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Scaffolding Middle School Students' Engagements with Historical Data Visualizations

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Abstract: We designed and implemented a data visualization project in a seventh-grade classroom focusing on the loss of tribal lands in Montana, United States of America. We aim to understand how students engaged with various scaffolds and how those scaffolds supported them in critically engaging with historical data through making hands-on projects. We analyzed data from multiple sources, including classroom implementation transcripts, student-created artifacts, and pre- and post-surveys. We observed that while students enjoyed creating data visualizations, they struggled to interpret them within their historical context despite the provision of multiple forms of scaffolds. We believe it is important to design a system of scaffolds to further support students in critically engaging with historical data and in developing critical data literacy.

Introduction

As increasingly large and complex data sets become more and more relevant to our personal, professional, and societal lives, it is more important than ever to provide K-12 students with opportunities to engage with data. While scholars have thought about data science education in a variety of ways, here we focus on the importance of developing students' data literacy skills, which are defined as the set of abilities which allows one to read, process, communicate, and produce data in a critical way (Tygel & Kirsch, 2016). In contrast to approaches focused on developing students' statistical knowledge or ability to work with computational tools, data literacy emphasizes developing students' abilities to read, interpret, and make meaning from data to inform decision-making and action-taking (Börner, Bueckle & Ginda, 2019). Data literacy further situates data in broader socio-political and historical contexts. We examine how to develop seventh graders' data literacy around historical data in the context of social studies. While many aspects of data science and data visualization are already present in social studies standards in the United States (e.g., College, Career, and Civic Life Framework, also known as C3 Framework), little research has examined how to engage students in working with historical data. In contrast to beginning with students' personal data or data from their own communities (Stornaiuolo, 2020), working with historical data is challenging because students often lack necessary context to make sense of the data.

We designed and implemented the Shrinking Lands project within a seventh-grade social studies class where students had recently learned about Westward expansion and its impact on Indigenous peoples in their state. The project asked students to connect what they had learned about their state to historical data from Montana as they created multiple data visualizations illustrating the loss of tribal lands through treaties with the U.S. Government. We sought to understand how students engaged with a variety of scaffolds and how those scaffolds supported them in critically engaging with historical data through making hands-on projects. By a scaffold, we refer to dynamic assistance provided by an expert to a beginner learner which is designed to support the learner in successfully engaging in activities they cannot yet accomplish alone (Wood, Bruner & Ross, 1976). Specifically, we pose the following questions:

(1) How do students engage with various scaffolds designed to support their learning about historical and personal data?

(2) How do students interpret historical data visualizations they create, especially in relation to broader historical issues such as the forced relocation of Indigenous peoples?

Background

Data literacy is defined as the ability to read, interpret, and make meaning from data to inform decision-making and action-taking (Börner, Bueckle & Ginda, 2019). Drawing on Freire's (1996) work, scholars call for incorporating a critical perspective into data science education. To critically engage data, students need to recognize and understand the historical and societal dimensions of data (Lee et al., 2020). For example, understanding family migration decisions requires an examination of national and global migration trends data over time to see how social and historical conditions impacted family movements (Kahn, 2020). Furthermore,

students are encouraged to examine and challenge power situated in the context and take action to address historical and socio-political issues in pursuit of a more just and equitable society (Lee et al., 2020).

Researchers have integrated data science education into K-12 content areas, most often leveraging personal data or publicly available datasets to develop critical data literacy (Rubel et al., 2016). While these datasets make data more relevant to students' lives, students also need to be able to make sense of historical data. Despite the importance of historical data and their connection to social studies standards around data visualizations (Shreiner, 2018), engaging students with historical data in social studies contexts remains relatively understudied.

In social studies education in the United States, there is a focus on making sense of data visualizations like maps and timelines (NCSS, 2013). Yet research shows that students often lack necessary context and struggle to make sense of data visualizations (Shreiner, 2018). As part of developing critical data literacy, students need to be able to create and make sense of data representations to develop their civics identities. Our goal was to see if we could leverage student-created data visualizations to enhance their abilities to make sense of historical data.

Given the challenges present as students make meaning from data visualizations, careful scaffolding is necessary to progress from their current level of competency to a higher level (Vygotsky, 1978). Scaffolds can take many forms ranging from instructional techniques such as fading scaffoldings employed by knowledgeable others or physical artifacts that students can think with to help them navigate complex problem spaces (Papert, 1980). Studies have examined the use of humans or online systems providing scaffolds to develop data literacy (Anderson, Nash & McCauley, 2015; Clegg et al., 2020) but few examine the materials students interact with as important scaffolds for learning (Litts et al., 2021). We focus on physical and digital objects as scaffolds that students can think with as they are engaging with historical data through creating hand-drawn and electronic textile data visualizations. Electronic textiles (e-textiles) involve components such as sewable microcontrollers, sensors, and actuators that can be sewn into textiles using conductive thread (Buechley et al., 2013). E-textiles is a common hands-on making activity that brings together familiar craft materials with circuitry design and coding to create a variety of wearable and/or interactive physical artifacts (Kafai, Fields, & Searle, 2014). While to the best of our knowledge, e-textiles have not yet been used to develop data literacy, Stornaiuolo (2020) explored students developing data literacy through making activities. Stornaiuolo found that students primarily focused on personal data sense-making rather than socio-political issues, highlighting the challenges of bringing a critical perspective into data science education. We chose to have students create e-textile data visualizations because we felt that creating and programming a tactile visualization would help them make abstract data more concrete for students. This work contributes to our understanding of how we can support students in developing critical data literacy as they engage with historical data through creating e-textile data visualizations.

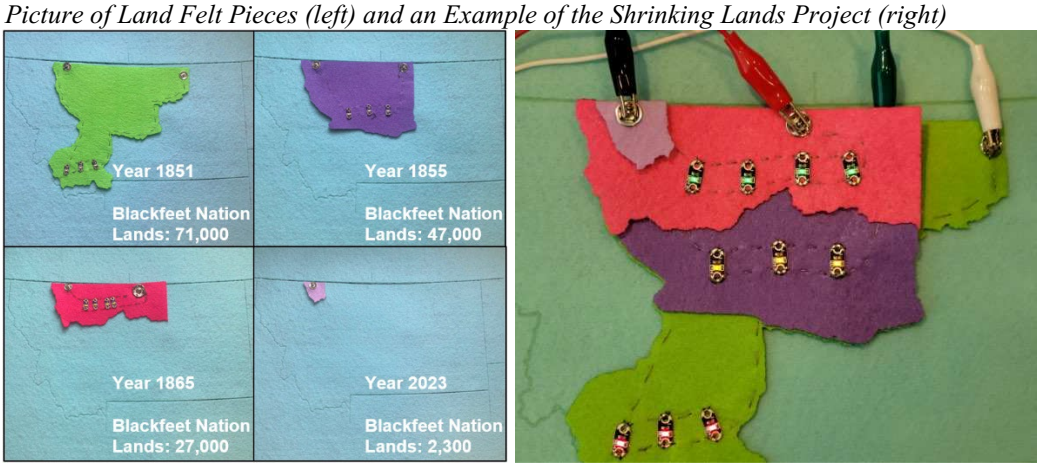
The Shrinking Lands Project

Based on the Shrinking Lands project (Searle & Fischback, 2022), we developed a unit which focuses on e-textiles data visualization depicting the historical loss of tribal lands in Montana, United States of America. This loss occurred due to treaties with the U.S. government and the outright land theft by white settlers. Table 1 provides an overview of the activities within this unit, each lasting 45 minutes. In this project iteration, our emphasis was on the loss of lands belonging to the Blackfeet Nation, the largest tribe in Montana. Students constructed an e-textile data visualization consisting of five felt pieces (see Figure 1) to represent the land loss. The bottom piece represents the current territory of the state of Montana and each of the other four pieces represents the shape and proportion of tribal lands that remained after the signing of three treaties with the U.S. Government in the 1850s. There are ten lights in total on this visualization and the number of LED lights assigned to each felt piece corresponds to the percentage of land represented. For example, the three lights on the deep purple piece in the example project represent the Blackfeet nation's loss of 30% of their land after the first treaty in 1885. The light purple felt in Figure 1, representing the present-day Blackfeet lands, does not have a light as it makes up less than 10% of the tribe's original homelands. Students programmed the LED lights using the Make Code blocks-based programming environment to initially all be lit up and then to turn off in a sequence, beginning with the largest felt piece and progressing to the smallest, visually illustrating the gradual loss of Blackfeet lands over time. Students were given the felt land pieces with the snaps that connect the pieces to one another sewn on. Students worked together in groups to construct and program the circuits with conductive thread, LED lights, alligator clips and a programmable microcontroller.

Table 1
Unit Design and Timeline

Time	Activities
Day 1	Project introduction, defining data, making bar graphs to show loss of Blackfeet Nation lands
Day 2	Introduction to circuitry and constructing paper circuits, pre-survey
Day 3	Collecting and reasoning with personal data, sewing e-textile visualizations with felts, LED lights, conductive thread and microcontrollers
Day 4	Treaty investigation based on texts and interactive maps from https://nativenews.jour.umt.edu/2018/history/
Day 5	Programming e-textile visualizations using Make Code
Day 6	Making connections between personal and historical data through Dear Data inspired visualizations of personal data, post-survey

Figure 1
Picture of Land Felt Pieces (left) and an Example of the Shrinking Lands Project (right)



Study design and method

Context and participants

We piloted this curriculum in a seventh-grade charter school classroom in the Intermountain Western United States during their "social studies with a twist" learning time on six consecutive Fridays. The students were accustomed to project-based learning. For the purposes of our project, the class was split into three groups that rotated between working with us and their other classes. 41 students participated in this study, mostly white, with no Indigenous students. Despite taking place outside Montana, the students had covered similar historical topics in their social studies class, such as Westward expansion and the forced relocation of Indigenous peoples. A key standard for seventh graders in this state centers on the ability to analyze and explain the connections between land and Indigenous communities using various forms of evidence, including geographic inquiry.

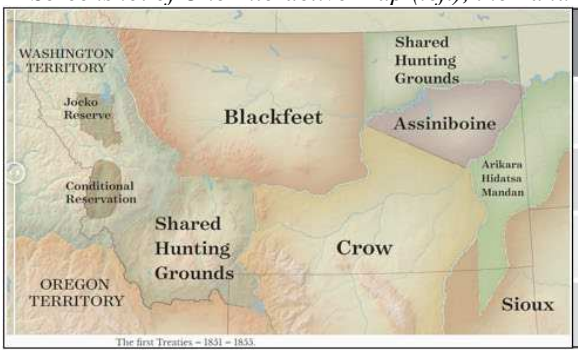
Students engaged with historical data related to the loss of Blackfeet nation lands on the first five Fridays. Various scaffolds supported students' learning during this time, including a land loss table, e-textile felt pieces and lights, and digital interactive maps with treaty investigation sheets. On day 1 they were introduced to the project and its context. Students created bar charts with colored markers based on the land loss table which illustrated how many square miles of land the Blackfeet retained after a series of treaties with the U.S. government. On days 3 to 5, they spent their time sewing and programming the e-textiles data visualization. Each student was responsible for sewing one felt land piece. During the programming phase, students individually tested each felt land piece. Any pieces that were non-functional or couldn't be easily fixed were replaced to ensure all groups could proceed with programming. On the fourth day, each participant was given a treaty investigation sheet and directed to a website (https://nativenews.jour.umt.edu/2018/history/) detailing the change of Indian Territories in

Montana over time. The website includes a text outline detailing each treaty and its impact on tribal lands and four interactive maps. Each map included a vertical slider that could move left or right. Sliding to the right revealed the tribal land before a treaty was signed, while sliding to the left displayed the land after it. In addition to online maps, each student was also provided with a treaty investigation sheet, designed to guide them in diving deeply into interactive maps to understand treaties and their impact on the Blackfeet Nation people. Students were expected to respond to ten questions on the sheet while navigating and making sense of the interactive maps.

Students engaged with various scaffolds throughout the unit and this study focuses on three - the land loss table, e-textile visualization, and online interactive maps with treaty investigation sheets- which essentially represent the same data and story (See Figures 1, 2 & 3). The land loss table is easy to read, and students can use it as a reference when interpreting the other two visualizations. E-textile visualizations allow students to make sense of the data by providing tangible materials and hands-on experiences. Interactive maps and treaty investigation sheets offer a visual comparison of the changes in the lands and prompts to guide students in understanding historical data.

Figure 2

A Screenshot of One Interactive Map (left), the Land Loss Table (right)



Year	Blackfeet Nation Lands (Square Miles)
1851	71,000
1855	47,000
1865	27,000
2023	2300

Figure 3

Questions on the Treaty Investigation Sheets

1. What have you learned about history in Utah in the 1840s and 1850s that might give us some clues about what's happening with the Blackfeet in Montana?
2. What happened that the Blackfeet had to start giving up their land?
3. What are the stories of the Blackfoot Peace Treaty and the Hellgate Treaty of 1855?
4. Why did the Blackfeet sell land in 1865? What did they get in exchange?
5. What story are the lights telling?
6. How else could we program the lights to tell a different story?
7. The story of the Shrinking Lands project is told from a Blackfeet perspective. What other perspectives are there on this story? Whose stories do you want to know more about?
8. Where does food enter into the Shrinking Lands story?
9. How did the population of the Blackfeet Nation change from 1850 to today?
10. What other things are you curious about?

Although outside the scope of this paper, students also engaged with and visualized personal data in parallel with historical data throughout the unit. This approach aimed to make data-related practices, such as reasoning and storytelling, more accessible to students. As literature suggests, students often find personal data more meaningful and relatively easier to engage with.

Data collection and analysis

We audio-recorded the curriculum implementation, documented observations through written fieldnotes (Emerson, Fretz, & Shaw, 2011), and took photographs of students' artifacts, including bar graphs, treaty investigation sheets, sewn e-textiles land pieces, and historical and personal data visualizations. Additionally, students completed pre- and post-surveys to examine changes in their understanding of historical data. All survey questions were open-ended.

As a first step of data analysis, audio recordings were transcribed using an automated transcription service and then corrected by a member of the research team. Our analysis primarily focused on the transcripts of group work during classroom sessions and fieldnotes to understand how students engaged with historical and

personal data using various scaffolds. We engaged in multiple rounds of open coding, focusing on moments when students attempted to interpret historical data visualizations and moments when students reasoned about personal data when creating visualizations. Throughout the process, we modified and consolidated our codes, subsequently identifying several themes to address our research questions. We triangulated our understanding of students' engaging with data and data interpretation from transcripts of group work and fieldnotes by analyzing the artifacts they produced and by reviewing pre- and post-surveys.

While we collected data from three sections of a larger seventh grade classroom, for this paper we conducted a case study (Merriam, 1988) with one section of 12 students. We chose this section for a case study because they represented the most complete classroom data set. In addition, this section was provided with several learning opportunities that were not present in the other sections. Finally, one student in this section engaged with interactive online maps that we envisioned as a key scaffold, but struggled to engage students in. All participant names are pseudonyms.

Findings

Throughout the coding process, we identified three themes regarding how students engaged with scaffolds as they were creating and interpreting historical data visualizations. They are: (1) a preference for hands-on activities, (2) struggling to make connections between visualizations, and (3) struggling to understand the story of historical data. We will unpack how each theme reflects students' interaction with historical data. Overall, students demonstrated various levels of engagement as they interacted with different scaffolds. They enjoyed sewing and programming while creating e-textile visualizations but were less interested in reading maps or creating bar graphs. Although students favored the hands-on nature of the e-textile projects, they struggled to interpret the data and understand the story behind it.

A preference for hands-on activities

Students actively participated in sewing and programming for the e-textiles project. They asked facilitators for assistance with sewing such as tying knots and fixing broken thread. Some students requested additional land pieces to sew because they enjoyed the sewing process. Students also demonstrated interest in experimenting with additional coding blocks in the Make Code programming environment and the features of the microcontroller. Through exploration and trial and error, some discovered how to make sounds or turn on lights to make patterns. They were enthusiastic about their discoveries that went beyond the taught content. For example, one student successfully lit up all built-in lights on the microcontroller with code and each light had a different color, forming a rainbow circle. She shouted with excitement, "Rainbow! Look at this, I made a rainbow!" When asked why they preferred e-textiles, some students responded with comments like "it includes shapes" and "it shows how much land they had and how much they lost." On the other hand, creating bar graphs and reading about treaties were not as appealing to students as the hands-on projects. Especially in the case of the reading task, which involved complex maps, we observed that many students strayed from the task, with some choosing to sew additional felt pieces instead and others simply refusing to engage in the activity at all. Eight out of twelve students turned in their treaty investigation sheets. One student handed in a blank sheet, while four others only responded to the last question, 'What other things are you curious about?', leaving the remaining nine questions unanswered. While this last question was the most answered among all ten, a few students wrote 'nothing', and the rest focused primarily on the daily life of the Blackfeet people. Although we recognize the value of these inquiries, the absence of responses relevant to the treaties indicates students' disinterest in the historical data they visualized.

Struggle to make connections between visualizations

Students struggled to make connections between the table which showed the loss of Blackfeet Nation lands and the e-textile data visualizations they created. When the facilitator held a completed e-textile project with all pieces connected and asked students what they observed, responses such as "it is getting smaller" and "it shows the disappearance of the Blackfeet territory" indicated their comprehension of the overall pattern of the Blackfeet Nation's territorial changes as depicted in the visualization. Some students could associate each felt piece with the corresponding entry in the table showing the treaty name, year, and the size of Blackfeet lands in square miles, but not all could. One student thought the largest felt piece represented the land in 1851, which in fact depicted the map of the state of Montana today. Although students sewed LED lights onto the felt land pieces and programmed them, they paid little attention to the bulbs' significance. Only one participant remarked on the light pattern, saying, "So lights going out is kinda like the land disappearing." None of them explained or questioned the number of lights on each felt piece. Yet, we designed the project so that the number of lights on at a given time represented the percentage of original Blackfeet Nation lands remaining.

While students were generally disengaged in the treaty investigation, one student engaged with the interactive maps in a way we hoped all students would engage with them. Liam expressed surprise at the significant decrease in land illustrated by the interactive maps. Scrolling back and forth over the interactive map, he noted, "Blackfeet is humongous, then after the... it was super big and then...", showing that Liam was able to interpret patterns of land loss demonstrated through a series of maps. He switched between maps, attempting to align them with the corresponding land field pieces of the e-textiles visualization. Throughout his exploration, Liam also noticed tribal territory changes that are not captured in the e-textile project and posed questions based on his observation. For example, he noticed that the Blackfeet owned a large amount of land on the 1860 map, yet their territory vanished on the 1870 map; then on the 1880 map, the territory of the Blackfeet reappeared. Intrigued by this, Liam turned to the facilitators and asked, "Why can't you even see the Blackfeet anymore?" referring to the 1870 map, and then he wondered, "How did they get it back?" when looking at the 1880 map. Overall, interactive maps hold promise as a scaffold to help students understand how tribal lands have diminished over time in a visual way, but only one student in the class was able to do so, suggesting that students need additional scaffolding to engage with the interactive maps in a meaningful way. Most students engaged with the worksheet we created to further scaffold their interactions with the interactive maps in an extremely limited way because they didn't like having to read and write things down. Thus, while Liam's engagement with the interactive maps shows the promise of this scaffold, most students needed additional support to be able to meaningfully engage with the interactive maps and to make connections between their hands-on projects and the interactive e-textiles visualizations.

Struggle to understand the story of historical data

Students struggled to interpret the e-textile data visualization within its historical context. Even though they had previously learned about similar history from their state's curriculum, they did not remember details about the treaties and their effects on Indigenous people. When asked about the history of their state in the 1840s and 1850s, students responded with vague answers like "I don't know," "Westward migration," or a general answer such as "colonizing Americans."

Although most students did not fill in the treaty investigation sheets, from limited numbers of answers we can still conclude that students did not understand the story the historical data visualization tells. For example, students' responses to the question "What stories are the lights telling?" reveal that they did not understand what the lights represented. Only three students answered this question. One's handwriting was illegible, one simply wrote "I don't remember,"' and another responded with "I don't know. I think it is where they (the Blackfeet Nation) lives now." When the facilitator asked students how they felt when all the lights went out, one student responded, "Scary. I don't know." Another said, "It feels like there's a monster in the closet," indicating their lack of understanding of the story depicted by the visualization. To help students think of historical data and connect to broader social issues, both the classroom teacher and the facilitator employed various strategies to make the data more relatable and meaningful. For instance, they referenced the populations of several states and cities, including Chicago, to provide students with a tangible sense of the decrease in the Native American population, which changed from 100 million to 10 million in both North and South America. Yet, some students still perceived 10 million as a large number, focusing on the absolute value rather than recognizing that 90% of the population had been lost. The teacher then prompted them to consider a scenario where only one out of ten people in the classroom would survive, to make the significance of the decrease in numbers more accessible. Analogies, such as cupcakes and academic grades, were also introduced to help them understand the loss of 90% of the land. This approach had some success: when students were asked to imagine their grade dropping from 100% to 10% due to someone else's actions, one student commented, "I would be mad." However, in general, they lacked understanding and displayed limited concern for the story behind the e-textiles data visualization. So, while students liked creating hands-on data visualization, they had no idea what the story of the visualization was.

From survey responses, we also discovered that despite their engagement with historical data throughout the entire unit, most students did not understand the concept of historical data. Out of twelve students, six responded with 'I don't know' when asked to think of any type of historical data in the post-survey. Other responses unrelated to historical data in a social studies context included paleontology and the number of years since someone's parent passed away. We also asked them to consider what data might be missing from the historical record. All students responded with "I don't know," except for two who provided answers demonstrating their understanding of perspective-taking in storytelling with historical data. They said, "I think that sometimes data doesn't show both sides of the story because we only ever see or learn about one side of a story"; "You don't always hear both sides of a story. For example, in war, the war is told from the perspective of the victor." This suggests more scaffolding is needed to introduce historical data, which is often disconnected from students' daily lives, to help them develop a concrete understanding.

Discussion

The literature on data visualization in social studies makes clear that social studies abounds with visualizations of data (e.g., timelines, graphs, maps), but students struggle to make sense of them, often because of a lack of understanding of the historical context surrounding a given data visualization. Unfortunately, given the pilot nature of this study, we do not know if students regularly engaged with data visualizations in their social studies class or how often they did so. We do know that students struggled with interpreting visualizations of data in our study. For instance, although Liam was deeply engaged in making sense of the interactive maps, his experience heavily relied on continuous support and guidance from one facilitator, and he frequently asked questions while navigating between maps. This suggests that understanding a map is challenging and therefore requires more structured, teacher-led scaffolding, as opposed to a student-led, inquiry-based approach. This echoes findings from the literature which challenge the assumption that data visualizations make information more accessible and easy to understand; students face significant difficulties in both creating and interpreting these visualizations (Shreiner, 2018). Indeed, we encountered the same problem in another middle school social studies classroom where the classroom teacher assumed students would be able to fill in a blank timeline without a lot of guidance but had to return to the activity the next day and explicitly instruct students on where to place information on the timeline and what the purpose of the timeline was.

Often, scholars suggest engaging students with personally meaningful data to introduce them to data visualizations as one component of a larger focus on data science. Yet, Stornaiuolo (2020) found that students struggled to move beyond personal data (e.g., a record of skincare products and their effects) to more sociopolitical engagements with data. While we focused our analysis on students' engagements with historical data, we also had students collect and visualize personal data on two of the six lesson days. Our goal was to encourage students to engage with personal data that was meaningful and relevant to them, hoping this would help them connect to historical data about the loss of tribal lands. Our findings resonate with what Stornaiuolo found; students failed to make connections and did not see the sociopolitical significance of historical data. It may be that students need a more structured progression of learning around data visualizations, moving from personal data to contemporary sociopolitical data to historical data. In more recent efforts to engage students with data as part of the larger study, we have let the classroom teacher take the lead on introducing students to a unit we designed and we have taken extra care to introduce students to the context of the data, spending a week introducing students to the people and places of the reservation they are learning about and their forms of governance before ever having students engage with data. Such an approach has helped provide students with the larger historical context surrounding the data visualizations they are creating and has led to further student engagement.

Finally, our study makes a contribution to the body of literature concerned with students constructing their own data visualizations, such as the images the students in Stornaiuolo's (2020) study screen printed onto t-shirts and tote bags. While making activities are often criticized for an "unguided discovery learning," approach to instruction, the Shrinking Lands project and other hands-on projects are carefully designed to simultaneously promote student agency and support student learning. While students enjoyed the process of making the e-textiles data visualization, only a few students were able to understand the product and then in the most limited terms. We suggest that our designed scaffolds fell short of our desired learning outcomes for students because we needed to more carefully consider how to balance learning about the historical context necessary to make sense of the data students were working with and learning how to create and interpret data visualizations with a constrained, six lesson timeframe. A more critical takeaway for future iterations of scaffold design is to consider the synergy between scaffolds of varying intents to amplify their functions and create a more engaging and productive learning experience. Literature suggests using various forms and a combination of scaffolds to provide a wide array of learning opportunities for students (Puntambekar & Kolodner, 2004). An array of scaffolds not only means a variety in form, such as a combined use of innovative technologies like e-textiles and traditional scaffolds like maps and worksheets, but also addresses a spectrum of challenges students meet when interpreting and creating data visualizations. This means we need to devise scaffolds to help students read and interpret visualizations, to understand the context around historical data and link it to socio-political issues, and to make connections between personal data and historical data explicit. For instance, we will need to introduce additional scaffolds that immerse students in the context of the data before having them work on a treaty investigation sheet. We might also complete the treaty investigation sheet as a whole class rather than in small groups, so that the instructor can serve as an additional scaffold for students learning.

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