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*Research Article*

# Scientific Data Awareness among Future Geography Educators

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**Abstract:** In an era of increasing dis- and misinformation, particularly in relation to social and natural crises like climate change, it is vital that geography students can decipher legitimate, high-quality scientific data from falsehoods to solve relevant problems. In students' education, geography teachers have a central role. We conducted an empirical study on German university geography education Bachelor students to better understand their *scientific data awareness* – their general understanding of what scientific data are, where they come from, and how to discern data quality – to determine how best we can support them in gaining (and ultimately teaching) skills to critically evaluate data. In their responses to an online survey, participants recognized their data usage within scientific and academic settings, but their perception of scientific geographic data in their daily lives was limited. Many respondents also displayed an inability to clearly articulate exactly how they would evaluate and verify data presented to them. Some individuals also indicated a strong inherent trust in scientific data – associating scientific data with "truth" and "fact". We provide recommendations on how to teach geography students to use scientific data and enhance scientific data awareness, but ultimately demonstrate a need for further studies. This work can benefit the creation of new educational modules that can teach students 1) that scientific geographical data are everywhere in our daily lives and 2) how they can critically determine data quality and analyze data found online and through generative artificial intelligence.

**Keywords:** Data Literacy; Information Literacy; Pre-Service Geography Teachers; Online Survey; Geography Education

**Highlights:**

- Scientific data awareness is the ability to recognize what data are and where they come from.
- Pre-service geography teachers may be missing important scientific data awareness skills.
- Pre-service geography teachers are not critical when selecting scientific data.
- Pre-service geography teachers struggle to compare and evaluate scientific data.

## 1. Introduction

Both through traditional media and the internet, we encounter scientific data through articles, apps, and social media (e.g., Deahl, 2014; Crusoe, 2016; Bowler et al., 2017; Pangrazio & Selwyn, 2019; Wolff et al., 2019). Everyday citizens are expected to interpret data in the face of crises like microplastic pollution, modern climate change, or a once-in-a-century pandemic (e.g., Catarino et al., 2021; Garcia-Vazquez & Garcia-Ael, 2021; Kwon et al., 2021; Canon et al., 2022; Dabran-Zivan & Baram-Tsabari, 2025). Citizens must decipher scientific data in all realms of these crises: from lists of causes, to potential impacts and risks, to possible creative solutions. To participate in the social discourse of democratic societies, it is therefore necessary to develop a critical understanding and awareness of what scientific data are, how they are used, how they can be validated, and how they can be applied. Scientific data literacy skills allow everyday people to participate in data-based active citizenship and informed decision-making in our current uncertain times.

Educators have a responsibility to impart knowledge of what scientific data are and how best to evaluate them, given their students' daily inundation of data and their increasing use of Artificial Intelligence (AI) in data acquisition (Bowler et al., 2017; Poushter, 2025). Particularly in geography, where data, from both social and natural sciences, are quite vast due to subdisciplines that address different facets of human-environment issues (e.g. climate change, potential economic adaptation and mitigation, urban planning strategies, etc.), teachers must be equipped with a scientific data awareness that allows them to impart knowledge and critical skills to the next generation. Scientific data awareness, which we believe to be a crucial aspect of data literacy, is the recognition of what scientific data are and how to discern their quality. Geography educators must have a strong scientific data awareness to shape a more robust and critical public among our youth during the current era of global social and natural crises.

This study aims to determine the scientific data awareness of geography pre-service teachers, whom we know very little in regards to how they think about scientific data, to guide our university-level instruction. We evaluated the scientific data awareness of 58 students enrolled in geography education at the University of Cologne, Germany across multiple physical geography courses through an online survey. Our survey addresses the following research questions:

1. What conceptions do geography education students at the University of Cologne have of scientific geographical data?
2. How might geography education students at the University of Cologne evaluate the quality of scientific geographical data?

Based on these research questions, our general research hypotheses are: (a) geography education students are unaware of how scientific geographic data are collected, produced, and handled and (b) geography education students do not have clear conceptions in how to determine the reliability of scientific geographic data.

In the following manuscript, we begin with an overview of our theoretical framework by exploring scientific data awareness as an aspect of data/information literacy. From there we provide information about our methods, leading into our preliminary results. We then present further interpretations based on our results regarding our participants' scientific data awareness and continue to explore our findings alongside similar research. Based on our results and the results of others, we then discuss potential ways to increase scientific data awareness within Bachelor-level geography courses, utilizing relevant studies across other fields. After that, we include recommendations for further research on scientific data awareness within geography education with a focus on its relevance to increasing use of AI.

## 2. Theoretical Framework

### *2.1. Scientific Data Awareness as an Aspect of Data and Information Literacy*

Scientific data awareness is a component of data literacy. Data literacy, despite its vast academic discourse, has not been clearly defined in didactical research, varying in definition depending on the agents that should be "data literate" (Crusoe, 2016; Gebre, 2022). For example, with the recent growth of big data and AI technologies to aggregate and summarize data points, data literacy within education often means pedagogical data literacy (Mandinach, 2012) or instructional decision making (Means et al., 2011), i.e. the ability for teachers to use data related to their teaching to evaluate and update their instructional practice (e.g., Mandinach & Gummer, 2013; Teacher Data Literacy, 2014; Jimerson, 2014; Reeves & Honig, 2015; Gebre, 2022; Mougiakou et al., 2023; Michos et al., 2023; Salas-Pilco et al., 2023), which is not the interest of this study. For other didactical researchers, data literacy is based in specific research questions and argumentation, such as that of Deahl (2014) ("the ability to understand, find, collect, interpret, visualize, and support arguments using quantitative and qualitative data"), Calzada-Prado & Marzal (2013) (the ability "to access, interpret, critically asses, manage, handle, and ethically use data"), and Wolff et al. (2017) ("the ability to ask and answer real-world questions from large and small data sets through an inquiry process, with consideration of ethical use of data… based on core practical and creative skills, with the ability to extend knowledge of specialist data handling skills according to goals"). For our research, we are not specifically interested in the competencies to create arguments or solve research questions based on scientific data, but rather our students' basic ideas of scientific geographic data.

### *2.2. Importance of Scientific Data Awareness*

We define scientific data awareness as the ability to understand where we encounter and potentially use scientific data in our lives, what they mean, and how their quality can be determined. We believe scientific data awareness is an aspect of scientific data literacy – defined by Qi (2018) as a component of data management related to the understanding of "the basic terms, key concepts, policies, roles, personal roles and responsibilities of data" in our lives. Qiao et al. (2024) similarly identified scientific data awareness as a critical component of scientific data literacy, highlighting three key aspects: data acuity awareness, the ability to know what kind of scientific data is needed for solving a particular scientific problem; data value awareness, the ability to recognize how different scientific data can be used to answer a particular scientific question; and data security awareness, the ability to understand the risks of scientific data leaks and how to implement protective measures. We similarly focus our study on the abilities, roles, and responsibilities our students have in relation to understanding and using scientific data properly.

Our interest in data awareness relates to the general competencies of data literacy of Gebre (2022) and Wolff et al. (2019), who considered data literacy a general skill that all citizens must develop in preparation for data-use in professional life. For our students, this role is currently at the university as students, but will be within classrooms as educators who must draw upon scientific data while teaching geographical topics. A critical understanding of data is crucial for future teachers to classify data and decide how they can be utilized through teaching and educational materials. By teaching general data literacy competencies, Gebre (2022) and Wolff et al. (2019) argue that citizens can use generic data skills to be data-literate employees capable of resolving tasks based on a knowledge of how to use data appropriately in certain situations (similar to Qi's (2018) data acuity awareness). By encouraging these skills, pre-service teachers could better prepare future generations to participate in social and public discussions, using scientific data in an informed way.

## 3. Materials and Methods

### *3.1. Survey Participants*

The study was conducted across four physical geography seminars ("Climate Geography", "Methods in Physical Geography", "Geomorphology and Soil Science", and "Vegetation Geography") at the University of Cologne, Germany based on the authors' and colleagues' teaching availability. The study was carried out at the beginning of the semester, so that students had not encountered themes related to scientific data and quality within the semester's coursework. 58 study participants (aged 18-28) were in their 1$^{st}$ to 8$^{th}$ semesters of their geography Bachelor's for teaching qualifications (Supplemental 1). The majority of the students were in at least their second semester, meaning most students had previously been exposed to the diversity of presenting and visualizing different kinds of geographical data. 56.9% of our surveyed students were female and 41.4% male, with one respondent preferring not to respond. All teaching students at the University of Cologne are required to major in another subject. The secondary subject breakdown of participants from most to least is: Economic Policy, 25.9%; English, 20.7%; German, 12.1%; History, 12.1%; Biology, 10.3%; Physics, 5.2%; Social Sciences, 5.2%; Mathematics, 3.4%; Religion, 3.4%; and Chemistry, 1.7%.

### *3.2. Survey Questions*

The online survey was conducted using Survey123 through ARCGIS. Our translations of the material from German into English (for the purpose of this publication) were first translated through DeepL and then reviewed and edited by the authors. Participants were first prompted for their demographic information including age, gender, semester, and second academic major (Supplemental 1). Students were then asked about their data usage ("how often have you used scientific data in the last month?" and "have you ever collected scientific data?") to see if previous academic research experience impacted their data awareness (Table 1). No such connections were found. Open survey questions based on our research questions were answered through written responses.

To answer our first research question, we asked several questions about the students' views of scientific geographical data (Table 1). Questions 1 ("what is the difference between scientific data and non-scientific data?") and 2 ("in your opinion, what is scientific data in geography?") were used to gauge students' general idea of what scientific data are. We then asked, "what is the purpose of scientific data in geography?" and "in which contexts do you use scientific data?" to better comprehend how students believe they are using and interacting with scientific data. We then asked two questions – "how are scientific data collected in geography?" and "which types of data used in geography can you distinguish?" – to better understand where students believe geographic scientific data come from. To answer our second research question, we asked students, "when assessing scientific data, how do you determine what they can or cannot say?".

**Table 1.** Questions from the survey and their relevance to the research project.

| Relevance to Research Project | Question from Survey | Answer Options |
|---|---|---|
| Previous Experience with Scientific Data? | How often in the last month did you use scientific data? | Never (0x)<br>Rarely (1-4x)<br>Often (5-9x)<br>Frequently (10-20x)<br>Regularly (>20x) |
| | Have you ever collected scientific data? | Yes<br>No<br>I Don't Know |
| What conceptions do geography students have of scientific geographical data? | What is the difference between scientific data and non-scientific data? | Open Response |
| | In your opinion, what is scientific data in geography? | Open Response |
| | What is the purpose of scientific data in geography? | Open Response |
| | In which contexts do you use scientific data? | Open Response |
| | Which types of geographical data can you distinguish and how are they collected? | Open Response |
| How might geography education students evaluate the quality of scientific geographical data? | When assessing scientific data, how do you determine what they can or cannot say? | Open Response |

### *3.3. Response Categorization and Analysis*

The students' open responses were evaluated using the content analysis method from Mayring & Frenzl (2019), whereby main categories and most subcategories were determined deductively in close relation to the above-named research questions (Tables 1 & 2). After selecting key quotations from the students' texts, categories were further refined and responses coded into categories/subcategories by two authors (E.R. and V.F.) (Table 2). The coding of the responses was then compared and combined through collaborative reevaluation whereby adjustments of subcategories were created inductively and all non-identical results were discussed and brought to consensus. The code of "no response and/or unclear" refers to students that did not respond, said they did not know, or responded unintelligibly to the question asked. The original German-language responses are accessible on Zenodo.

The two questions "how are scientific data collected in geography?" and "which types of data used in geography can you distinguish?" yielded similar responses from our students and indicated students' confusion in their distinction. We therefore combined the responses during coding into a two-part question – "Which types of geographical data can you distinguish and how are they collected?". Despite trying to simplify these responses, they were quite complex and difficult to interpret. We believe these questions were not clear/specific enough in their construction and confused participants. We therefore chose not to include them in our analysis. We do not believe that the removal of these two questions impacted our interpretations based on the numerous other questions that address research question 1 (Table 1). We therefore do not believe that their exclusion impacts the overall findings from this study.

In order to observe patterns and trends in the students' scientific data awareness and identify potential gaps and misconceptions, qualitative data were converted into quantitative data following the principles of Mayring (2010). Figures based on the student responses and categories were created using Microsoft Excel, ggplot2 in R (Wickham, 2016), and Adobe Illustrator. For all figures of open-ended responses, results are presented as the percentage of participant responses per category or subcategory (N=58). For categories where respondents could have responses coded into more than one subcategory, the responses were only accounted for once in the category percentage calculation. Based on the results, we derived three key interpretations on the student's scientific data awareness (listed in section 5) that were further refined into recommendations in the context of other related studies.

**Table 2.** Questions, categories, and subcategories (if applicable) with examples from the student responses.

| Question | Category | Subcategory | Example |
|---|---|---|---|
| **What is the difference between scientific data and non-scientific data?** | **Scientific Standards** | Objective | Student #38 "Proven through testing and free from prejudice and opinion." |
| | | Methods (Documented, Reproducible, etc.) | Student #8 "Scientific data are verifiable, meaning if the same experiment were repeated under the same conditions, the same result would be obtained." |
| | | Trusted Publication Sources | Student #19 "For now, I would say: references" |
| | | Large Scope and Evidence | Student #34 "Cover a larger scope" |
| | | Results through Systematic Survey (Documented, Reliable, etc.) | Student #43 "Scientific data are verified, while non-scientific data are not verified and more likely to be speculative." |
| | **Accuracy Descriptors** | Truth and Fact | Student #51 "They are 98% certain and correct." |
| | | Accuracy and Precision | Student #4 "They are generally accurate and not randomized." |
| **In your opinion, what is scientific data in geography?** | **Data Types** | Numerical Data | Student #17 "Measured facts and numbers, such as air or ground measurements" |
| | | Statistical Analyses | Student #13 "Statistics or other reliable data" |
| | | "Information" | Student #52 "Systematically collected and verifiable information" |
| | | Documentation and Observation | Student #24 "Geography examines and explains the processes and structures of space. To do this, it uses scientific data such as coordinates, which describe location and shape. However, it can also use data that describes characteristics." |
| | | Measurements | Student #38 "Temperature, proportions of elements in the atmosphere and soil, salt content in water, speed of plate movement—in other words, anything that can be measured." |
| | **Foundation of Data** | Results of Scientific Research | Student #8 "Data collected under scientific conditions, i.e., data that is well-founded and reliable" |
| | | Answers Research Questions | Student #48 "Very important because they serve as evidence for theories or provide answers to problems." |
| | | Sources and/or Scientific Publication | Student #30 "All data contained in books or obtained through activities." |
| | | Based in Theory | Student #16 "Data that presents something clearly using a scientifically verifiable foundation." |
| | **Data Visualization** | Photos | Student #35 "Statistics, photos" |
| | | Diagrams | Student #27 "Diagrams, tables, facts" |
| | | Maps | Student #59 "Maps, GIS, scientific work" |
| | **Specific Geographic Data Types** | Spatial Data | Student #18 "They are data that provide spatial information that can be analyzed." |
| | | Statistical Spatial Data | Student #46 "In human geography, data would be the results from surveys, interviews, and statistics, e.g., country |

| | | | |
|---|---|---|---|
| | | | demographic statistics. In physical geography, scientific data are, in my opinion, obtained through the analysis of rock and soil samples, etc." |
| | | Physical and/or Human Geographic Data | Student #11 "Information about the world or population to better help us understand certain phenomena" |
| | **Description of Data** | Informed, Substantiated, Provable | Student #8 "Data collected under scientific conditions, i.e., data that are well-founded and reliable" |
| **What is the purpose of scientific data in geography?** | **Research (non-descript)** | | Student #3 "To research" |
| | **For Scientific Investigation and/or Knowledge Creation** | | Student #13 " To better understand issues and arrive at scientific responses" |
| | **To Prove Theories** | | Student #16 "To test and explore theories and ideas." |
| | **To Describe the World** | | Student #28 "To offer a perspective" |
| | **To Understand the World** | | Student #22 "To help understand the world more generally, and to help understand certain research more specifically" |
| | **To Explain Facts/Teach** | | Student #55 "To explain and understand phenomena" |
| | **To Prepare/Make Decisions** | | Student #12 "To better understand geographical relationships or identify and solve problems" |
| | **To Document and Inform** | | Student #56 "To preserve knowledge about our Earth and society" |
| **In which contexts do you use scientific data?** | **University** | | Student #3 "Homework, presentations" |
| | **Information, News, To Gain Knowledge** | | Student #38 "To understand how things work around me" |
| | **Daily Tasks (Weather, Traffic)** | | Student #24 "Scientific data is used, for example, in weather forecasting and navigation." |
| | **Primary/Secondary School Planning** | | Students #49 "Completing assignments in school or university, for example the ability to prepare professional presentations" |
| **When assessing scientific data, how do you determine what they can or cannot say?** | **Verification Procedures** | Compare with Other Data | Student #10 "Recheck everything yourself with other sources/data." |
| | | Review Author and their Motives | Student #54 "Through the sources and author" |
| | | New Study/Data Analysis | Student #5 "Change a variable to discover connections and correlations" |
| | | Evaluation of Limits of Informative Value | Student #20 "By recognizing the limits of its informative value" |
| | | Review Hypotheses/ Research Questions | Student #59 "They have a clear goal, everything is clear and well-structured” |
| | | Review Interpretation | Student #41 "By inferring: A means B; but does B also mean A?" |
| | **Features of Scientific Data** | Systematic Survey | Student #44 "By critically examining where they come from (e.g., survey method)" |
| | | Data Quality (Complete, Accurate, etc.) | Student #43 "You can check whether there is evidence for the data." |
| | | Sources and Publisher | Student #22 "You should check whether the sources are reliable and how relevant they are to the topic." |

## 4. Results

This section is structured according to the survey questions related to the research question that they answer (Table 1). For clarity, results that do not contribute to this discussion are not reported on, but can be found on Zenodo in original language.

### *4.1. What conceptions do geography education students have of scientific geographical data?*

#### *4.1.1. Clear understanding of why we use scientific data in geography*

Respondents demonstrated an ability to articulate the relevance of scientific data to geography, with all students providing a response, although 12.1% of the students' responses used "research" in a non-descript way (Figure 1a). A majority of responses indicated that scientific data in geography is used to gain scientific knowledge (53.4%), with 9 additional mentions that scientific data can test theories/hypotheses and answer research questions. This highlights that students tended to think about scientific data mostly in academic contexts to gain scientific knowledge (Student #5 "To gain knowledge in geographic topics") or to test theories/hypotheses and answer research questions (Student #16 "To test and explore theories and ideas"). This is also visible in the large proportion of respondents that use scientific data at university (Figure 1b).

Respondents described many reasons for using scientific data in geography (n=129), whether to understand the world (Student #22 "*To help understand the world more generally, and to help understand certain research more specifically*") or describe it (Student #28 "*to offer a perspective*"). 15.5% of the student responses described geographic scientific data's role in society as helping to prepare and make decisions (Student #12 "*To better understand geographical relationships or identify and solve problems*"). This bodes well for a generation of teachers who can then pass on their belief geographic data's importance to understand, learn, and teach about the world.

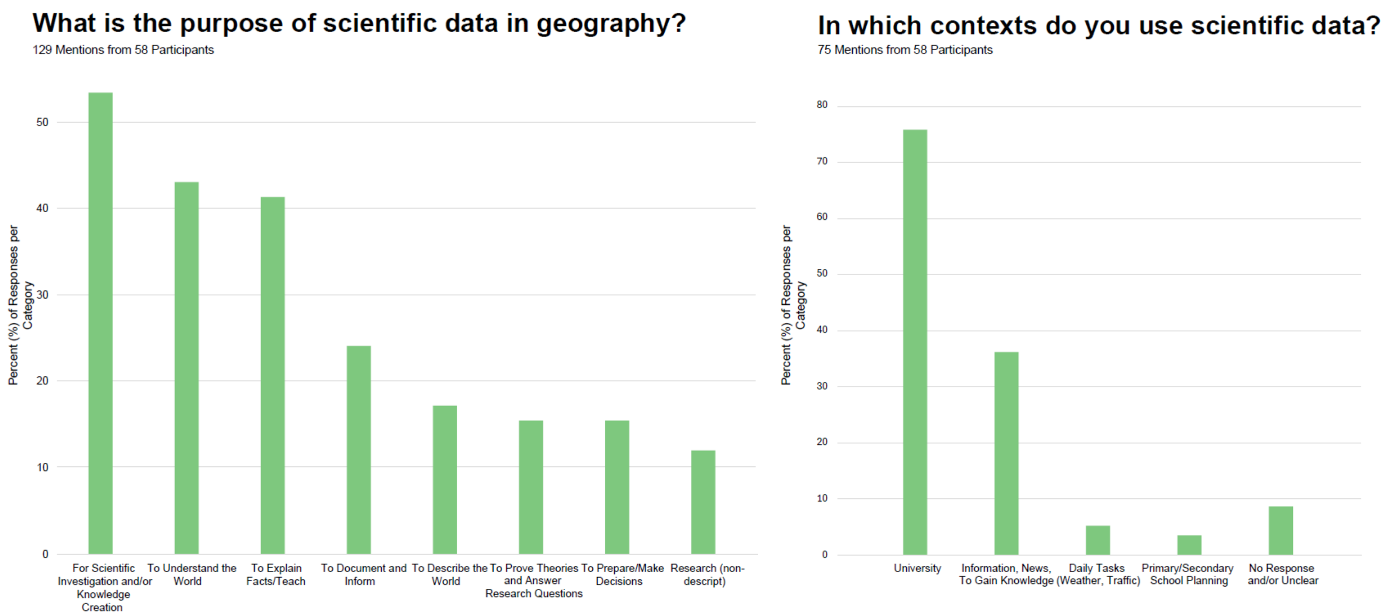


**Figure 1.a (left)** Percent of the responses to the question "what is the purpose of scientific data in geography?" shown in a bar plot. **1.b (right)** Percent of the responses to the question "in which contexts do you use scientific data?" shown in a bar plot (own representation).

#### *4.1.2. Scientific standards are critical, but ambiguous*

It was clear to the respondents that "scientific data" is directly related to scientific standards, with the overwhelming majority of students making this connection (Figure 2). For example, in response to "what is the difference between scientific data and non-scientific data?", Student #18 wrote "*Scientific data is collected systematically and methodically, differing in this respect from non-scientific data. [Scientific data] follows certain* *standards and is verified*" and Student #37 wrote "*Scientific data is considered to be well-researched and serves to prove or support a particular argument. Science allows you to make a stronger case for this argument than you could using non-scientific data.*" The range of responses per subcategory of scientific standards was large from 5.2% having large scope and evidence (Student #34, *"[Scientific data] cover a larger scope*") to 41.4% and 37.9% methods (Student #8 "*Scientific data are verifiable, meaning if the same experiment were repeated under the same conditions, the same result would be obtained.*") and results through systematic survey (Student #43, "*Scientific data are verified, while non-scientific data are not verified and more likely to be speculative.*"), respectively. Many students had responses coded in both the methods and results categories (Student #33, *"[Scientific data] are verifiable. They were collected correctly according to certain standards and thus follow a certain logic. They are usually also reproducible, because they can be verified. Non-scientific data has its own logic and can contradict itself. It serves its own purposes*"), as these standards are often related. Other students focused more on sources (Student #14 "*I don't think non-scientific data is sufficiently substantiated, and uses sources such as Wikipedia, for example.*"). Overall, this diverse spread of aspects of the scientific process indicates that while students generally understand that scientific data are based in scientific methods, they struggle to articulate what scientific methods entail. In a way, our students seem to understand what they *should* say (sitting in a university classroom) but struggle to make a greater connection to those methods themselves. In a teaching context, this could mean that students are simply reciting the importance of scientific standards but have a weaker understanding of why these standards are critical to the scientific process.

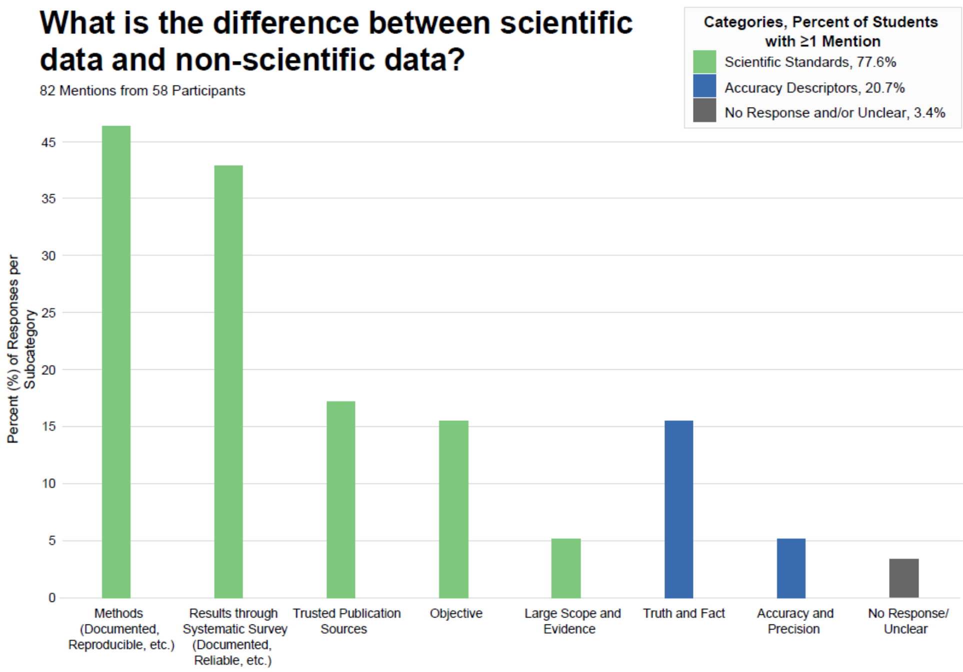


**Figure 2.** Percent of the responses to the question "what is the difference between scientific data and non-scientific data?" in the legend with the percentage of students with at least one mention of the subcategories of each category ("scientific standards", "accuracy descriptors", and "no response/unclear") and as a bar plot for the subcategories (own representation).

4.1.3. Universities are the hub for scientific data

As mentioned earlier, our results indicate that our students have a solid understanding of the relevance and use of scientific data in academic settings but are less aware of scientific data in their daily lives. Figure 3 shows student responses to the question "how often have you used scientific data in the past month?" (Q1) colored according to their response to "have you ever collected scientific data?" (Q2). The students' confusion about their interactions with scientific data is evident, given that the majority of the students believed they had interacted with scientific data less than nine times in March 2025. Only two students responded that they had interacted with data more than 10 times.

In addition, in response to “have you ever collected scientific data?”, 20.7% of the responses were “I don’t know”, displaying their uncertainty about when they might collect scientific data. A clear example of this is Student #27 who responded to Q1 as using scientific data over 20 times in March 2025, but could not answer whether or not they had ever participated in data collection before (Figure 3) – a strange response of uncertainty for someone who reported using data regularly.

Similarly, very few students recognized how they interact with scientific data outside of university. 75.9% of student responses to “in which contexts do you use scientific data?” indicated that they use scientific data at university (Figure 1b). Compared to other questions (n=82 to 146), very few responses coded into multiple categories (n=75) (Student #47 “*academic presentations”*/Student #56 “*scientific work”*). Only 36.2% of student responses indicated that they use scientific data when they want to learn more or understand the news in a private context. No other responses were nearly as highly mentioned, with only three responses for daily tasks (weather, traffic) and two responses for primary/secondary school planning. When one thinks about how often students use scientific geographical data through weather apps, GPS services, or demographic data, it is surprising how few students recognized their scientific geographic data usage. If students are uncertain how they use geographic scientific data, then it may then be difficult for them to use scientific data as future teachers.

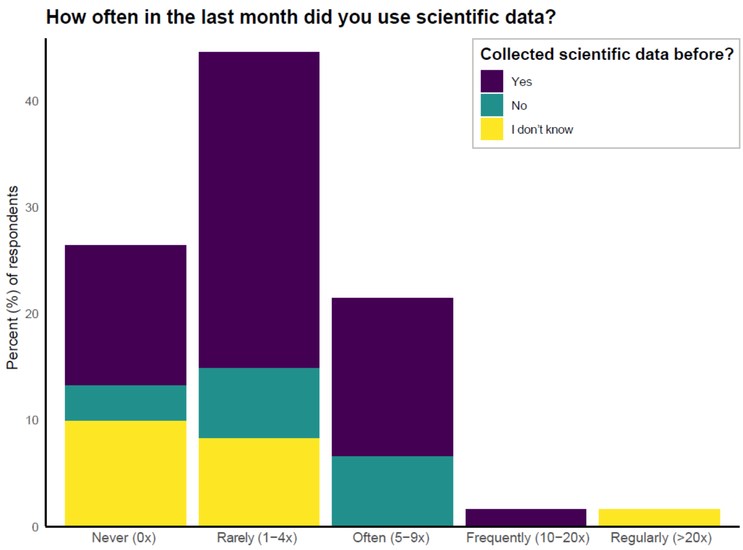


**Figure 3.** Percent of 58 responses to the question “how often in the last month did you use scientific data” in the categories “Never (0x)”, “Rarely (1-4x)”, “Often (5-9x)”, “Frequently (10-20x)”, or “Regularly (>20x)” as a barplot. The barplot is colored by respondents’ answers to the question “have you ever collected scientific data?” to reflect the relationship between how often respondents use data and whether or not they have collected data (discussed further in section 4.1.3.) (own representation).

### *4.2. How might geography education students evaluate the quality of scientific geographical data?*

#### *4.2.1. Inherent trust in scientific data*

In thinking about how students might evaluate scientific data, “scientific” had a powerful meaning to some respondents. 20.7% of students responded to “what is the difference between scientific data and non-scientific data?” indicating that scientific data has inherent truth behind it (Student #51 *“[Data] are 98% certain and correct*” or Student #30 *“[Data] are proven and truthful*”) or are inherently precise and accurate (Student #4 "*They are generally accurate and not randomized*.") (Figure 2). This demonstrates that some students do not understand that scientific data can change through time or be refuted. This may also be evident by students’ ideas of what scientific data in geography are, with more students focused on the outcomes of data (data types) rather than the foundation of data in response to the question “in your opinion, what are scientific data in geography?” (Figure 4). It is evident that the respondents may not think as critically about the processes that can create and eventually refute data in comparison to the outputs from the data themselves. This unclear understanding of how scientific data are generated and that they may change through time indicates a poor scientific data awareness amongst our students which could result in teachers who are unable to appropriately communicate what scientific data are.

*4.2.2. Inability to clearly describe how to verify data*

The question "when assessing scientific data, how do you determine what it can or cannot say?" was the most difficult for our students to answer, with over a quarter of their responses unclear and/or vague (Figure 5). This can either indicate true uncertainty or a reluctance to respond given that it was the last question of this section of the survey. The spread of the subcategories of verification procedures was small compared to other categories (net range of 15.5%), providing potential evidence of the uncertainty of participants in answering this question. Subcategory verification strategies include conducting a new study/data analysis (Student #27 "*Secondary tests*" or Student #36 "*By compiling statistics and filtering out specific information*"), reviewing hypotheses/research questions (Student #59 "*They have a clear goal, everything is clear and well-structured*"), comparing with other data ( Student #10 "*Recheck everything yourself against other sources/data*"), reviewing the interpretation (Student #41 "*By inferring: A means B; but does B also mean A?*"), reviewing the author and their motives (Student #54 "*Through the sources and author*"), and evaluating the limits of informative value of the data (Student #20 "*By recognizing the limits of its informative value*"). The broad spread of the main category of verification procedures across the subcategories highlights how difficult data verification is for respondents. It indicates that as teachers, many may struggle to teach data verification strategies. While they may have learned about some scientific methods, the actual steps to get there are less clear. This requires more analysis and could represent the most critical aspect of scientific data awareness going forward.

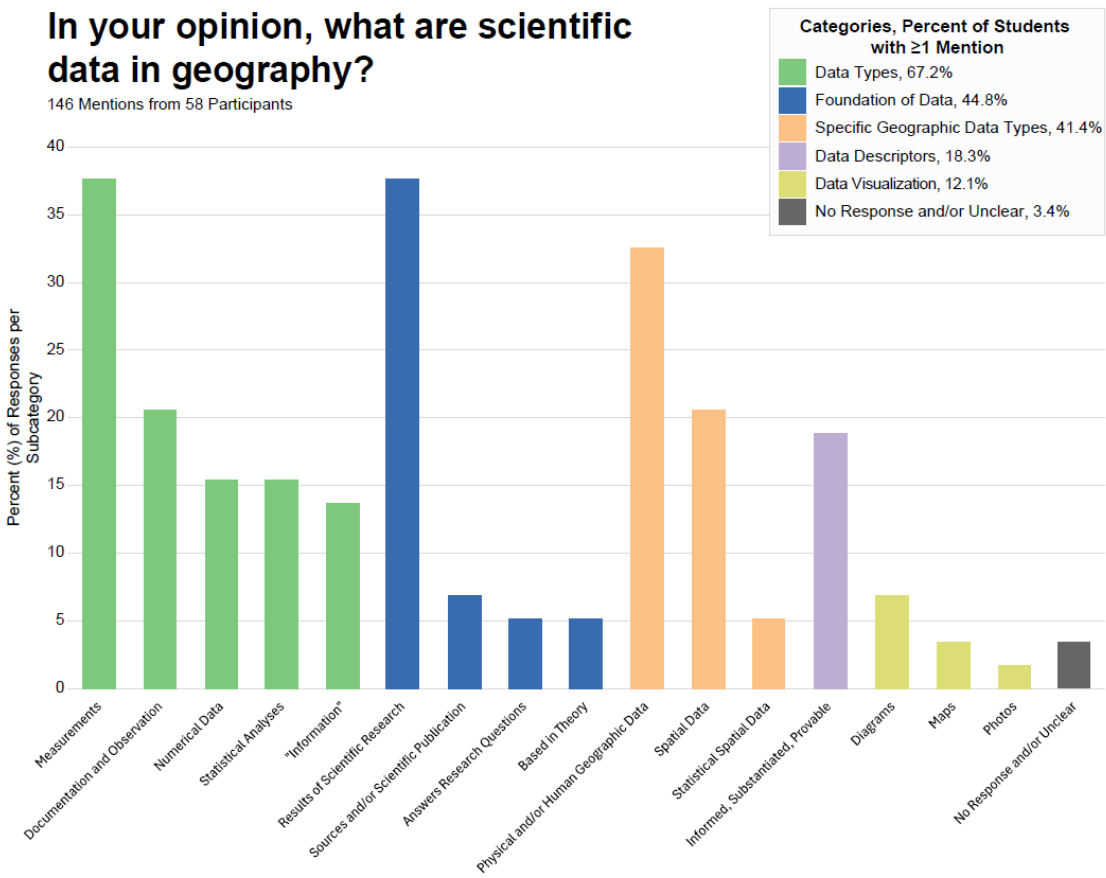


**Figure 4.** Percent of the responses to the question "in your opinion, what are scientific data in geography?" in the legend with the percentage of students with at least one mention of the subcategories of each category ("data types", "foundation of data", "specific geographic data types", "data descriptors", and "no response/unclear") and as a bar plot for the subcategories (own representation).

### *4.3. Alternative Explanations*

There are several alternative explanations that could have an impact on our results. The first is the scope of our study. We surveyed 58 geography education students at the University of Cologne, meaning our findings may not be representative of all geography education students. Similarly, the age, stage of study, prior coursework, etc. (with many of our students in their earlier semesters (Supplemental 1) and with minimal prior data experience (Figure 3)) could impact our results. Secondly, our students were asked to take the surveys in physical geography classrooms. This may have impacted outcomes to favor responses related to quantitative data, although an even split of quantitative and qualitative data types in our survey indicate this is likely not a hugely important factor. Thirdly, the use of an online survey rather than interviews could have limited the depth with which our students responded. We chose to use an online survey as we were able to increase the number of student responses we received which we believe provided a good overview of many students' scientific data awareness.

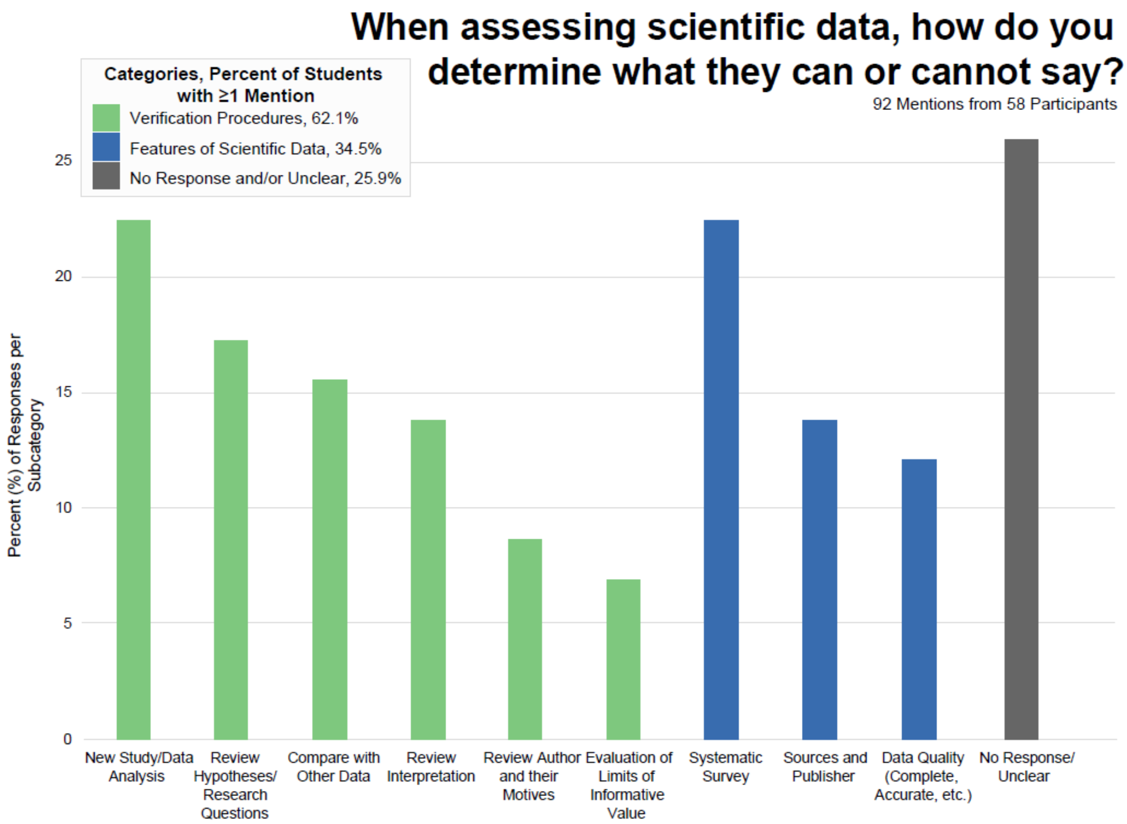


**Figure 5.** Percent of the responses to the question "when assessing scientific data, how do you determine what they can or cannot say?" in the legend with the percentage of students with at least one mention of the subcategories of each category ("verification procedures", "features of scientific data", and "no response/unclear") and as a bar plot for the subcategories (own representation).

## 5. Discussion

### *5.1. What conceptions do geography education students have of scientific geographical data?*

**(I1) Many geography pre-service teachers at the University of Cologne lack critical scientific data awareness.** This interpretation is based on many of our respondents not seeing scientific data in their lives (4.1.3; Figures 1b & 3), potentially in part because they do not have a broad overview or understanding of what data might look like (4.1.2; Figure 2). While they might understand where scientific data come from and why they are different from general information, particularly through scientific standards (4.1.2; Figure 2), they are unaware of the scientific data in their daily lives.

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**(I2) Many geography pre-service teachers at the University of Cologne are not critical (enough) when selecting scientific data.** This interpretation is related to our students' seeming uncertainty in how to select high-quality data (4.2.1 & 4.2.2; Figures 2 & 5). While this was not necessarily the goal of our survey, student responses about data usage were passive. Their relationship with data and using data was not relevant in their responses. Students indicated that data is used by other people (such as researchers at the university), rather than themselves (4.1.3; Figures 1b & 3). Students exhibited little critical examination of data quality because data is irrelevant to them outside of the classroom. Students might be less critical in data selection because of their lack of personal connection/need for it. This may be problematic to their personal data usage as well as their selection of data for future geography lessons.

### *5.2. How might geography education students evaluate the quality of scientific geographical data?*

**(I3) Many geography pre-service teachers at the University of Cologne have difficulty comparing, structuring, and evaluating scientific data.** Related to the earlier explained passive relationship with data in 5.1, when we asked students to reflect on how they would evaluate data, there were many mixed responses (4.2.2; Figure 5). While this question is in-depth and no student would be able to include all potential data evaluation methods, we believe it may reflect what students have been told to do at university rather than what they might actually do in their daily lives. We are skeptical that our students would be able to properly compare, structure, and evaluate scientific data based off of their survey responses.

### *5.3. Didactical Relevance of Scientific Data Awareness*

While we are not aware of any other studies about pre-service teacher scientific data awareness, we compare our findings to those from secondary school students that could provide additional insight into how scientific data awareness could trickle down from teachers onto students.

Gebre (2018) found that students in secondary school mostly saw data as "(a) information obtained from experiments and surveys, (b) utility- and usage-related information, and (c) quantitative information in the form of graphs and charts". In addition, students described data more narrowly than the data they used within their research projects (Gebre, 2018), indicating that their perception of data is smaller than their actual use. Bowler et al. (2017) found that half of the studied teenagers saw data as numbers with an additional number of students thinking about the visualization of those numbers. It is not surprising that the younger students from Bowler et al. (2017) and Gebre (2018) were more likely to discuss quantitative data and data visualization, as that is how data is often presented in textbooks. Our students were less likely to include data visualization (photos, diagrams, maps) in their responses and were better able to identify both quantitative and qualitative data types (Figure 4). This is likely explained by the fact that our students are at university and have had more experience working with data. This could indicate that while early geography educators may know the various kinds of data and the difference between data and their visualization, this difference may not be explicit enough in primary and secondary school classrooms.

In terms of data usage, Gebre's (2018) secondary school students thought that data impacted them in their learning and decision-making within classroom structures. Similarly, Bowler et al. (2017) found that most students saw their interactions with data occurring within the classroom. Overall, it seems to be consistent, including with our respondents (Figure 1b), that students perceive data within academia rather than in their lives. This therefore indicates that from primary to tertiary education, students may not be aware of their daily use of data.

Another interesting point from Gebre (2018) is that many students saw an inherent truth in data. This mirrors our students who sometimes included the words "truth", "precise", or "exact" when describing scientific data (Table 2 & Figure 2). Data can change through time. Data can also be collected under poor scientific standard conditions (not objective, not held to clear standards, etc.), making some data lower quality than others. Our students' responses as well as Gebre's (2018) results indicate that young people may not reflect on scientific data as critically as we might hope. Students see data as an end result rather than the beginning of a scientific process or of important discussions, reflecting a need to highlight data quality concerns across all classrooms.

Other studies have highlighted that students struggle to verify whether information is correct (Julien & Barker, 2009). Walraven et al. (2008) found that students in the Netherlands were often not successfully evaluating the sources, results, and information they found on the internet. And while students knew that they could identify/evaluate more reliable information based on certain criteria (source reliability, publication year, increased number of sources, etc.), they admitted to often not doing so (Walraven et al., 2008). Engelen & Budke (2020) similarly found that German secondary school students were unable to scrutinize retrieved information indicators like publication year. The uncertainty in how to verify scientific data therefore exists beyond this study (Figure 5), seemingly a common result in didactical studies. It is therefore critical that data verification and analysis become more integrated into all classrooms.

### *5.4. Promoting Scientific Data Awareness amongst Pre-Service Geography Teachers*

Poor scientific data awareness of educators exacerbates poor scientific data awareness of the public, since educators are responsible in conveying an understanding and expertise to students. Our results highlight – as suggested in our earlier hypotheses – major themes including unawareness of data in daily lives, limited understanding of data quality, and uncertain data verification and analysis skills. It is therefore critical to reflect on our results, and the related results of others, to recognize potential methodologies that benefit students and create a more holistic and complete scientific data awareness amongst future geography teachers.

#### *5.4.1. Addressing I1 – Using various kinds of data (including raw and real-world data) in the classroom*

We believe that teaching material, like textbooks and worksheets, should utilize more raw geographic data. While only 12.1% of our students conflated data visualization with data itself (Figure 4), other studies show a clear conflation (see 5.3; Bowler et al., 2017; Gebre, 2018). This can likely be attributed to the fact that outside of the classroom, data are often depicted in figures and charts. It is critical for students to understand that data visualizations are a tool to understand data and not data themselves (usually).

Working with real-world geography data not only allows students to increase their abilities to utilize scientific reasoning (Shofiyah et al., 2025a), but also is a cause for excitement and enthusiasm for many students in understanding complex, real-world problems (Schultheis & Kjelvik, 2015). Because the majority of our students think they only work with data in classrooms (Figure 1b), as is reflected in other studies (see 5.3; Bowler et al., 2017; Gebre, 2018), using real-world data can increase student scientific data awareness by connecting classroom data with the outside world.

Similarly, studies by Lütje & Budke (2021; 2022) show that qualitative data is often mixed with fictional narratives in school textbooks. It is almost impossible for students to distinguish between factual and fictional narratives and discuss them critically due to a lack of sources and contextual information regarding the data collection. While there may be reasons to utilize fictional narratives in texts (whether for educational reduction and/or linguistic adaptation to the students' level of learning), in an age of overwhelming data, school materials should use authentic geography data as often as possible.

#### *5.4.2. Addressing I2 – Focusing on where data come from and their quality*

Studies have shown that the more students interact with data, the more critical of those data they become (Wolff et al., 2019). Entwistle & Walker (2000) found that the data that students understand the most are related to their previous data experience. This means that the more engaged students are with geographic data, especially during collection, the more critical of data they become and the more data they understand. This is crucial to address the unawareness of many of our students in whether or not they had engaged in data collection (Figure 3).

Relatedly, in materials given to students, it is critical that all sources are clearly cited. As highlighted in 5.3, while students may know they should evaluate sources using criteria like source reliability, publication year, etc. they often do not (Walraven et al., 2008). Whether this is in figures or charts in textbooks or in materials that teachers distribute in class, teachers must demonstrate a good example to ensure that students understand where data come from. This could increase students' scientific data awareness by more clearly addressing that data without citations are less reliable or that citations must be checked to ensure that data come from a reliable source. This ultimately strengthens scientific data awareness by showing students that the contexts of data are important, not just the data themselves.

Data presented in schools have often been cleaned and organized in ways that make them more understandable. But data collection can be messy. Data should reflect complex geography data from the real-world, rather than simple, easily collected metrics (Schultheis & Kjelvik, 2015). When students work with less clear and messy data, it could increase their scientific data awareness by forcing them to reflect on data quality and distinguish relevant data from less relevant data to resolve certain problems.

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*5.4.3. Addressing I3 – Working through the data life cycle, particularly verification and analysis*

Lessons to increase scientific data awareness must be all-encompassing and thorough. In a 2025 survey of teachers across the US, Sultana et al. (2025) found that most data-related lessons concentrated primarily on organizing, visualizing, and collecting data. Less often did lessons include modules on higher-order reasoning and interpretation of data, minimizing their impact on student scientific data awareness. Our results show that our students struggled to articulate how they can verify data (Figure 5). To achieve science data awareness, lessons that use data should focus on the entire data life cycle from inception/collection to archiving (Qi, 2018). By focusing on data as part of a cycle, we can improve scientific data awareness by providing space for students to utilize scientific reasoning (Shofiyah et al., 2025a&b) and understand complex, real-world data (Kjelvik & Schultheis, 2019; Wolff et al., 2019).

Lessons related to data should require students to utilize higher-order skills. Tsai et al. (2011) found that explicit strategies, like detailed reading and analysis, were more crucial for students in successfully searching for and utilizing data compared to implicit skills. Lessons should be complex enough to focus on the evaluation of data thereby enhancing scientific data awareness skills. By formulating more complex tasks, teachers can bolster argumentation and evaluation skills as students conduct research (Budke & Meyer, 2015; Walhout et al., 2017), therefore using higher-order processing to better prepare students for critical data evaluation in their lives.

Relatedly, it is important for students to understand *why* they are learning data literacy skills such as scientific data awareness. Metzger et al. (2015) found that students who handled data in classrooms were not always better at distinguishing real from fake information. They found it was critical for students to understand why data literacy skills were important to more accurately spot fake information. Within geography classrooms, the importance of data literacy skills can be explained through being informed and providing solutions to real world problems.

One potential way to address why data literacy is important is by integrating inquiry-based learning as heralded by Roberts (2003; 2013; 2023) in geography education. By using inquiry-based learning, geography teachers promote a questioning attitude towards knowledge, enabling them to more critically evaluate that knowledge. Inquiry-based learning, which can vary in its implementation (Arifin et al., 2025), inherently occurs through the collection, interpretation, and analysis of data (therefore focusing on the data life cycle) promoted here. Inquiry-based learning focuses on using knowledge to build arguments and reflect on presented material, which is greatly relevant to establishing stronger scientific data awareness. Such methods have already been recommended by geographers focusing on spatial data and geomedia (e.g., Bunch & Lloyd, 2006; Gryl et al., 2010; Bearman et al., 2016; Kholoshyn et al., 2021; Jekel et al., 2024). We propose to expand these ideas into broader data types and the wider field of geography. While the potential benefits of inquiry-based learning to promote scientific data awareness will need to be tested in future research, we believe it to be a good starting point.

## *5.5. Outlook: Artificial Intelligence and Scientific Data Awareness*

Artificial Intelligence is being used more regularly within the classroom and by students, which has already had revolutionary impacts on the education system (e.g., Farrokhnia et al., 2023; Lo, 2023). While this technological shift can have great benefits for students when used properly (Bueno-Picazo & Tirado-Olivares, 2026), such as students whose native language is not the language of instruction (Bowker, 2021) or students who learn at different rates (Baidoo-anu & Owusu Ansah, 2023), there are considerable downsides (Tlili et al., 2023) that can hinder scientific data awareness. Chatbots like ChatGPT do not necessarily support a deeper understanding of material, with students often unaware of its limitations or uncertain how to critically evaluate its outputs, thereby demonstrating poor scientific data awareness (Farrokhnia et al., 2023). Students have illimitable access to digital libraries and databases, providing endless options for deep dives and research in geography, but if students are unaware of where data comes from or how to evaluate them, they are fundamentally underprepared (Parveen & Ramzan, 2024). Therefore, we believe that the promotion of scientific data awareness can begin to prepare us to address this new AI reality.

While not explored in our study, part of increasing scientific data awareness is having open dialogues about how AI technologies work and how best to use them. Large Language Models (LLMs), such as ChatGPT, can hallucinate false information and, without the proper scientific references, can mislead students (Cooper, 2023; Tlili et al., 2023). Even if citations are prompted, users must double check that those citations exist, given LLM's propensity to synthesize new, imaginary sources rather than regurgitating established, existing ones (Buchanan et al., 2023; Cotton et al., 2023). In

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addition, because ChatGPT synthesizes information, strong biases on the internet itself are built into the responses from the system (Tlili et al., 2023; Baidoo-anu & Owusu Ansah, 2023), making critical reflection of the scientific data outputs vital. As a tool, ChatGPT simplifies information and answers, which can negatively impact students' motivation and ability to perform independent research and arrive at their own conclusions (Kasneci et al., 2023).

Fighting against the increased use of AI amongst students is futile. But, in relation to geography data which is relying more and more heavily on AI (Oğlakcı & Uzun, 2025), AI is best used as a *tool* rather than a *generator*. Geography educators should create data lessons that use AI focused higher-order thinking skills to evaluate the accuracy of the presented material. Because students struggle to come up with scientific conclusions when using AI (e.g., Farrokhnia et al., 2023; Kasneci et al., 2023; Tlili et al., 2023), more honest discussions about AI's weaknesses and benefits can help educators utilize these tools, while establishing boundaries of their usefulness so that students can better understand the need to develop strong scientific data awareness. Given that dialogue can be beneficial in supplementing critical thinking skills among students (Abrami et al., 2008), honest conversations will better prepare students to evaluate materials they are fed by AI and the methodologies promoted above could act as a barrier to ensure that students are critically examining data presented to them.

## 6. Conclusions

In an era of growing social and natural challenges in the world, geography teachers will be crucial in preparing young people to work with highly diverse qualitative and quantitative data in the context of addressing current social issues. To demonstrate strong *scientific data awareness*, students must be able to understand what scientific data are, how they were collected/where they come from, and how to critically evaluate them. We conducted an empirical study on German pre-service geography teachers to better understand their scientific data awareness. While our participants seemed comfortable recognizing data within scientific and academic contexts, their perception of scientific geographic data outside of university was limited. Some of our students implied that data have an inherent certainty and truth – a fundamental misunderstanding of the use, reuse, and refutation of scientific data in geography. When students were asked how they might critically evaluate data, many displayed an inability to explain how they might do so. From these findings, we conclude that our pre-service geography teachers (1) lack critical scientific data awareness, (2) are not critical enough when selecting scientific data, and (3) have difficulties in comparing, structuring, and evaluating scientific data.

To address these concerns, we recommend utilizing more raw and real-world data in geography classrooms; ensuring students engage in data collection and reflection of data sources and quality; and working through the data life cycle (particularly verification and analysis) with students through inquiry-based learning. We believe this pursuit of stronger scientific data awareness has benefits to improve students' active citizenship in this uncertain era and to educate them in an era of increasing AI use. This work is relevant to educators responsible for teaching the next generation of geography teachers who must exhibit strong scientific data awareness to prepare their students for the modern and rapidly changing data environment. We recommend further studies that better address some of these concerns about data awareness (particularly in relation to AI) as well as modules to teach our students that scientific data are everywhere and support them in critically analyzing data in their daily lives.

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**Data Availability Statement:** All data from this study can be found in the supplementary materials. Demographic data is only provided as figures rather than as tabular responses for privacy purposes.

**Supplementary Material:** Available on journal's website here.

**Contribution to the Special Issue Topics:** Geography teachers are crucial in preparing the next generation to navigate highly diverse qualitative and quantitative geographic data in addressing natural and social issues. This work evaluates scientific data awareness (how data are perceived) of pre-service geography teachers at the University of Cologne to provide the foundation for future work and modules to better prepare students to combat and understand mis- and disinformation of complex socio-scientific issues using data.

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