International Society of
the Learning Sciences

Students' Strategies for Understanding Visualizations about Space and Time

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Abstract: Spatiotemporal (ST) data are used to illustrate information across a wide range of disciplines, so it is crucial that students learn to interpret the ST data. Twenty-three undergraduate students were presented with different ST data visualizations (both with and without context) and asked which were most/least useful, what they noticed, what strategies they used, and what they wondered about the data. Students found thematic U.S. maps easiest to interpret, whereas raster maps were most challenging. Video representations were reported to be the most interesting. We identified fifteen unique strategies that students employed when interpreting different types of ST data representations, including color grouping, comparing images, using prior knowledge, and horizontal/vertical scanning. Color grouping was the most common strategy used, but strategies varied across ST data types and level of context.

Introduction

Spatiotemporal (ST) data, or data that vary across space and time, are integral to understanding phenomena across a wide range of disciplines. For example, ST data can represent climate patterns over space and time, contributing to our understanding of climate change. ST data can also illustrate the location and timing of socially relevant issues like political events and socioeconomic inequities. It is crucial that adolescents develop the expertise required to successfully interpret the ST data representations that they encounter in school and in the world (NASEM, 2018). Prior research has considered how students comprehend either spatial *or* temporal data alone. When interpreting temporal data, people better comprehend event-related information than the continuous passage of time (Shipley & Zacks, 2008). Students also better understand temporal information within the scale of human experience (e.g., minutes, days, years) than information on micro (e.g., milliseconds) or macro (e.g., millennia) scales (Cheek et al., 2017). The types of temporal data and representations students encounter may impact the strategies they use to decipher the information, such as whether they estimate or guess (Lee et al., 2011). When it comes to spatial data, students' prior knowledge (Cook, 2006) and existing spatial skills (Uttal et al., 2013) impact their thinking. The form of the spatial data representations, such as whether students are shown one or many representations or whether the representations are stationary or animated, also affects students' thinking (Shipley et al., 2013). ST data can be uniquely challenging for high school and undergraduate students to understand (Myer et al., 2018), as it requires students to integrate information from multiple data representations and identify patterns (Kozma, 2003). Therefore, it is important to investigate what types of data visualizations students find easiest and most difficult to understand and to uncover strategies that support students in making sense of complicated ST visualizations. In this paper, we (1) explore the types of ST data representations that students find most useful, least useful, and most interesting and (2) identify the strategies students use when interpreting different types of ST data representations.

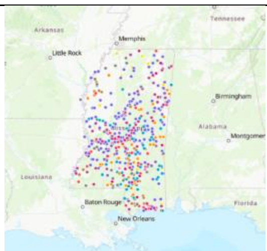
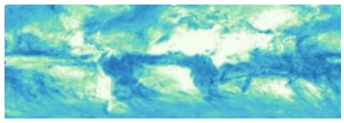
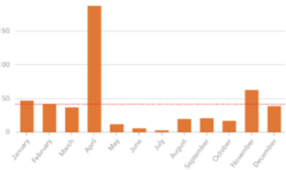
Method

Participants and procedure

Twenty-three undergraduate students from a large midwestern university (61% female, 39% male; 35% as Asian, 9% a black, 4% as Latine, 17% more than one ethnicity) participated in our study. Participants met with a researcher on Zoom, who explained that we would show them a series of visuals and ask them to "think aloud" about what they observed. We showed students visuals from three data sources, and the order in which students saw the visuals was counterbalanced. All participants were first shown the data sources without context—there were no titles or keys to help students determine what the visuals represented. After thinking aloud about these visuals, students were then given the context of the visuals and again asked to think aloud about them.

To understand students' preferences and strategies across different representation types, we showed students point data, thematic maps, raster data, and bar charts. The first visual used point data to depict tornadoes in Mississippi from 2010-2019 (see Figure 1 for all visualizations). Students also viewed a bar chart showing the average number of tornadoes by month. The second series of visuals were thematic maps of U.S. presidential elections from 2004-2012. The democratic and republican parties were shown in purple and orange instead of blue and red so as not to give away the context. The third series of visuals depicted global rainfall from 2000-2023 through sequential raster images and video. Each time students viewed visuals, both before and after receiving context, we asked (1) what patterns they noticed, (2) what strategies they used, and (3) what they wondered about the visuals. At the end of the procedure, we showed a slide with all of the data representations and asked students which representations they found (1) most useful, (2) least useful, and (3) most interesting.

Figure 1
Spatiotemporal data visualizations used in procedure before giving context

	Tornado Point Data	Election Data	Rainfall Raster Data
Image 1			
Image 2			

Data sources and analysis

After transcribing students' responses, we analyzed students' reports about which visuals were most useful, least useful, and most interesting. The rest of the students' responses were organized by data set (i.e., tornado point data, election data, rainfall raster data) and level of context (i.e., one visual with no context, multiple visuals arranged sequentially with no context, bar chart with no context, multiple visuals with context, videos with context). Our current thematic analysis focused on identifying strategies students used to help them make sense of the different data visualizations with and without context. Each participant produced up to six responses about their processes and strategies (N = 107 responses, M = 4.7 responses per student). We also examined whether or not students correctly guessed what each visual representation depicted (i.e., tornadoes, elections, rainfall) before receiving context and explored differences in strategy use between these groups.

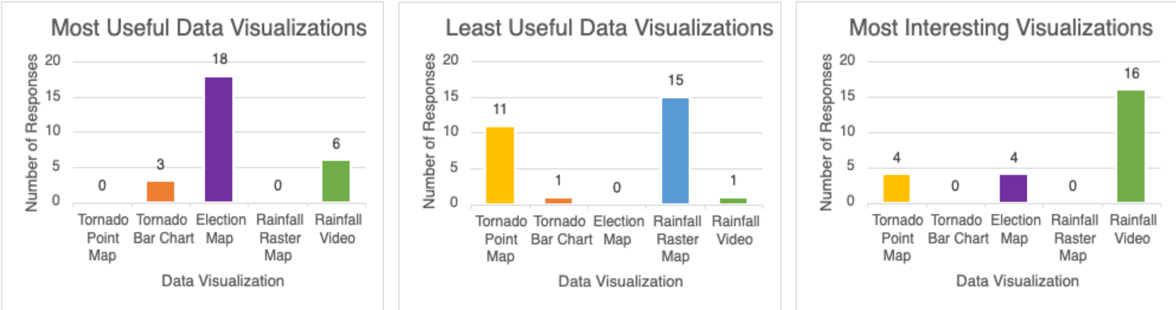
Findings

Students' visual representation preferences

When answering questions about which visual representations they found most useful, least useful, and most interesting, some students offered more than one response (see Figure 2 for all responses). For the most useful data visualization, 18 students (78%) reported the election map, six students (26%) reported the rainfall video (with context), and three students (13%) reported the bar chart for the tornado data. Likewise, 13 students (57%) guessed that the U.S. map depicted election data without context, whereas only six students (26%) guessed that the rainfall raster map depicted a weather pattern, and only four students (17%) correctly guessed that tornado point map and corresponding bar chart represented weather-related events. For the least useful visualization, 15 students (65%) reported the rainfall raster map (without context) and 15 (65%) reported the tornado point map (without context). The most popular choice for most interesting data visualization was the rainfall video (70%), followed by the tornado point map (17%) and the election map (17%).

Figure 2

Students' reports of most useful, least useful, and most interesting data visualizations



Students' strategies for interpreting visual representations

In our thematic analysis, we identified fifteen unique strategies that students used to interpret the visual representations (See Table 1). Students could report using multiple strategies in their responses, so our coding was not mutually exclusive, and each student responded to prompts about six different visual representations.

Table 1

Definitions and examples of students' strategies

Strategy	Number of responses	Definition	Example
Color grouping	47 (44%)	Searching for groups or clusters of the same color	"I was grouping into purple and orange clumps"
Prior knowledge	29 (27%)	Drawing on things they already know or have seen before	"I've seen similar things on the news"
Comparing images	20 (19%)	Identifying differences across multiple images or looking for changes	"I tried to see if there were differences across the three images"
Identifying clusters	19 (18%)	Searching for groups or clusters by features like shape, size, or density	"I was looking where the dots were most crowded"
Searching for patterns	18 (17%)	Stating that they were looking for patterns or repetition	"I was trying to look for a pattern"
Horizontal scanning	15 (14%)	Looking from right to left, east to west, or side to side	"I was looking from east to west"
Vertical scanning	8 (8%)	Looking from top to bottom, north to south, or up and down	"I started from the bottom and moved up"
Focusing on small areas	17 (16%)	Looking at small sections or areas such as states or countries	"I focused on Texas and Florida"
Focusing on large regions	7 (7%)	Focusing on large geographical regions	"I went by each hemisphere"
Focusing on map details	6 (6%)	Remarking on things like cities, roads, borders, and topographical features	"I'm seeing details or greenery and where rivers are"
Center-Edge Scanning	5 (5%)	Focusing on the middle and moving outwards, or zooming in and out	"I started from the outer edges and moved in"
Attending to dates/times	3 (3%)	Tracking days, months, or years	"I was paying special attention to April"
Guessing	2 (2%)	Explicitly stating that they were guessing what the visual representation depicted	"Using my intuition kind of"
Using the key	2 (2%)	Explicitly stating that they were using the key provided	"I was using the key at the bottom"
Looking for motion	1 (1%)	Looking for what is moving or staying still	"I'm seeing it all move together"

Importantly, students' strategies varied by data set and number of visuals. Students were more likely to use prior knowledge (X^2 (1, N = 107) = 10.76, p = .001) and color grouping (X^2 (1, N = 107) = 8.04, p = .005) when looking at a single map image, compared to multiple sequential images. In contrast, students were more likely to compare across images (X^2 (1, N = 107) = 27.15, p < .001) and use horizontal scanning X^2 (1, N = 107) = 6.55, p = .01) when viewing multiple sequential images, compared to one. Students were significantly more likely to search for patterns when viewing the rainfall raster maps (28% of students) and tornado point maps (23%), compared to the thematic election maps (4%), X^2 (2, N = 107) = 8.74, p = .013. But focusing on small areas (X^2 = 7.55, p = .023) and large regions (X^2 (2, N = 107) = 10.32, p = .006) were both more common for the thematic election map than the other two visuals. Focusing on map details like roads and topography occurred significantly more often for the tornado point maps (18%) than the thematic election maps (3%) and rainfall raster maps (2%), X^2 (2, N = 107) = 8.28, p = .016. Our analyses also revealed gender differences in students' strategies, such that male students (39%) were more likely to draw on prior knowledge than female students (19%), X^2 (1, N = 107) = 5.03, p = .025, but female students (57%) were more likely to use color grouping than male students (25%), X^2 (1, N = 107) = 10.87, p < .001.

Discussion and Implications

Many students are familiar with thematic U.S. maps that depict event-based data, which may be why students found that this visualization was most useful. A limitation of this work is that, in addition to using different types of ST data visualizations (raster, point, thematic), we also presented different topics (rainfall, tornado, thematic). Future research should consider students interpretations of ST data when visualization types differ, but the topic remain constant. Students described the rainfall raster maps as the least useful, yet the video of the same rainfall data was considered the most interesting. In future work, we will explore students' understandings of video data representations of point and thematic data to better understand the benefits of static and dynamic ST data visualizations. Overall, we identified fifteen strategies that students used to make sense of ST data and observed that strategies varied by student gender, data type, and number of images. We are coding students' reports about what they noticed and wondered about the ST data visualizations, and future analyses will include high school students. Based on these findings, educators may choose to explicitly communicate effective strategies for interpreting ST data visualizations and encourage students to adopt a variety of strategies.

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