this study aims to answer the following research question:

> (RQ) Which knowledge of the phenomenon do students use when analysing and reflecting on statistical argumentations and in which ways does this knowledge influence their analysis and reflections?

Method

Methodological background and participants

This study is part of the larger *cli.math* Design Research project (see also Büscher, 2022). Research is conducted in iterative cycles of designing or refining a teaching-learning arrangement on statistical literacy and analysis of design experiments, in order to gain insights into the mechanisms behind students' learning processes (Prediger et al., 2015). The reported study draws from 12 design experiments conducted in June 2022 with 24 students from Grade 5, in which the students worked in pairs on a developed digital learning environment, with the author acting as interviewer and teacher. The design experiments were videotaped, and on average lasted for about 40 minutes.

The cli.math digital learning environment

In the project, a browser-based digital learning environment was designed and developed. In the learning environment, students progress through activities in three "worlds". In the *story world*, the students are presented with information on the phenomenon or Arctic sea ice decline in the form of articles, interviews, and social media posts. The goal of the activity in the story world is to investigate the stories and to extract information and claims about Artic sea ice in the form of "claim cards" and "information cards". Through this card-collecting mechanic, context knowledge about the phenomenon of Arctic sea ice is built. Afterwards, students progress to the *data world*, in which they are tasked with creating visualizations and explanations for the collected claim cards, so-called *data snapshots*, using provided data and analytic tools (Figure 2, top).

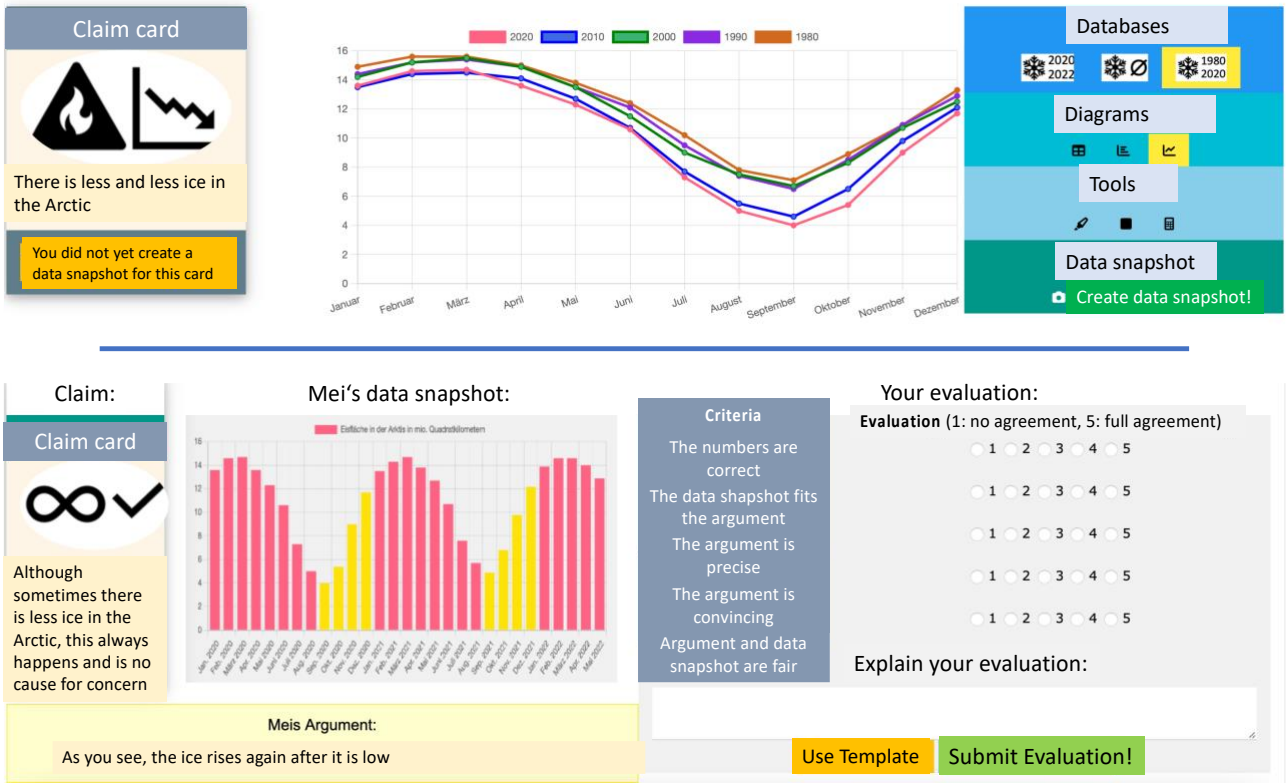

Figure 2: The data world (top) and argument world (bottom) of the cli.math digital learning environment (translated from German)

After creating own data snapshots to claim cards, the students progress to the *argument world*. Here, they find claim cards with data snapshots from fictitious students (Figure 2, bottom left). The students are then tasked with evaluating these data snapshots. After their first reactions, they are provided with prompts of possible criteria as a scaffold for evaluating the data snapshots and are asked to rate the snapshot based on these prompts, and to explain their evaluation (Figure 2, bottom right). Since the current result stem from the first iteration of design experiments, these prompts are still subject to change during the design research project.

Data analysis

From the 12 design experiments, the sequences involving the argument world were taken and transcribed, which resulted in 12 transcripts from sequences of 10-15 minutes in length. These transcripts were then subject to a qualitative analysis involving deductive coding and inductive category generation in the style of open and axial coding (Corbin & Strauss, 1990). In this analysis, codes were assigned to students' utterances signifying the addressed argumentation domains of phenomenon, data, model, and text. By comparing and contrasting cases with minimal and maximal differences, inductive categories were generated describing the role of students' knowledge of the phenomenon when reflecting on statistical argumentations.

Empirical results

In the analysis, three categories of students' use of context knowledge for reflecting on argument of the fictitious student "Mei" that Arctic sea ice is not declining, because during the last two years, the ice regrew in winter (Figure 2): reflecting on the (1) limitations, (2) the relevance, and (3) the consequences of a statistical argument.

Reflecting on limitations

In the first example, the student Cedrik (C) outlines limitations based on contextual knowledge to the interviewer (I).

C: And, well, with two years you cannot really say that it's correct. You have to have something like a couple of decades.
I: Why? You said something like that earlier, and now again. Why?
C: Because changes just cannot be that clear here. Because water is – it doesn't get cold that fast and it doesn't get warm that fast.

In this exchange, Cedrik criticizes Mei's insufficient data base of only two years (a "couple of decades" would be needed). He does so not through theoretical considerations related to sampling, but by drawing on context knowledge: because of the inertia of temperature changes in water (it "doesn't get cold that fast"), a larger timeframe of observation would be needed. What is notable is that the phenomenon from which Cedrik draws – inertia of temperature change in water – is not the same as the phenomenon of Arctic sea ice decline. In fact, as the data show, the temperature of the Arctic did change "that fast", or the ice would not have melted and grown. Nevertheless, for Cedrik, there subjectively is a connection between the phenomena, and this allow Cedrik to articulate a reflection on the limitations of the argumentation at hand.

A different kind of limitation is articulated by Franziska:

F: But, maybe it's possible that […] it gets broken someday, and that it melts, and afterwards when it gets cold, new ice floes appear, but […] maybe not as many as those that disappeared.

Here, Franziska does not directly criticize the data or argument at hand, but goes beyond the data to hypothesize about a future ("someday") in which the mechanism observed in Mei's argument gets disturbed, and the ice does not recover. At this point, it is unclear whether she is aware that this future in fact is already present. However, Franziska frames her reflection in the language of the

phenomenon (melting ice floes and rising temperatures). This indicates an awareness of the phenomenon to be capable of change, so that her context knowledge guides this reflection.

Reflecting on relevance

At a different moment of the design experiment, Franziska and her partner Elena, use their context knowledge in a different way.

F: When it's warm, cold, warm, cold, that's not good for the animals that live there. And maybe not for the ice also, because it's not used to this.

E: Yes, […] and for example it's like that with people. […] So, yesterday it rained sometimes […], and then it got warmer again and then cold again and warm again, and that's dangerous for the human body […].

And, similarly, Robert:

R: So, she says that the numbers go down, and then they go up again. But she ignores that, when the numbers aren't that good, that it can get very bad […], for example, that the animals there cannot find a habitat and go extinct. She doesn't consider this in her argument.

Franziska and Robert draw on context knowledge surrounding Arctic animals to articulate concern about rising and falling sea ice extent. Elena shows a similar use of context knowledge as Cedrik before when she uses knowledge of the human body as a metaphor to also articulate a concern about the Arctic sea ice extent. In this way, the students use very different phenomena as a source of their reflection by "borrowing" relevance. Notably. for all three students, their point of criticism is not the data of the argumentation at hand, but the relevance of the model of the cycle of melting and growing ice. Whereas Mei does not attribute great relevance to the model, the students do. And while their reasoning remains very subjective (e.g. the human body as a metaphor for Arctic sea ice), they still show the ability to reflect on the relevance of a model by using context knowledge.

Reflecting on consequences

In the third category, Cedrik situates Mei's argumentation in a different type of phenomenon:

C: It just feels like a scam, I guess. Because, if you would give it to a person with *[makes air quotes]* 'relatively little education', they would believe it.

Here, Cedrik articulates a concern not with the argumentation itself, but with its possible consequences for society. Earlier, Cedrik rejected Mei's argumentation because of its small reported timeframe. But this is not Cedrik's main point here. Instead, he knows that an argumentation that may be flawed can nevertheless convince other people that are easily manipulated (those with "relatively little education"). Here, Cedrik draws on the social phenomenon of discourse *about* phenomena like Arctic sea ice to reflect on Mei's argumentation.

A similar reflection is articulated by Elena:

E: Well, if you don't worry at all, then you start to not be interested at all. Like, some people would be, but most would stop to care at all, if you would not have any worries.

Similar to Cedrik, Elena does not reflect on the data or model of the argumentation, but of the consequences of an argumentation that calls for stopping to worry about Arctic sea ice: people would stop to be interested at all, which she frames as very undesirable. Both students are not concerned with the truth of Mei's claims, but of the consequences they would have, for which they have context knowledge: knowledge about how people react to convincing information.

Discussion

The empirical analysis shows three categories for using context knowledge for reflecting on statistical argumentation: reflecting on (1) limitations, (2) relevance, and (3) consequences of an argumentation. These identified areas of reflection resonate with the findings of a study by Büscher and Prediger (2019), in which the development of critical abilities is conceptualized as the development of "reflective concepts". Limitations, relevance, and consequences could be considered such reflective concepts. This study's closer inspection reveals the wildly different phenomena from which the context knowledge which grounds these reflective concepts is drawn. The students do not only use knowledge of the phenomenon described by the data – Arctic sea ice – but also knowledge of phenomena such as Artic animal habitats, human health, and mechanisms of convincingness in the social phenomena of public discourse. In this way, the students' critical reflections are grounded in contextual knowledge of a surprising richness.

These findings shed some new light on the role of context for statistical literacy, a concern that has surfaced in other studies (Vahey et al, 2012; Stephan et al., 2021). For example, Stephan and colleagues (2021) find that students' critical consciousness depends on the context of a problem. Building on this study's results, a varying critical consciousness could be the result of reflections on limitations, relevance, and consequences that vary depending on the students' context knowledge. In light of such findings, the place of context knowledge for statistical literacy might have to be revisited: Whereas Gal (2002) places context knowledge alongside, but separate to critical questions and critical stance, this study shows that critical abilities are not independent from context knowledge.

Conclusion

This study reports on a Design Research project in which a digital learning environment for middle school mathematics classrooms was developed. The learning environment pays special attention to building context knowledge of the phenomenon of Arctic sea ice decline and to providing scaffolds for criticising statistical argumentations. The qualitative analysis of 12 design experiments with 24 Grade 5 students has revealed the central role of context knowledge for students' critical reflections of data-based arguments. Although the students' critical reflections in such an early grade are encouraging, they nevertheless provide only the first stepping stones towards developing critical statistical literacy. The analysis has also shown that students' reflections are often highly subjective and not well elaborated. This opens up a perspective for further research to investigate how students could generalize from these context-based reflections to develop a more general critical statistical literacy. Additionally, this study can make no claim regarding the prevalence of such critical context knowledge in other groups of students. As such, more research is required to map out the possibly useful critical context knowledge and to find ways to effectively build on it to develop critical statistical literacy.

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