ARGUMENTATION BASED ON STATISTICAL DATA AT THE VERY BEGINNING OF PRIMARY SCHOOL – EVIDENCE FROM TWO EMPIRICAL STUDIES

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Although students' argumentation is subject of high interest in mathematics educational research, specific studies on argumentation based on statistical data are still scarce, especially with a focus on young students at the beginning of primary school. Therefore, relatively little is known so far to what extent children starting school may already be able to engage in argumentation based on statistical data. Addressing this research need, evidence is reported from two empirical studies, which were conducted with N = 11 and N = 29 students during their first weeks in school. The results show that data-based argumentation is possible for many students from the beginning of primary school on, and provide insight into the broad spectrum of students' data-based arguments.

INTRODUCTION

From the beginning of primary school on, fostering students' argumentation is considered as an important aim of the mathematics classroom, which is reflected in several empirical studies (Sommerhoff et al., 2015), in a variety of literature promoting suggestions on how to foster students' argumentation in the mathematics classroom (Stylianides et al., 2016), as well as in curricula of many countries (e.g. NCTM, 2000). Even if the importance of argumentation is also highlighted frequently in the context of statistics education (e.g. Ben-Zvi & Sharett-Amir, 2005), it appears that data-based argumentation received relatively little attention so far, in particular in the discourse on primary mathematics education. In prior studies (e.g. Krummenauer & Kuntze, 2018, 2019), we have found that many older primary students were able to evaluate interpretations of data and to develop corresponding data-based arguments in different task contexts, including even relatively complex tasks which require considering statistical variation when developing data-based arguments. This raises the question, to what extent data-based argumentation is possible for younger students; in particular, what prerequisites related to data-based argumentation students have when starting school.

Addressing this research need, this paper is focused on the extent to which primary students are able to develop data-based arguments in different task contexts at the beginning of their first year in school. The empirical evidence reflected on in this paper has been gathered in two studies, applying an innovative study design. The results presented in this paper substantiate that data-based argumentation is possible for many

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students, in appropriate task contexts, already at the beginning of primary school, and give insight into the spectrum of complexity in students' data-based arguments.

In the following, the theoretical background of the research reported in this paper is presented, and the research interest is specified. Subsequently, the methodological background and empirical evidence from two studies are reported. The results and implications of both studies are discussed in the concluding section.

THEORETICAL BACKGROUND

When students encounter statistical data in real-life contexts, these data often are accompanied by different and sometimes conflicting interpretations. For dealing with statistical data and related interpretations it is, therefore, crucial that students are able to evaluate whether or not interpretations of data indeed can be substantiated by the respective data, and that students are able to justify their position based on data. We refer to this by the term *data-based argumentation*, which is considered as a specific case of argumentation in which statistical data are used to convince others that certain statements are true or false (Krummenauer & Kuntze, 2019). As presented in detail in a research report at PME 42 (Krummenauer & Kuntze, 2018), key requirements of data-based argumentation can be described from a theoretical perspective building up on psychological theories on children's *scientific reasoning* (e.g. Kuhn, 2011; Sodian et al., 1991; Zimmerman, 2007). In this perspective, interpretations of data have the status of hypotheses (in a broader sense, *theories*), while the statistical data these interpretations refer to represent the available *evidence*. When students develop data-based arguments, they are required to *coordinate* interpretations of data with the status of a *theory* and the statistical data with the status of *evidence* with each other, e.g. when evaluating whether interpretations are consistent with corresponding data or when basing own interpretations on data. In the literature, several strategies for coordinating theory and evidence (e.g. Zimmerman, 2007) are described, which are highly relevant for data-based argumentation: a fundamental strategy for coordinating theory and evidence is, for instance, to distinguish elements representing theory, such as claims or own beliefs, strictly from elements representing evidence (e.g. Kuhn, 2011); another scientific reasoning strategy, which is particularly helpful for data-based argumentation, is to search intentionally for counter-evidence (e.g. Sodian et al., 1991), instead of primarily searching for supporting evidence.

During the past decades, a large body of research on the development of scientific reasoning has emerged (Zimmerman, 2007). Several studies have shown that already children in kindergarten and primary school can be able to master tasks on coordinating theory and evidence (e.g. Koerber et al. 2005). However, at the same time, there is frequent evidence of insufficient strategies hindering the coordination of theory and evidence. For instance, Koerber and colleagues reported in the mentioned study that kindergarten children showed a tendency to be influenced by own assumptions when coordinating theory and evidence. Further, there are studies implying that young students tend to have difficulties to consider statistical variation when coordinating theory and evidence (Masnick & Morris, 2008). In conclusion, the available studies on scientific reasoning imply that students at the beginning of primary school may already have some cognitive preconditions for data-based argumentation; at the same time, it needs to be expected that difficulties regarding the coordination of theory and evidence may cause difficulties in data-based argumentation.

In empirical studies with older primary students specifically targeting on students' data-based argumentation (e.g. Krummenauer & Kuntze, 2018, 2019), many participants were able to evaluate interpretations of data and to develop arguments based on the data for substantiating their evaluation; in the case of the study reported in Krummenauer and Kuntze (2018), this required students even to take into account statistical variation of the data. These studies also revealed that some students gave answers indicating specific difficulties, which appear to be interrelated with difficulties in students' scientific reasoning; for instance, some students used only aspects of data for argumentation which were in line with their assumptions but did not consider disconfirming data (Krummenauer & Kuntze, 2019).

RESEARCH INTEREST

Building up on the research with older primary students, the studies reported on in this paper were conducted in order to investigate the extent to which data-based argumentation is possible already for primary students starting school. In particular, the research presented in this paper is targeted on the following research question:

To what extent is it possible for students at the beginning of the first grade to evaluate data-related statements and to develop data-based arguments in order to justify their evaluation?

STUDY I

Design of the Study

As there had been hardly any specific research on young primary students' data-based argumentation so far, a first exploratory interview study has been conducted (Krummenauer et al., 2020). In preparation for this study, an interview design needed to be developed, which addresses the specific needs of young students. As it cannot be expected that children produce data-based arguments spontaneously, an elicitation method was developed, implemented in a one-to-one interview design. For that, a set of tasks had been adapted specifically to the needs of students at the beginning of primary school. In the interviews, the tasks were presented to the students one after another, following a highly standardised interview guideline. Each task consists of a data set (two examples are given in Figure 3) visualised by means of pictograms, in combination with corresponding statements expressing interpretations of the data (e.g. "Most students like chocolate ice cream" in case of the data set in part b) of Figure 3). In the interviews, the task context and the data as well as a statement to be evaluated were presented to the students. Subsequently, the students were asked to evaluate the statements and to justify their evaluation, so that the students were required to develop data-based arguments. In this first study, *N* = 11 students (6 girls, 5 boys) were interviewed during their first weeks in school. There had been no prior intervention and the interviewer carefully avoided giving any examples or hints. The transcribed interview data were subjected to a dichotomous top-down coding in order to find out whether the students developed consistent data-based arguments in respondence to the tasks. To be rated as "consistent data-based argument", answers had to contain a correct evaluation of the statement (e.g. "no, that's not true") and a reference to aspects of the data which allow to substantiate the given evaluation; sample answers fulfilling these criteria are presented below in detail. Answers not meeting these requirements were subjected to a further bottom-up analysis (overall inter-rater reliability: κ = .96) investigating types of students' difficulties, which is reported in Krummenauer et al. (2020); in the present report, we deepen the analysis regarding the top-down analysis in order to gain deeper insight into the qualitative spectrum of students' successful data-based arguments identified in the top-down analysis.

Results

Figure 1 gives an overview of the number of consistent data-based arguments for each student. All participants were able to develop at least one consistent data-based argument, and most of the students developed consistent data-based arguments in more than half of the tasks. In one case (S6), a student provided consistent data-based arguments for almost all 11 tasks. To give insight into the coding and into the spectrum of students' successful answers, two sample answers differing in their complexity are discussed in the following, beginning with an example with relatively low complexity, but still fulfilling all above-mentioned criteria of data-based arguments.

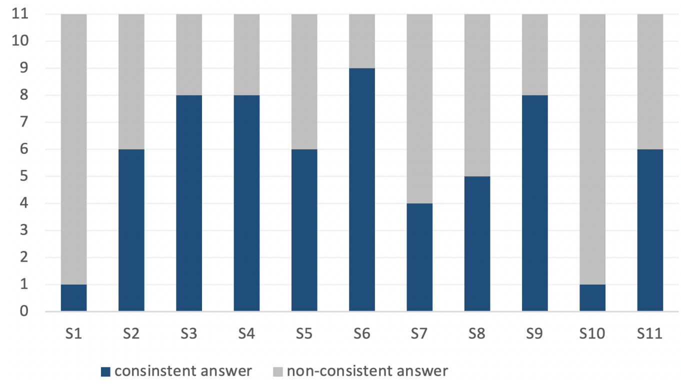

Figure 1: number of answers containing data-based arguments per student (cf. Krummenauer & Kuntze, 2020)

The following transcript (translated from German) is related to a task, which is about a fictive competition in which the drivers of four cars meet once a week for a race. The diagram in part a) of Figure 3 displays the number of trophies won by each driver. The transcript starts after the interviewer had introduced the data set and its context. In (1), the interviewer presents (by means of and in the name of a hand puppet) the statement which shall be evaluated based on the data.

(1) hand puppet: If I would take part in the race, then I would take the red car, it looks the fastest.

(2) student: But it isn't. The green car is the fastest, because it has the most trophies.

In (2), the student rejects the hand puppet's statement ("But it isn't"), i.e. the student gives a negative evaluation of the statement. The student then substantiates this evaluation by correcting the statement ("The green car is the fastest") and connecting it with the term "because" to the number of trophies, i.e. aspects of the data which support the student's evaluation of the hand puppet's statement.

The next sample answer refers to a – in terms of coordinating theory and evidence – more complex task, which is about a school excursion with two participating classes ("hedgehog class" and "mouse class"). During the excursion, each student was allowed to order one scoop of ice cream; the two data sets (part b) of Figure 3 represent the number of scoops of ice cream ordered in each class.

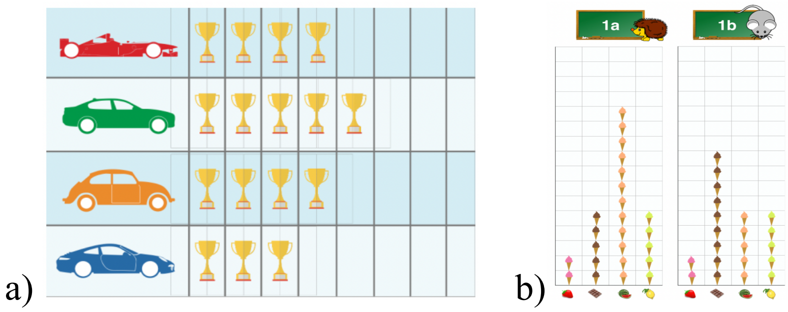

Figure 3: task examples (Krummenauer et al., 2020, p. 5; 7)

The transcript starts after the task context was introduced.

(1) hand puppet: In the hedgehog class are more children than in the mouse class.

(2) interviewer: Is this true?

(3) student: (agrees).

(4) interviewer: How do you know that?

(5) student: (points to the data in the diagram) look, here are two. Then here are two. Look, both are five, that is both five / So, this is two times five, this is two times five, this has one times two and this [the bar of chocolate scoops] has this height, but this here [the bar of melon scoops] is a bit higher.

After the statement to be evaluated was presented in (1), the student indicates in (3) a positive evaluation of the statement. After the interviewer asked for a justification, the student substantiates the evaluation in (5) based on the data: the student identifies and matches bars with the same height in both data sets (bars with the height 2 and bars with the height 5) and shows that the remaining bar in the diagram of the hedgehog class is higher than the remaining bar in the diagram of the mouse class, so that more students need to be in the hedgehog class than in the mouse class. In comparison to the first sample answer, this argument has a much higher complexity in terms of coordinating theory and evidence, as the student needs to relate the data for all sorts of ice cream to each other. This results in an argumentation with multiple steps, while developing an argument in the first example only requires to relate fewer elements of the data with the statement being evaluated.

STUDY II

Based on the first study, which had shown a relatively broad spectrum in students' data-based argumentation – both in regard to the number of data-based arguments per student as well as in regard to the complexity of students' arguments – a second study was conducted recently in order to investigate in more detail and with a larger sample size the qualitative spectrum of students' data-based argumentation at the beginning of primary school.

Design of the Study

For this, the methodology of the first study was further developed. In order to make the full spectrum of students' data-based argumentation visible, the set of tasks was systematically further developed in order to be able to provide a spectrum of tasks to students, differing in their complexity under the perspective of coordinating theory and evidence. The tasks were implemented in a similar interview design as in the first study and were administered to $N = 29$ primary students at the beginning of their first year in school, again without any prior intervention. In the following, we reflect in detail on the quantitative results related to three tasks, which provide further insight into the spectrum of students' data-based argumentation at the beginning of primary school. The inter-rater reliability of the top-down coding conducted for this analysis is $\kappa = .88$.

Results

At first, we would like to put the focus on the task in part a) of Figure 3, which had the highest rate of successful answers in the study; 82.8% of the students were able to develop a consistent data-based argument in respondence to this task. The task is about the number of marbles of three children displayed in the diagram. The statement to be evaluated in this task by the students is "Jana has got three marbles". Compared with the tasks presented above, the complexity in terms of coordinating theory and evidence is reduced, as the data which is needed for evaluating the claim can directly be taken from the diagram; no further steps, such as comparing different data sets, as required in the case of the task on ice scream scoops shown above, are necessary.

The data set on ice cream scoops had also been used in the second study, combined with a modified statement ("in the mouse class, more children like chocolate ice cream than in the hedgehog class"). In contrast to the marble task, this task requires to compare data from two data sets in order to gain the relevant evidence for evaluating the statement. Empirically, the increased complexity is reflected in a lower success rate of 48.3%.

Beyond such tasks, we implemented further, more complex tasks in which coordinating theory and evidence does not only require to take into account and to compare several data points, but also to consider that the given data may vary to some extent. A sample task is shown in part b) of Figure 3. The task includes two diagrams displaying how many deers have been observed during the past five days in a forest (right diagram) and in a city park (left diagram). In the task context, the students had to evaluate the statement (claimed by a character of the context story) “If I really want to see a deer, I should go to the park“. As the data imply that the number of deers can change from day to day, and as the statement is about the future, the task requires students to take into account that the data may vary, which needs to be addressed when developing a corresponding data-based argument. In our study, several students compared the number of deers and argued, that it would be better to go to the forest as the number of deers in this diagram is higher; however, no student in the sample considered that the data may vary, which appears to be a challenging requirement for the participating students.

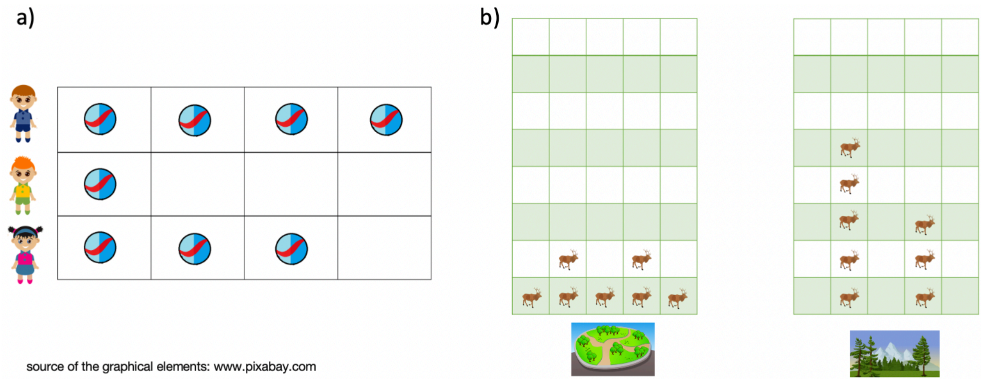

Figure 3: sample tasks

DISCUSSION AND CONCLUSIONS

Both studies have shown that the participating school starters were in many cases able to evaluate given interpretations of data and to develop consistent arguments based on the data in order to substantiate their evaluation. Although the samples of the studies are clearly not representative, the qualitative and quantitative analyses revealed a broad spectrum of students’ data-based argumentation, both regarding the frequency as well as the complexity of their arguments. Against the background that both studies had been conducted without any prior intervention, it appears that young primary students have a high potential related to data-based argumentation, which should be addressed and fostered in the mathematics classroom during primary school (and beyond). As implied by research on children’s scientific reasoning (Masnick & Morris, 2008), the students showed difficulties in tasks which require considering statistical variation when developing data-based arguments. Fostering students in this regard, e.g. by providing learning opportunities which allow for experiences in dealing with statistical variation, may therefore be a promising approach for fostering students’ data-based argumentation, which is planned to be evaluated in an intervention study.

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