

Data-based argumentation tasks in the context of climate change and primary students' reported self-efficacy growth in climate change-related discourse participation

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Education for sustainable development should enable citizens to take part in social discourses and decision-making through argumentation in favour of the protection of resources. As misinterpretations of statistical data are often part of sustainability-related discourses, the mathematics classroom should empower future citizens by building up competence in data-based argumentation as well as fostering self-efficacy necessary for responding to misinterpretations of data and actively participating in sustainability-related discourses. However, empirical research about the role of data-based argumentation for self-efficacy in taking part in climate-related discourses is scarce, especially for young learners. This study responds to this research need: 86 primary students took part in a survey in which they were asked to comment on incorrect interpretations of climate-related data and to justify their answers. These stimuli showed impacts on students' reported self-efficacy growth with respect to argumentational participation in climate change-related discourse.

INTRODUCTION

Climate change being one of the major urgent challenges, knowledge and competences related to climate change and climate protection are a key topic domain in education for sustainable development (ESD). Beyond acquiring knowledge about climate change and its origins, school students should build up competences which enable them to take part actively and responsibly in argumentational discourse related to climate change as citizens and (future) decision-makers in their daily lives. Preparing young citizens for participating in climate-related discourse implies educational goals from the primary school level on (UNESCO, 2020). As argumentation on interpretations of climate-related data plays a major role for such goals (Kuntze & Krummenauer, 2025), there is a need of investigating the role of data-based argumentation (theoretical background e.g., in Krummenauer et al., 2022) in this context. Further, research has shown that students' self-efficacy (e.g., Maddux, 1991; Bandura, 1977; Pekrun, 2006) can play a key role in terms of participation (e.g., Solhaug, 2006). We therefore expect that students' self-efficacy regarding participation in discourses plays an important role for students' tendency whether they actually would actively engage in data-based argumentation in relevant real-life situations. Consequently, in this study, we focus specifically on the interplay of data-based argumentation and students' self-efficacy related to participating in climate-related discourse.

Despite its significance and a growing body of literature related to ESD, empirical research on data-based argumentation in ESD topic contexts, on aspects related to self-efficacy, as well as on their possible interplay is still scarce. This study explores whether stimuli in data-based argumentation related to climate change contexts may have an impact on students' reported change in self-efficacy related to taking part in climate change-related discourses.

In the following, we (1) introduce shortly to the theoretical background related to ESD, to data-based argumentation, as well as to discourse-related self-efficacy, (2) deduce the research questions, (3) inform about the design and the methods used in this study, (4) report on empirical results, and (5) discuss these together with implications for practice and for follow-up research.

THEORETICAL BACKGROUND

Goals related to education for sustainable development (ESD) cover a broad spectrum of domains and topics (UNESCO, 2020). Thus, competences related to citizens' knowledge-based participation in social discourse and decision-making processes can be seen as overarching to many of them. At the same time, being able to deal with data and interpretations of data, including the use of statistical models and representations, need to be considered as key to such competences, as sustainability-related topics often refer to data and their interpretation. In discourses connected to climate change, for instance, statistical data is continuously used to justify predictions, to support warnings, to substantiate the need for political measures for climate protection, but also in

disinformation campaigns or greenwashing (Ödmo et al., 2023; Coles, 2023; Kuntze & Krummenauer, 2025). Consequently, being able to deal with data in *argumentation* contexts appears as a primordial competence aspect for enabling citizens to participate in discourse on climate change, and such competences should be prepared from the primary school level on (UNESCO, 2020).

Even if, in the context of approaches to statistical literacy or statistical thinking (Wallman, 1993; Watson, 1997; Watson & Callingham, 2003; Shaughnessy, 2007; Kuntze et al., 2008, 2015, 2017), aspects such as the examination of statistical data, the competent use of statistical models and representations, as well as the critical evaluation of claims based on data have been emphasised since more than 30 years, a targeted focus on data-based argumentation in empirical research has been rather rare in mathematics education and statistics education research. Consequently, a research program has been taken up in this domain (e.g., Krummenauer & Kuntze, 2018; Krummenauer et al., 2020; Krummenauer et al., 2022, 2023). The challenges students encounter in data-based argumentation can be described based on existing theories on scientific reasoning (e.g., Zimmerman, 2007; Dunbar & Klahr, 2012; Bullock & Ziegler, 1994). In this perspective, statements under discussion have a status of a *theory* or a hypothesis, while the statistical data represent the *evidence*; both need to be distinguished and coordinated in the sense that theories or hypotheses have to be rejected in case of counter-evidence. For this, students need sufficient strategies (e.g., Morris et al., 2012). Data-based argumentation is accessible from the beginning of the first grade in primary schools on (Krummenauer et al., 2020; Krummenauer et al., 2022, 2023), it is not identical to abilities of reading from diagrams and it can be fostered through focused interventions (Krummenauer & Kuntze, accepted).

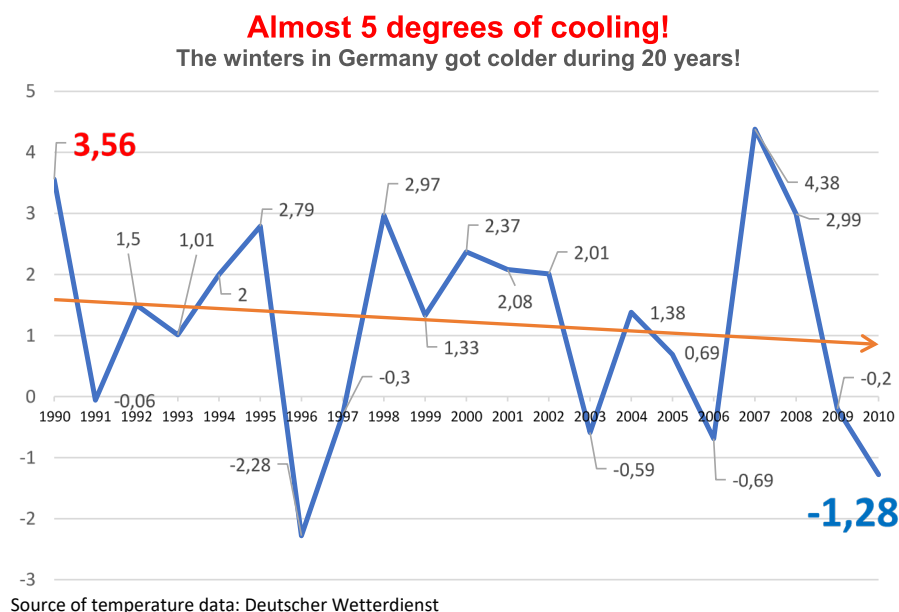
Data-based argumentation tasks which require to deal with statistical variation, i.e., with the need to reconsider the evidence in the data with respect to its variation, and which require to weigh different data-based argumentations, have shown to be particularly demanding (Krummenauer et al., 2022).

In ESD contexts in general and in climate change-related topics in particular, citizens are often confronted with disinformation and/or greenwashing attempts. While, in many cases, such attempts only consist in stating false or misleading claims (without an actual connection to available data), there are also more complex cases in which such claims are suppositiously connected to data in order to substantiate the claim. In such cases, it is necessary to actively question the claim and its substantiation by the data – i.e., students have to engage in data-based argumentation. Figure 1 shows an illustrative ESD-related sample task representing such requirements. Such tasks can be expected to be demanding to students, as dealing with statistical variation and weighing different data-based arguments are needed.

In the illustrative task in Figure 1, data on average winter temperatures in Germany is displayed. The headline of the diagram includes a claim about the data: “Almost 5 degrees of cooling!”. Below the diagram, a statement is presented, which includes a data-based argument. In the argument, the statistical variation included in the data is rather not acknowledged. In order to evaluate the headline and the statement in the sense of criticism, students could, for instance, compare pairs of the given data points (e.g., of the years 1996 and 2007). Moreover, it appears that there is a sampling issue: The years prior to 1990 and after 2010 are left out. Considerations on how these data may look like could be included in a more comprehensive data-based argumentation, so that also the “regression arrow” shown in the diagram could be subjected to a more comprehensive and deeper data-based argumentation. Further, the possible effect of choosing a limited data set could also be examined on the base of the data given in the task – for instance, choosing the time interval from 1991 to 2008 instead would lead to a regression line with a positive slope. Such considerations related to data-based argumentation can lead to a well-substantiated contribution to a discussion, highlighting the potential contribution of data-based argumentation to ESD.

A key idea related to ESD goals is that students should not only acquire knowledge, but should also be empowered to be able and ready to apply this knowledge in real life situations – i.e., in this case, to participate argumentatively in discourses on ESD-related topics. We expect that students’ self-efficacy (Pekrun, 2006; Bandura, 1977; Maddux, 1991), which is considered in this study as students’ expectations related to the success in certain tasks (Maddux, 1991), may be interrelated with students’ readiness and willingness to participate in ESD-related discourse. However, empirical research on students’ competence related to tasks with ESD relevance is scarce, and also with respect to students’ self-efficacy, there is a need of empirical research on whether stimuli in data-based argumentation can

have an impact. In particular research about young learners from primary school on is needed, as the interplay of growth in learning and related self-efficacy starts early. Consequently, this study focuses on this research need.



Climate change is everywhere in the media, but you have to look at it with more precision. If you take the average winter temperatures from 1990 and 2010, you get a drop in temperature of almost 5 degrees! How can you speak of global heating against this background?

Evaluate this claim – and don't forget to justify your answer.

Figure 1. ESD-related task (topic area climate change, Kuntze & Krummenauer, 2025, p. 326).

RESEARCH AIM

Against the background of the research needs outlined above, this explorative study focuses on the following research questions: (i) How do primary students perform in climate change-related data-based argumentation tasks in which a non-optimal data-based argumentation statement is given and has to be evaluated? (ii) To what extent do stimuli of data-based argumentation in climate change-related contexts impact on reported growth of self-efficacy in participating in discourse about climate change?

DESIGN OF THE STUDY

In order to respond to the research questions, a paper-and-pencil survey field study was carried out. $N = 86$ primary school students (4th year) were randomly assigned to two groups: Group A received data-based specifically designed argumentation tasks (see Fig. 3 for a sample task), then answered a multiple-choice questionnaire on the reported growth of self-efficacy aspects related to actively taking part in climate-related discourse, and then worked on tasks on reading data from diagrams. Group B received the task variants in inverted order (overview in Figure 2). All data/diagrams in the tasks were on climate change and they were kept parallel across task variants.

Figure 3 shows a sample data-based argumentation task in an ESD context which has been designed for the purpose of this study and its target group. Data with variation is given in a diagram,

and a cartoon character (“Mia”) claims that it is not possible to see from the data that it has become warmer over the years in Germany. As a support for this claim she refers to a pair comparison of the average temperatures from two years (2021 and 1994). The students’ answers were coded in a top-down coding procedure. A successful data-based argumentation answer had to express critique towards the given statement and to justify this critique by referring to the data consistently, e.g., pointing to the higher frequency of years with higher average temperature on the right hand side of the diagram. Five more data-based argumentation tasks were designed in a structurally parallel way for the use in this study, with different context and data configurations. For all six tasks, an additional task version was designed focusing on reading data from the diagrams only, with questions asking students about values shown in the corresponding diagram (this time without asking students to generate an argument). This parallelised set of 6+6 tasks made the design of the study in Figure 2 possible.

The scales on reported growth of self-efficacy were newly developed and focused on knowledge, participation, and argumentation with respect to climate-related discourse. Table 1 in the results section gives an overview on the scales and provides sample items.

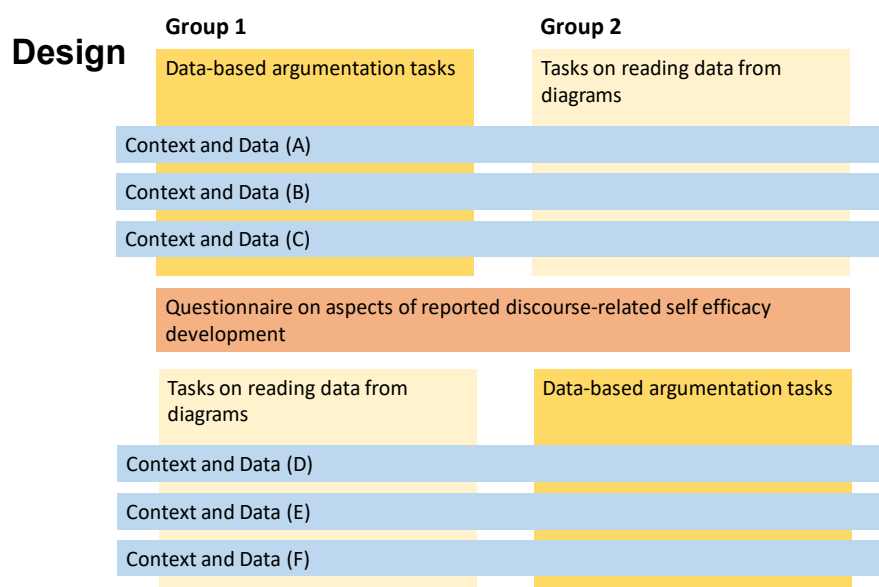


Figure 2. Overview of the design of the study.

Coding of students’ solutions was done by two raters ($\kappa=0.82$), a response to a data-based argumentation task was coded as correct if non-agreement with the given statement was substantiated consistently with a reference to the given data (criterion-based top-down coding, cf. also Krummenauer & Kuntze, 2018, accepted, for more detail). Inter-rater reliability was hence completely satisfactory.

RESULTS

Research question (i) focuses on the students’ data-based argumentation. The coding yielded a frequency of 19,3% (group A) of students who were able to generate at least one successful data-based argumentation. The following transcript is a sample student answer (translated) assigned to group A: “*She is right, because it was indeed warmer in the year 1994 than in the year 2021. But she is also not right because in the year[s] from 2014 on it was almost always somewhat warmer than in the year[s] 1983 to 2013.*”

This answer was coded as successful data-based argumentation, as the answer includes criticism of the statement (“*But she is also not right...*”), which is supported through a clear reference to the data of the years 2014–2022. The student uses the expression “*almost always somewhat warmer*” in order to deal with the statistical variation of the data and to express the upward tendency s/he has identified in the data.

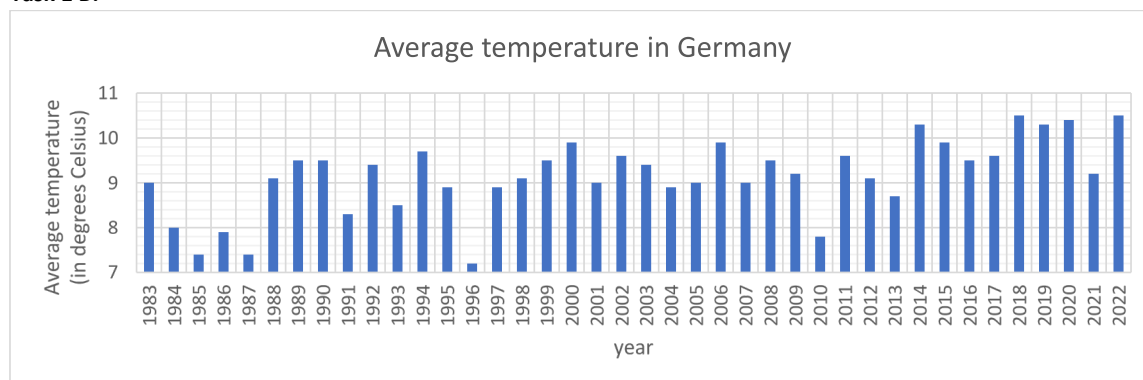
In the following, we would like to focus on a further sample answer (translated): “*It is half correct. The temperature does on average not go below 8 degrees centigrade after 2010. But it is correct that 2021 was much colder than 2018*”. This student also criticises the given statement (“*It is half*

correct...”) by supporting this claim by data, here the lower boundary of 8 degrees is used for completing the argument. Also in this answer, the weighing of arguments against the background of statistical variation can be observed, in this case a pair comparison between 2021 and 2018 (which may have been seen by the student as analogous to the given comparison between 2021 and 1994) is made.

A third sample answer for the category of successful argumentations is the following (translated): “Yes, the year 2021 was colder than the year 1994. Yes, the temperature has always been varying, but it gets somewhat warmer, as the bars become higher”. In this answer, the given statement is commented on part by part. In this case, the statistical variation is acknowledged by the first part of the second sentence (“Yes, the temperature has always been varying”), so that the final concluding argument (“but it gets somewhat warmer, as the bars become higher”) has to be read as a tendency observed by the student in the data. In the successful answers, different individual student strategies of dealing with statistical variation and weighing arguments could hence be detected.

Look at the following diagrams and read the statements of the children. Judge on whether they are right. Justify your decision.

Task 1 B:



Source: DWD – Deutscher Wetterdienst (o. J.): Zeitreihen und Trends, retrieved from: <https://www.dwd.de/DE/leistungen/zeitreihen/zeitreihen.html#buehneTop> (9 may 2024)

Mia says on the data in the diagram above:



The average temperature has always been varying. You cannot see from the data that it has become warmer over the years with climate change. The year 2021 was colder than the year 1994, for instance.

Is Mia right? Justify your answer.

Figure 3. Sample task (data-based argumentation) for the tasks used in this study.

However, the majority of the students’ answers were coded as unsuccessful data-based argumentation attempts, such as the following example (translated): “Yes, she is [right], as the year 1994 is clearly warmer than 2021.” In this answer, the given pair comparison is verified in the data, whereas the student does not acknowledge that the given conclusion “You cannot see from the data that it has become warmer over the years” cannot be deduced from this pair comparison which focuses only on 1994 and 2021.

Research question (ii) concentrated to the reported self-efficacy growth in discourse participation. First of all, the newly developed scales showed satisfactory reliability values (Table 1).

Table 1. Scales on reported aspects of self-efficacy growth and reliability values.

Scale: Reported self efficacy growth ...	Sample item	Number of items	α (Cronbach)
... in knowledge about climate change	...I have learned something new about climate change.	4	0.76
... in climate-related communication	...I can better participate in conversation on climate change.	3	0.73
... in climate-related argumentation competence	...I have learned to evaluate what other persons say about climate change and to justify my statements well.	4	0.79

Group A with the data-based argumentation tasks showed significantly higher reported self-efficacy growth in communication and argumentation than group B (Figure 4).

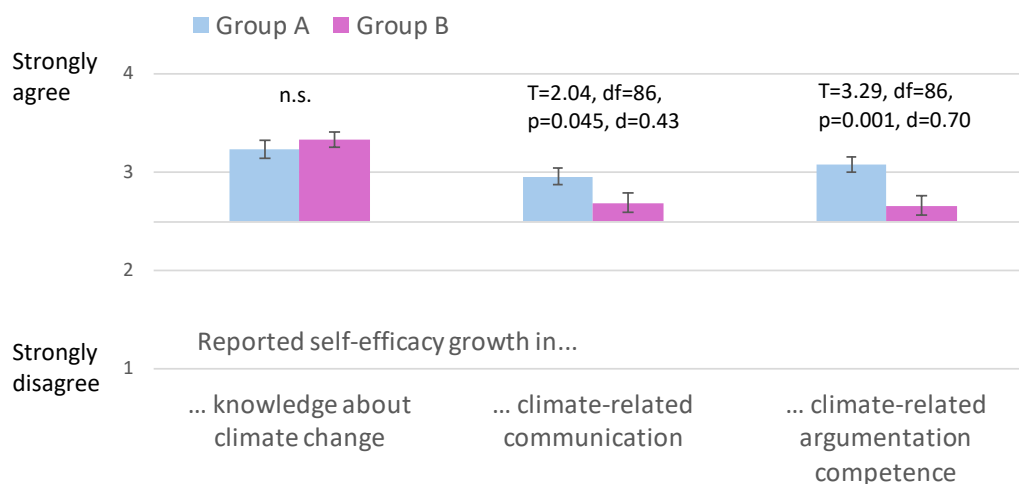


Figure 4. Reported self-efficacy growth in discourse participation (means and their standard errors).

DISCUSSION AND CONCLUSION

First of all, we would like to recall the limitations of this explorative study. The sample is of course not representative for primary students in Germany. Moreover, due to limited testing time, the findings are only based on three argumentation tasks (e.g., Krummenauer & Kuntze, accepted) per group. The indicator-like focus on reported growth in self-efficacy aspects is a further limitation of the study. However, the research questions could be answered.

Research question (i) focused on the students' success in data-based argumentation. The results show that successful argumentations were rather non-frequent, which corresponds to the expectation that tasks which require dealing with statistical variation and some weighing of different argumentations are, without prior intervention, demanding for primary students. This corresponds to observations of a high empirical task difficulty in prior studies (Krummenauer & Kuntze, accepted; Krummenauer et al., 2022). Also beyond studies with a specific focus on data-based argumentation, dealing with statistical variation has been shown to bring comparably high complexity (Kuntze et al., 2008; cf. Watson & Callingham, 2003). In the cases of students' successful data-based argumentation, different strategies of dealing with variation and of weighing argumentations could be observed. For classroom practice, the findings showcase the need to foster students' competences in ESD-related data-based argumentation. When creating such learning support, a rich variety of student strategies can be included in the classroom discourse, so that students can build up a set of multiple strategies for generating data-based arguments in ESD contexts. Relatively elementary ways of analysing data for argumentation purposes can be foregrounded in the early classroom, such as considering frequencies of high and low values for

detecting tendencies, for example. More sophisticated models can be introduced later and could be motivated through specific needs of argumentation. Like this, the added value of learning more about statistical models becomes visible, as they are needed for replying to non-satisfactory argumentation attempts.

The findings related to research question (ii) suggest that students can be encouraged through data-based argumentation tasks to feel confident in participating in climate change-related discourse and in justifying their viewpoints: The reported self-efficacy growth scale mean values of group A, the group with the stimulus of the three ESD-related data-based argumentation tasks were significantly higher for self-efficacy in climate-related communication participation and climate-related argumentation than in the group which had the data reading tasks related to the same data sets (group B). There was no significant difference for the self-efficacy growth scale on climate change-related knowledge between the groups. This is in line with the expectation, as both groups were in contact with the same data sets and climate change-related sub-topics as represented in these data sets. The climate-related knowledge learning opportunities (development of average temperatures, etc.) were similar in both groups.

Prior research on self-efficacy (e.g., Pekrun, 2006; Bandura, 1977) indicates that higher self-efficacy is associated with more learning effort, a higher frustration tolerance, and thus higher subsequent learning success. Consequently, the findings of this study suggest that even the small stimulus of posing data-based argumentation tasks related to ESD can improve students' self-efficacy and may lead to the expectation of higher ESD-related learning success.

The findings can hence be seen as promising for follow-up research: Syntheses between data-based argumentation and climate change-related learning should be explored further, both in theory development and classroom practice.

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