The Information Won't Just Sink In: Helping Teachers Provide Technology-Assisted Data Literacy Instruction in Social Studies

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Structured Practitioner Notes

What is already known about this topic

- Data literacy is an important part of social studies education in the United States.
- Most teachers do not teach data literacy as a part of social studies.
- Teachers may adopt technology to help them teach data literacy if they think it is useful and usable.

What this paper adds

- Educational technology can help teachers learn about data literacy in social studies.
- Social studies teachers want simple tools that fit with their existing curricula, give them new project ideas, and help students learn difficult concepts.
- Making tools useful and usable does not predict adoption; context plays a large role in a social studies teachers' adoption.

Implications for practice and/or policy

- Designing purpose-built tools for social studies teachers will encourage them to teach data literacy in their classes.
- Professional learning opportunities for teachers around data literacy should include opportunities for experimentation with tools.
- Teachers are not likely to use tools if they are not accompanied by lesson and project ideas.

Abstract

In this study, support for teaching data literacy in social studies is provided through the design of a pedagogical support system informed by participatory design sessions with both pre-service and in-service social studies teachers. It provides instruction on teaching and learning data literacy in social studies, examples of standards-based lesson plans, made-to-purpose data visualization tools, and minimal manuals that put existing online tools in a social studies context. Based on case studies of eleven practicing teachers, this study provides insight into features of technology resources that social studies teachers find usable and useful for using data visualizations as part of standards- and inquiry-based social studies instruction, teaching critical analysis of data visualizations, and helping students create data visualizations with online computing tools. The final result, though, is that few of our participating teachers have yet adopted the provided resources into their own classrooms which highlights weaknesses of the technology acceptance model for describing teacher adoption.

Keywords: Literacy, Visualization, Secondary Education, Participatory Design, Technology Acceptance Model

The Information Won't Just Sink In: Helping Teachers Provide Technology-Assisted Data Literacy Instruction in Social Studies

It is an image familiar to many of us. A man dressed in a suit and standing behind a podium points to a busy, nonsensical mess of lines and curves over a grid system – a line graph, the reader presumes, that the man expects his audience to interpret. Below the image, the caption reads simply, "I'll pause for a moment so you can let this information sink in." The cartoon, one of the late Gahan Wilson's well-known *New Yorker* contributions, is amusing because most of us can relate to its premise (Maslin, 2019). At one point in our lives, we have sat in a classroom or lecture hall, read an article, or watched a news report where we are expected to look at a data visualization and somehow, intuitively, understand the information it is communicating.

For students in elementary and secondary social studies classes, this experience is probably all too common. Data visualizations such as timelines, maps, and graphs are ubiquitous in social studies. They fill the pages of textbooks, appear prominently in online resources, and are frequently included on social studies standardized tests (National Assessment Governing Board, 2018a, 2018b, 2018c; Shreiner, 2020). Reading these data visualizations can be challenging for students, particularly if they lack understanding of context or content related to the data, or if a data visualization contains information not directly related to a question or topic a student is trying to address (Friel et al., 2001; Maltese et al., 2015; Shah & Hoeffner, 2002; Strobel et al., 2018). If students are to make sense of the multitude of data visualizations they will encounter in social studies, they must be data literate—that is, they must be equipped with skills to understand what data mean, draw conclusions from patterns, trends, and correlations in data, and recognize when data are being used in inappropriate or misleading ways (Börner et al., 2016; Carlson et al., 2011). Yet, recent research suggests that less than a quarter of social studies teachers regularly provide explicit instruction around data visualizations (Shreiner & Dykes, 2021). This tendency may be rooted in assumptions that data visualizations are easy to read (Shah & Hoeffner, 2002), but it is more likely that teachers feel they lack the knowledge, preparation, and resources to teach data literacy effectively (Shreiner & Dykes, 2021).

In light of this gap in social studies teachers' knowledge and teaching resources, we have built a technology-assisted support system to help teachers incorporate data literacy into social studies instruction. This system includes an open educational resource (OER) with guidance for teachers on analyzing and using primary and secondary source data visualizations, exemplary lessons that integrate data literacy, and manuals to guide teachers in using online data visualization creation tools. Additionally, embedded in the OER is a task-specific computing tool our team has designed to support data inquiry in social studies. We have built this support system using participatory design research methods with both undergraduate pre-service and practicing social studies teachers as design informants (DiSalvo et al., 2017; Druin, 2002). Our research asks:

RQ1: How do we give social studies teachers effective, accessible professional learning opportunities that will help them feel prepared and supported in teaching data literacy in social studies?

RQ2: What features of purpose-built educational technologies and resources do teachers find useful and usable for teaching data literacy in social studies?

Background

The Role of Data Visualizations in K-12 Social Studies

Data literacy is an essential part of social studies education. All the core disciplines of social studies—history, geography, civics, and economics—use data visualizations extensively to provide information, and to support inquiry and arguments. Maps, for example, are critical in geography for mediating spatial understanding of the world by modeling vast spaces that humans can never directly experience (Uttal & Sheehan, 2014). Historical maps can also serve as primary sources for historians, and historians regularly use them to visualize and analyze complex spatial processes, changes, and relationships. Timelines for displaying chronology and change over time are another type of data visualization in the toolbox of historians, and they often use graphs to compress and analyze broad, otherwise invisible patterns (Shreiner & Zwart, 2020). Political scientists use and visualize survey and polling data and use graphs of political trends and relationships in their work (Barbour & Wright, 2015). And economists depend on data visualizations such as time series or line graphs to show how economic variables change over time, or scatterplots to show relationships between economic variables (Council for Economic Education, 2010; Goodwin et al., 2017). Therefore, if students are to become literate in the disciplines of social studies, they must also be data literate (Shreiner, 2018b).

The importance of data visualizations in the social studies disciplines is reflected in social studies standards, standardized tests, textbooks, and online resources as well. Social studies standards across the United States require students to interpret, analyze, use, and create maps, graphs, or charts, typically as early as kindergarten or first grade. (Shreiner, 2020). Data visualizations are also embedded in the National Council for the Social Studies' (2013) *College, Career and Civic Life (C3) Framework*, a document that has influenced revision of state social studies standards throughout the United States. The document recommends that students create chronological sequences, and construct and use maps, graphs, and other visual representations beginning in the early elementary grades and throughout high school. It is no surprise then, that standardized assessments such as the National Assessment of Educational Progress (NAEP) in

U.S. history, geography, and civics include test items that require students to interpret and construct a variety of data visualizations (National Assessment Governing Board, 2018a, 2018b, 2018c). Social studies textbooks are also filled with data visualizations. In the typical elementary textbook, a data visualization is likely to appear every 13.6 pages, and in middle school textbooks, every 7.2 pages. By high school, students will encounter a data visualization every 4.8 pages (Shreiner, 2018a). Data visualizations are also common in some of the most popular online repositories of online social studies lesson plans, such as *Stanford History Education Group*, *C3 Teachers*, *EDSITEment*, and *Library of Congress*. Across those four websites alone, there are data visualizations in 39% of the social studies lesson plans (Finholm & Shreiner, 2022).

Finally, and most importantly, data visualizations can help students learn social studies. As several scholars (e.g., Norman, 2012; Roberts et al., 2015; Schnotz & Kurschner, 2008) have argued, reading data visualizations and other visuals can improve overall comprehension and quality of reasoning. Data visualizations often extend information provided in verbal text by providing contextual information, illustrating changes or movement across space and time, or providing evidence for an argument or explanation (Fingeret, 2012; Shreiner, 2018a). They are also a mode of information through which students can acquire disciplinary content knowledge, which will serve as critical background knowledge in later studies. And, there is evidence to suggest that reading data visualizations helps students better understand historical and geographic context, multiple causation, and change over time—all important concepts for them to grasp in social studies subject areas (Shreiner, 2019).

The Importance of Teaching Data Literacy in Social Studies

However, students cannot learn from data visualizations if they do not know how to make sense of them. Despite assumptions that data visualizations are easy to understand, students are likely to face several challenges when working with them (Brugar & Roberts, 2017b; Duke et al., 2013; Maltese et al., 2015; Shah & Hoeffner, 2002; Shah et al., 1999). Consider timelines, for example, which are often included in textbooks or provided as handouts to frame and contextualize an event or phenomena under study. When trying to extract information from a timeline, a reader must be aware of all the chronological conventions that denote quantities and passage of time, including terms like decades or centuries, as well as notations such as BCE (Before Common Era) and CE (Common Era). These chronological conventions are not necessarily intuitive for students and can therefore hinder their ability to reason chronologically. Furthermore, timelines often display only points or tick marks to indicate when events begin or end, thereby masking durations of events as short as an hour or as long as thousands of years (Blow et al., 2012).

Maps, which are the most common type of data visualization students encounter in social studies, can also be challenging for students to read (Shreiner, 2018a). To even begin to understand the information maps convey, students must recognize that all maps are inherently incomplete and distorted—merely representations of real space that cannot possibly show us everything about the place they are intended to represent. And of course, different map projections cause different distortions in the shape and size of landmasses. The Mercator projection, for example, which students probably see in their textbooks and on classroom walls most often, famously makes Africa look much smaller and Greenland much bigger than they are in reality (Marshall, 2016). If teachers do not address different projections and their distortions with students, students may then walk away from school with misconceptions about the world.

Research has also indicated that reading graphs is a complex process with several discrete steps, and a breakdown in any one of these steps could negatively impact a student's understanding (Brugar & Roberts, 2017a, 2017b; Roberts et al., 2013). Because data is encoded as various visual elements (e.g., shapes, colors, text) in a graph, readers must first identify visual elements such as the shape and directions of a line or numbers on an axis (Friel et al., 2001; Harsh et al., 2019; Maltese et al., 2015; Shah & Hoeffner, 2002; Shah et al., 1999). Ignoring or skipping over visual elements is like skipping over words or punctuation in a paragraph—doing so can change the meaning of the passage. Then, viewers must relate the visual elements to the conceptual relations that are represented by those elements—that is, they must map between the elements themselves and their meaning, such as recognizing that a curved line implies an accelerating relationship. This ability is largely dependent upon the viewer's experience with different graphics, or their understanding of graphical conventions (Friel et al., 2001; Maltese et al., 2015; Shah & Hoeffner, 2002; Shah et al., 1999). Finally, a viewer must make associations between the graphic representation and the context or the referents (e.g., immigrant population or number of casualties) that are being quantified (Friel et al., 2001; Maltese et al., 2015; Shah & Hoeffner, 2002; Shah et al., 1999). This last factor indicates that students should work with graphs within a specific context, such as in social studies classes, rather than as abstractions disconnected from content (Shah & Hoeffner, 2002).

Yet, despite the important role of data visualizations in social studies and the many challenges students face in reading them, most teachers do not regularly teach data literacy as a part of social studies instruction (Shreiner & Dykes, 2021). This is not to say that they believe data literacy is unimportant. On the contrary, most teachers agree it should be taught, but report having had little coursework to prepare them for such a task, and that they lack confidence in their own data literacy skills as well as their ability to teach it effectively. On top of that, many of the social studies-specific resources teachers have access to provide little guidance for teaching data literacy. For example, in school textbooks, most data displays contain no information to help students make sense of the data or connect it back to the running text. Likewise, running text rarely directs students to refer to the data visualizations on the page (Shreiner, 2018a). If teachers are unaware of the importance of helping students notice data visualizations as sources of information, it is likely that students will learn to ignore them altogether (Duke et al., 2013; Shreiner, 2019). And online social studies lesson plans with data visualizations are hardly better. Even though data visualizations are often included in slide presentations or student handouts in online lessons, a significant portion of them provide no guidance for teachers to help students make sense of them (Finholm & Shreiner, 2022). Too often, the underlying assumption seems to be that the information will just sink in.

Technology Supports for Teaching Data Literacy in Social Studies

Technology offers some possible solutions to the challenges teachers face in implementing data literacy in social studies. First, technology allows for the design and delivery of open educational resources built to support learning. Online, open resources can be disseminated widely, allow teachers to access them beyond a teacher education course or professional learning opportunity, and can easily be updated or modified (Baker, 2019). Secondly, using an online platform for design and delivery of curriculum materials provides opportunities to build an "educative curriculum"—that is, materials designed with both student and teacher learning in mind, and that can take advantage of hyperlinks and embedded videos to connect ideas and materials for teachers (Davis & Krajcik, 2005; Davis et al., 2017). Finally, technology tools give teachers and students access to a wide array of data and datasets, and allow them to create and manipulate data visualizations for themselves, likely enhancing their understanding of and ability to critically analyze them (e.g., Bausmith & Leinhardt, 1998; Irgens et al., 2020; Philip et al., 2013).

However, technology can only influence student learning of social studies if they actually use the technology within the context of studying social studies topics, which is most likely to happen through formal education. The technological-support framework that we are creating requires teacher adoption to influence student learning. We frame this problem in terms of the Technology Acceptance Model (TAM; Davis, 1993; Lee et al., 2003), which predicts that teachers will only adopt technology if teachers perceive the technology is *useful* (e.g., facilitates learning towards standards and objectives) and *usable* (which includes computer interface usability but also context, like fitting into course schedules). In order to adopt technology for data literacy, the teacher must believe the technology can help them achieve their learning goals (e.g., address a student learning challenge) while fitting into their existing structures and constraints (e.g., existing curriculum, class time), and that they can successfully implement the activity (Holden & Rada, 2011).

TAM has had mixed success in predicting teacher adoption (Ertmer & Ottenbreit-Leftwich, 2010; Ottenbreit-Leftwich et al., 2010; Tondeur et al., 2017). Teacher beliefs, knowledge, confidence levels, and setting (e.g., what technology teachers around them use) also influence teacher adoption, beyond measures of usability and usefulness. In other words, a teacher's choice to adopt is only partially about the technology. Our theoretical framework, described below, begins with TAM, but must also include theories about other aspects of teachers that address personal choice.

Theoretical Framework

Our research design sits at the intersection of research on teacher knowledge, research on teacher efficacy, and the Technology Acceptance Model. First, several scholars (Ball & Forzani, 2009; Ball et al., 2008; Putnam & Borko, 2000) have argued that the specialized knowledge of teachers has a significant impact on teacher decision-making and their ability to affect student learning. Such knowledge is complex, consisting of subject matter content knowledge, curricular knowledge, and pedagogical content knowledge (PCK; Shulman, 1986). Teacher education and professional development should provide teachers with situated learning environments that build their knowledge for teaching, and teacher educators should consider ways to provide pedagogical tools for teachers that will distribute cognitive processes of teaching and alleviate cognitive load (Putnam & Borko, 2000). Models of how PCK interacts with technology can be powerful for understanding how teachers learn to use technological tools in their teaching (Özgün-Koca et al., 2010). Teacher education programs can provide the knowledge needed to adopt and use technology, but in-practice context (e.g., the common practices and technologies used in the school) can have greater influence on teacher adoption than what was learned in the preparatory program (Ottenbreit-Leftwich et al., 2012; Tondeur et al., 2012).

Another line of research (e.g., Bandura, 1997; Tschannen-Moran et al., 1998; Wolters & Daugherty, 2007) has focused on teacher efficacy, arguing that a teacher's belief that they can successfully carry out a teaching task influences the teacher's performance of said teaching task. Mastery experiences (direct teaching experiences); vicarious experiences (watching peers teach); physiological and emotional states (feelings of success and confidence); and social and verbal persuasion (receiving positive feedback) are key sources of efficacy information for teachers (Bandura, 1997; Tschannen-Moran & Hoy, 2001; Tschannen-Moran et al., 1998). As Tschannen-Moran et al. (1998) have argued, teachers process efficacy information to assess their teaching competence and analyze the teaching task. Perceived competence involves judgments about one's current functioning related to the teaching task, while analysis of a teaching task entails making judgments about the difficulty of the task and likelihood of success. Teacher beliefs and confidence influence the choice of technology for a given task (Ertmer & Ottenbreit-Leftwich, 2010; Ottenbreit-Leftwich et al., 2010). Therefore, while professional learning opportunities can help strengthen teachers' knowledge and provide efficacy information through teaching experiences and positive feedback (Charalambous et al., 2008; Newton et al., 2012), consideration should also be given to teachers' judgements about their own competencies, as well as their judgments about the kinds of resources and conditions that will help them achieve success with students.

Our work assumes that computational technology can contribute to teachers' knowledge and sense of efficacy, but TAM tells us that to influence adoption we should focus on usability and usefulness. While we know that this is insufficient to predict teacher adoption (Aldunate & Nussbaum, 2013; Zhao & Cziko, 2001), it is a reasonable starting place. We recognize that there are interactions between specific technologies and the contexts for which they are designed. For example, our purpose-built visualization tool has an explicit programming component, but we know that programming is not a context-free activity and that the context associated with a programming activity influences student success (e.g., engineering students have been more successful with programming grounded in an engineering context; Forte & Guzdial, 2005). Languages that are built for specific domains are easier to use and lead to fewer errors when used within those domains compared to general-purpose languages (Albuquerque et al., 2015; Kosar et al., 2012; Kosar et al., 2010). To be sure, a recent study found that pre-service mathematics teachers struggled to learn a general purpose programming tool because of conflicts between how mathematics and computer science treats common terms like "variable" and "function" to meet different things (Kalathas et al., 2022). This is an example of how factors related to the teacher (e.g., the subjects being taught) and features of technology interact, underscoring the importance of a teacher-specific notion of usability and usefulness.

Methods

Our work uses participatory design research (PDR) methods (Spinuzzi, 2005) to develop a support system consisting of an OER and a task-specific tool called DV4L. Our goals for the support system, guided by our theoretical framework, were to (1) build teachers' knowledge about data literacy in social studies; (2) increase social studies teachers' confidence in their competencies related to teaching data literacy; (3) alleviate perceived challenges in implementing data literacy; and (4) provide social studies teachers with data literacy-related tools they believe are useful and usable enough for adoption. PDR focuses on tacit use of resources and tools by participants in the early phases of design. Like other studies on the use of technology in education (Abel & Evans, 2013; Wilkerson, 2017), the main participants or stakeholders in our work are teachers. We view PDR as means to empower current and future social studies teachers by designing or redesigning resources and tools to be better attuned with what teachers actually do in their classrooms and the kinds of tools they use, based on their unique context, students, and needs (Bang & Vossoughi, 2016).

Design of OER

Our research process focused on improving two separate but interrelated parts of the support system we are designing: the OER (see Figure 1) and the task-specific tool embedded within the OER (see Figure 2). Shreiner, a former social studies teacher and current social studies teacher educator, led design of the OER to help pre-service and in-service social studies teachers learn about data literacy, while providing them with multiple resources to help with standards-based implementation. It has six "modules" organized around driving questions and with one or more subsections of content or resources (see Table 1 for module descriptions). The content is based on several studies (e.g., Shreiner, 2018a, 2019, 2020) related to data literacy in social studies, including the role that data visualizations play in curricular materials across the United States. Resources included are primary source data visualizations, links to websites with data visualizations, and links to several free, online data visualization tools (e.g., Google Earth, Timeline JS, ArcGIS Storymaps) that can be used for social studies-specific projects. Accompanying these tools are "minimal manuals" (Carroll et al., 1987) designed to help both teachers and students use the tools.

[Insert Figure 1 about here]

[Insert Table 1 about here]

Design of DV4L

We also embedded in the OER the task-specific tool (see Figure 2) we have been working on, DV4L (Data Visualization for Learning) at our History in Data website. The tool uses computing to enhance learning of data literacy in social studies while also helping students learn concepts and skills in computing. It was initially designed using results from participatory design sessions with pre-service social studies teachers enrolled over two semesters in Shreiner's class, which focuses on data literacy for social studies teaching (Naimipour et al., 2019, 2020; Naimipour et al., 2021). In our participatory design sessions with pre-service teachers, our participants used different visualization tools as "design probes" (Wallace et al., 2013b) to elicit from them needs and constraints for data visualization tools for social studies classrooms.

Our first trial used two design probes. The first was a traditional programming language (JavaScript) calling upon graphing facilities as a library (Google Charts). While some of the pre-service teachers appreciated the value of using a programming language that might also be used in a science or mathematics course, most of the pre-service teachers found the complexity forbidding. They explicitly were concerned about getting error messages and being stuck in the middle of a lesson. We also used Vega-Lite, a data visualization tool created for professional journalists and others who needed data visualization (Satyanarayan et al., 2017). The pre-service teachers appreciated the high-quality graphics produced from Vega-Lite, and the editing environment for Vega-Lite scripts scaffolded the teachers' explorations. However, they still found it difficult to understand. Their exploration was not a purposeful inquiry into their driving questions—they felt disconnected from the data.

In a second participatory design session with pre-service teachers, we added a third tool, CODAP (Common Data Analysis Program), which was explicitly designed for middle and high school classes, especially in science and mathematics (Finzer & Damelin, 2016). This proved to be most successful with the pre-service teachers. Unlike JavaScript and Vega-Lite, CODAP is a drag-and-drop visualization tool that offers a spreadsheet-like view of the data and a wide variety of visualization types. Teachers in our sessions enjoyed generating the full range of visualizations, which included maps. However, some teachers told us that they did not understand how to ask questions with those visualizations. The process was too complicated. One teacher told us that she could imagine teaching her students to use CODAP with a few hours of class time, but she did not know if she would be using CODAP enough to make it worth that much time.

From the results of these sessions with pre-service teachers., we developed our own tool, DV4L, which is aimed at giving the teachers the usefulness they needed, with a level of usability that would work within their classroom contexts. In our tool, students specify visualizations with pull-down menus (on the left of Figure 2). We always show two visualizations (center of Figure 2) because historical inquiry often begins with two pieces of data or accounts that do not agree (Bain, 2000). The visualizations thus become the focus of the inquiry process and are intended to support a historical inquiry process.

[Insert Figure 2 about here]

An inquiry process involves more than generating a couple of graphs. In DV4L, graphs from the center can be dragged into spaces on the right to create a visual trace of an inquiry process. Students can then scan over a set of graphs they generated to see which have a characteristic of interest.

We support development of computing knowledge and skills by showing the program (see Figure 3) as a concise description of how the graph is presented. The student does not write the program. We present the program as a useful description to read which can be edited for ease (see Figure 4). The programming aspects of DV4L are not about programming for its own sake, but as a way to explore rapidly a set of variables (e.g., different databases or date ranges) during inquiry.

Clicking on a graph overlays a script (see Figure 3) that describes how the graph was generated. The structure of the script is based on Vega-Lite because of its success with pre-service teachers. Clicking on "Customize" takes students to a scripting version of DV4L (see Figure 4) where the graph can be modified through the pull-down menus or through editing the script directly. The menus and the script are multiple, linked representations (Vosniadou et al., 2012)—changes to one representation will be reflected in the other. The goal is to scaffold users (teachers or students) in understanding the role of a program in defining a visualization and understanding what the script is doing in terms of the already familiar pull-down menus.

[Insert Figures 3 and 4 about here]

The features described here are the core of DV4L, but additional features and user interface elements have been added to address social studies teachers' needs. For example, the current version of DV4L explicitly prompts for a driving question. In social studies classrooms, teachers structure inquiry learning around driving questions (Krajcik & Blumenfeld, 2006; Marx et al., 2004).While the task of data visualization does not require a driving question, building data visualizations in the context of social studies does. DV4L may be the only visualization and programming tool ever to build in explicit support for driving questions.

DV4L is a purpose-built visualization tool. It includes programming, but in a domain and even task-specific form. Our goal was to have high usability and usefulness to meet the acceptance demands of TAM, but also to fit within the contexts and knowledge of social studies teachers.

Participants

The first set of stakeholders for the present study were pre-service social studies teachers[1] enrolled in Shreiner's class. They were mostly juniors and seniors who were far along in their preparation program but had not yet begun student teaching. Although this was the third group of pre-service teachers with whom we worked, they were the first to use DV4L, along with Vega-lite and CODAP as two additional design probes (Wallace et al., 2013a). None of our participants knew DV4L was our prototype until the end of the session.

[1] A small number of the second set of stakeholders had been practicing teachers who had returned to school for additional certification.

Our second group of stakeholders were 11 practicing social studies teachers who participated in two separate professional learning opportunities (PLO) in which we gave them access to the OER and asked them to go through each module to learn about data literacy and explore resources. One of the resources they could explore was DV4L. There were six middle school and five high school teachers. Ten teachers taught U.S. and/or world history, and one teacher taught civics and economics. Two teachers were first-year teachers, two had taught between two and five years, and seven had over five years of experience. We will be focusing more of the description below on this second of stakeholders because we have more comprehensive data for this set.

Data Collection and Analysis

Pre-Service Teacher Data

After introductions in the in-class session, we divided the pre-service teachers into three groups, and each group explored one of the three tools for ten minutes. We scaffolded social studies data manipulation and visualization with activity sheets (Wilkerson, 2017). Then they came together as a whole group and discussed their experiences for ten minutes. At that point, based on their initial experience and the class discussion, the pre-service teachers chose what tool they wanted to explore for the following ten minutes. This approach gave the pre-service teachers the agency to choose and made them more inclined to provide their thoughts and opinions while being more engaged in the tool they chose to explore. After ten minutes, everyone came together to discuss their experiences for the remaining thirty minutes of class. This was a longer more fruitful discussion since most had tried a second tool and were able to compare and discuss what they liked or did not like about the tools. The following week, each participant anonymously reflected on their experience and current tool preference in writing. Our data sources include pre- and post-session questionnaires, observations of pre-service teachers' tacit use of the tools, and notes on the whole group discussions where the goal was to elicit their design ideas and needs.

We used thematic analysis to review these data (Boyatzis, 1998). Our goals were to understand these teachers' needs and to inform our developing designs. The results of these analyses have been published previously (Naimipour et al., 2019, 2020; Naimipour et al., 2021).

Practicing Teacher Data

The 11 practicing teachers were participants in the most comprehensive version of the support system and thus provided feedback on all aspects. They participated in a PLO that consisted of three synchronous one-hour sessions, and asynchronous work on the OER and with the resources and tools embedded in the OER. During asynchronous work, we asked teachers to look specifically at DV4L, along with other tools of their choosing. All teachers completed pre- and post-questionnaires, which consisted of Likert-scale questions to measure their current experiences with teaching data literacy, their confidence with teaching and working with data visualizations and technology, and their views on the importance of data literacy. The questionnaires also included open-ended questions about their use of technology tools. We used a semi-structured focus group protocol for all sessions, which were recorded and transcribed. The first session was focused on meeting the teachers and learning about their teaching context and experience. We used the two additional meetings to ask for feedback on the OER and DV4L.

We generated descriptive statistics to compare teachers' responses from pre-questionnaire to post-questionnaire, looking for changes in responses. We analyzed transcripts from the focus group sessions using a combination of *a priori* and emergent codes (Miles et al., 2020). Our *a priori* codes were focused on statements about the structure of the professional learning opportunity, knowledge gained through the experience, and comments about the usefulness and usability of the lessons and tools in the OER, including DV4L (see Table 2).

[Insert Table 2 about here]

Findings

Effectiveness of the Pedagogical Support System

Our first research question asked: How do we give social studies teachers effective, accessible professional learning opportunities that will help them feel prepared and supported in teaching data literacy in social studies? We wanted to build a support system that would build teachers' knowledge about data literacy in social studies and increase teachers' confidence in their competencies related to teaching data literacy.

At the outset of our work with practicing teachers, they all indicated that they believe data literacy is important. For example, all 11 practicing teachers indicated on their pre-questionnaire that they agreed that it is important for students to learn how to analyze timelines, maps, and timelines. Almost all of them indicated that it is also important for students to create timelines, maps, and graphs, the one exception being a high school teacher who said they disagreed that it is important for students to create maps. All eleven teachers also indicated that timelines, maps, and graphs help students learn social studies. Yet only three teachers reported having had any classes or professional development related to teaching data literacy. Two teachers said they had a single professional development session that touched on data literacy, and one teacher said data literacy was a part of a general literacy education class in college.

Despite lack of training, teachers were already relatively confident in their abilities to help students analyze and create data visualizations. At the beginning of the PLO, all teachers felt confident in their abilities to help students both analyze and create timelines. Only one teacher disagreed that they were confident in their ability to help students analyze maps and graphs, and only one teacher disagreed that they were confident in their ability to help students create graphs. However, three teachers reported lacking confidence in their ability to help students create maps (see Figure 5).

Interestingly, teachers were less confident in their own abilities to analyze and create data visualizations. For example, although ten teachers reported being confident in their ability to analyze timelines and graphs, this did not extend to confidence in their abilities to recognize flaws and inaccuracies in timelines and graphs. For these items, nine teachers said they could recognize inaccuracies in timelines and only seven said they could recognize inaccuracies in graphs. Eight teachers reported being confident in their ability to analyze maps, and the number fell to six for confidence in abilities to recognize flaws and inaccuracies (see Figure 6). As for creating data visualizations, almost all teachers reported feeling confident in creating data visualizations with paper and pencil but were far less confident in their abilities to create them with computers (see Figure 7).

The post-questionnaires indicated promising growth in teachers' confidence in several areas. Even though most teachers were already confident in their abilities to help students analyze data visualizations, all teachers were confident in their abilities by the end of the session. There was similar growth with respect to helping students create data visualizations, except for the creation of maps; here, one teacher grew in confidence but there were still two teachers who did not feel confident in their ability to help students create maps (see Figure 5).

[Insert Figure 5 about here]

We saw more dramatic growth in teachers' confidence in their own abilities, particularly in their abilities to recognize flaws and inaccuracies in data visualizations. For example, at the beginning of the PLO, only six and seven teachers felt confident in their abilities to find inaccuracies in maps and graphs, respectively (see Figure 6). By the end, however, these numbers had grown to ten and eleven. Teachers' growth in confidence with respect to using computers to create data visualizations was less promising. We saw no growth in teachers' confidence in using computers to build timelines and maps, and only two teachers reported feeling more confident using computers to create graphs (see Figure 7).

During the focus groups, teachers also reported knowledge growth in several key areas. The most frequent comments were about knowledge of the different ways data visualizations can be manipulated to mislead, and the importance of critical data literacy. Nine out of 11 teachers spent time talking about this during the focus group. This likely explains the growth in teachers' confidence to find flaws and inaccuracies in data visualizations. There were also several comments about the primary source data visualizations and tools featured on the website, and not previously realizing that many primary sources used in history are examples of data visualizations, or how many tools were "out there." In addition, a few teachers commented on gaining knowledge about how prevalent references to data visualizations are in state standards, and the importance of background knowledge for students trying to interpret data visualizations.

[Insert Figures 6 and 7 about here]

Feedback on the Usefulness and Usability of Resources in the OER

Our other two goals for the support system were to alleviate perceived challenges in implementing data literacy and to provide teachers with data literacy-related tools they believe are useful and usable enough for adoption in social studies classes. We tried to meet this goal by providing social studies-specific resources for teachers throughout the OER, including existing online tools and DV4L, which were accompanied by minimal manuals for creating social studies projects.

Three themes surfaced through teachers' focus group comments about usefulness of the OER and its resources: connections to their existing curriculum, inspiration for new project ideas, and student learning. Ten of the eleven teachers mentioned that certain resources or tools "spoke" to them when they could see its connections to topics they already taught. They commented about a unit of instruction or activity they would teach every year, and how a primary source, or online resource, activity, or tool could supplement what they already do. A couple of teachers also noted their appreciation when resources had explicit references to state standards, and by extension, standardized tests. Comments about standards typically surfaced when discussing primary source data visualizations or the lessons and activities that were connected to websites with data visualizations.

Where teachers seemed most enthusiastic in their comments, however, were instances when they were inspired by an online tool and the ideas provided for students completing a project with the tool. Eight teachers spent time during the focus groups discussing tools and accompanying minimal manuals they liked and how they would use them for projects. The most frequent mentions were of Google Earth, Timeline JS, and StoryMapsJS, but there were also mentions of Google Sheets/Charts and ArcGIS StoryMaps. Teachers were particularly drawn to high-quality appearance in the final products, and the tools' abilities to help them teach temporal and spatial thinking. For example, one teacher, Henry (all names are pseudonyms), who explored Google Earth using our minimal manual said:

> I totally geek out last night on the Google [Earth] project…I was actually looking this past spring for something like that and I could not find any. I didn't even think to look at

> Google Earth as possible place to have that. But yeah, that's…That is such a cool feature I will be using this year and years to come in my class, both to present information and then have the kids create projects to present information.

Of Timeline JS, Samantha said:

> I looked at this and thought, 'Okay, so I could totally use this in history,' but then I started going crazy because the English brain in me was, "oh my god my kids would love this" when I teach the Odyssey because half the book is in flashback, so I always have them make timelines for that novel, and I was, "I could use that timeline for plot structure," I could use this in almost every class I teach, no matter if it's English 12 or English 9, or World History, or US History, I could use this resource across the curriculum here.

Not surprisingly, students were clearly at top of mind for many of the teachers as they reviewed the tools and resources. For example, Apollo looked at the project accompanying Google Earth and stated:

> There's so many times we're talking about a place and, believe it or not, at the grade level they're at, they don't realize like, sometimes the oceans between them and, or like, where in our country things are even located… Some kids have never left the state and they just have no idea where that stuff is or how far away it is and so on. So, I thought those were really, really good activities.

And when we asked teachers to give us ideas about the kinds of resources and tools they would find useful and that were not featured on the OER, they focused on two areas: First, simple tools for creating timelines and maps, especially those that would help students visualize time and space simultaneously. Second, visuals that would help explain complex processes and concepts that are difficult for students, such as latitude and longitude, and map projections.

As for comments related to usability, teachers were discouraged from using tools—even ones they found intriguing like Timeline JS—if they felt they were too complicated or difficult to use for themselves and their students. Eight of eleven teachers mentioned this as a deterrent. Teachers expressed a desire for tools that had a simple user interface and left little room for error, primarily so students would not be distracted or frustrated, and so they could concentrate on helping students gain content knowledge, rather than skills in using the computing tool. Teachers also mentioned different abilities of students within a grade and across grades. In both tools and activities, teachers wanted ideas for differentiating instruction and meeting the needs of diverse learners.

Feedback on the Usefulness and Usability of DV4L

Similar themes about usefulness and usability ran through our first two sessions with pre-service teachers, where they were introduced to DV4L and other computing tools. Most pre-service teachers in our first session wanted a tool they perceived as useful for their students' learning, while those in our second session preferred tools they "perceived as easy to use" for themselves (Naimipour et al., 2020). In our third session, we were confident the teachers would think were usable, pedagogical usefulness was the primary theme. Yet, interestingly, the pre-service teachers seemed less focused on meeting standards than the practicing teachers were. Instead, they focused mainly on how creating data visualizations might help students learn or help them focus students' attention on ideas they were trying to teach. For example, more than half of the pre-service teachers stated that they want data visualizations tools to create exemplars or models for students or that might be used by students in their own inquiry. One pre-service teacher said "(with discipline-specific K-12 technology) I like that if you are able to create your own visualization you can format how your students think about the visual." More than a third of the pre-service teachers discussed how making their own visualizations changed the ways they and their students might learn about data literacy. We heard one pre-service teacher say: "I think making your own data visualization allows for a deeper connection and understanding of the data" and another said "It (technology) helps one better understand how data works and what it is telling someone."

Around three fourths of the pre-service teachers preferred DV4L over the two other data visualization tools CODAP and Vega-lite, and comments revealed the importance of both its usability and its usefulness. One pre-service teacher explained that they preferred our prototype over other tools because "(with the prototype DV4L) I found myself asking questions connected to the data itself, rather than asking questions in order to figure out how to work the visual." Another pre-service teacher felt that DV4L "focus(ed) on the information being relayed rather than the coding that goes into creating it." These pre-service teachers wanted to adopt a tool for themselves that "focus(es) more on the data than on trying to figure out how to use the tool." Tools like DV4L offer them all these possibilities, while also respecting a teachers' time limitations, making it worth the effort for them to adopt DV4L into their data literacy curricula.

Yet, when we asked practicing teachers to share which tools in the OER they would use with students, only three shared that they planned to use DV4L in their teaching. The practicing teachers who talked about experimenting with DV4L during the PLO said they liked it for some of the same reasons they liked other relatively useful and usable tools: they could see how the data sources connected to topics they already taught, and it had a simple design that would not be overwhelming for students. However, teachers also commented about the need for more datasets connected to topics they teach, and for the tool to be more supportive of critical data literacy by providing source information and links to raw data. The most salient comments for us though were ones that related to teachers' desire to be inspired by new projects – we had not provided enough information or directions about how they could use this with students or how to build interesting projects and activities around it. In what follows, we will discuss these findings and the implications for future work.

Discussion

Data literacy is important for students to learn, and helping students become data literate through social studies can provide them with tools they need to view data through a critical lens (Irgens et al., 2020; Philip et al., 2016; Shreiner, 2020). Unfortunately, research indicates that teachers do not often teach data literacy in social studies, and standards do a poor job of giving teachers guidance they need to teach it well (Shreiner, 2020; Shreiner & Dykes, 2021). But if we want teachers to teach data literacy, they must have access to tools and resources that will give them a sense of efficacy, and that they judge as useful and usable. The support system consisting of an OER and social studies-specific computing tools has been constructed with this mind. We set out to (1) build teachers' knowledge about data literacy in social studies; (2) increase teachers' confidence in their competencies related to teaching data literacy; (3) alleviate perceived challenges in implementing data literacy; and (4) provide teachers with data literacy-related tools they believe are useful and usable enough for adoption. Our research indicates both successes and areas for improvement.

Teachers gained new knowledge through the OER, especially about different ways data can mislead. This seemed to give teachers more confidence that they could recognize flaws and manipulations in data visualizations. In addition, several teachers learned about the prevalence of references to data visualization in state standards, the vast number of primary sources that are also data visualizations, and the number of tools that exist to help them create data visualizations. By providing resources that would help them connect data literacy instruction to their state social studies standards, as well as providing several resources that they could see connected to the standards-based instruction they already provide to their students, we seemed successful in helping to alleviate some of the perceived challenges to implementing data literacy. We also provided scaffolding in the form of manuals and social studies activity ideas around several online tools, such as Google Earth and Timeline JS, that made the tools seem more usable and useful for teachers.

However, we were not as successful as we had hoped in convincing teachers to adopt our task-specific programming tool, DV4L. Nor were we as successful as we hoped in helping teachers feel comfortable using computers to create data visualization and data-based projects. These results point to the weakness of relying solely on TAM. While we achieved high usability and usefulness, we did not achieve the kind of adoption we were hoping for.

Based on our broader theoretical framework related to teacher knowledge, beliefs, and context, we have three hypotheses to explain these shortcomings. First, teachers indicated in their post-questionnaires that they did not have enough time to explore the OER and its tools with our support, nor to discuss possible uses for the tools with their peers. Several teachers suggested that we structure the PLO as a full day or multi-day workshops to provide such support. This relates to the teacher's need for knowledge, including PCK and technological pedagogical content knowledge (TPACK).

Second, we need to provide teachers with more ideas for using DV4L with students, especially activities that are clearly tied to the state standards and therefore connect to themes and topics teachers are already likely teaching. We need to create more simple, usable computer-based tools and accompanying curricular resources to meet social studies teachers' specific needs—preferably those that address common student challenges. This is about increasing the fit to the teachers' contexts.

Finally, we likely must provide evidence that DV4L has been vetted in classrooms and helps students learn. After all, teachers must believe that the technology will fit in their existing structures and can help to achieve their learning goals (Holden & Rada, 2011). Such evidence could help to develop teacher confidence that the tools can help them achieve their goals.

The work to develop more tools that fit teacher contexts is already underway. For example, we have a working prototype timeline visualization tool (TimelineBuilder) which we have designed to address the usability challenges teachers reported with TimelineJS. We are also working on a set of tools that will help teachers differentiate instruction for students with differing levels of experience and skills in analyzing data visualizations. This includes a tool that will help students slowly construct data visualizations by drawing their attention to specific visual elements, as well as a tool that helps students slowly analyze data visualizations by masking all but one visual element at a time and allowing them to make connections among all the elements to extract information. These tools may help students understand how the different visual elements collectively convey meaning. And with these tools, students can work at their own pace, and independently, allowing the teacher to attend to the needs of students who are struggling.

Given the limitations of TAM in predicting teacher adoption of our tools, we are also exploring the decomposed theory of planned behavior (DTPB) model to apply to our work (Smarkola, 2011; Taylor & Todd, 1995). This model emphasizes usefulness and usability like

TAM but also incorporates the key facet of perceived behavioral control, which includes self-efficacy with technology (whereas our study focused more on self-efficacy with data literacy) and resource facilitating conditions (such as the curricular resources we are designing). In addition, the DTPB model incorporates subjective norms like peer and superior influence. Our future work will explore the effects of school-wide technology-assisted data literacy professional learning opportunities on teacher adoption of our tools. In other words, we will explore the degree to which peer influence affects teacher adoption.

Our work is explicitly driven by the needs of the teachers who are contributing to our research through their participation in design sessions. We hope that by continuing to build usable and useful tools and providing teachers with the supports they need to feel knowledgeable and confident about teaching data literacy, we will in turn help students gain the data literacy skills they need for informed, competent citizenship.

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Statements of Open Data, Ethics, and Conflicts of Interest

The data used in this study are from our pre-service and practicing teacher sessions. The data on pre-service students are pre- and post-surveys and observer notes. The surveys contain no identifying information. The observer notes are not available. The practicing teacher data are survey results and de-identified transcripts of on-line professional learning sessions. All of the survey and transcript data are available upon email request to the authors.

The findings presented in his paper were the reviewed in several protocols by the human subjects review boards of the University of Michigan and Grand Valley State University. All participants completed a consent form before the studies, and were reminded at several points in each session that they could withdraw their consent at any time.

- The pre-service teacher studies were reviewed and monitored by the GVSU human subjects review board. In those studies, students completed an on-line consent form, a pre-survey, and a post-survey. Their names were only recorded on the consent form. The pre-and post-surveys were not linked. Only observational notes by the research team were collecting during the participatory design sessions, since FERPA concerns prevented us from making recordings of those sessions.
- The practicing teacher studies were reviewed and judged to be `exempt' by the U-M human subjects review board. In those studies, there are pre- and post-surveys which are linked by a code created by the participants. The sessions were digitally audio recorded. The recordings were transcribed by a professional service approved for human subjects data and they deleted the data after transcription. The research team compared the transcripts to the recordings for accuracy, then deleted the recordings. All names in the transcripts were changed to pseudonyms, and then the mappings were deleted. There are no connections between the participants' codes and the transcripts.

No conflict of interest has been declared by the authors.

References

Abel, T. D., & Evans, M. (2013). Cross-disciplinary Participatory & Contextual Design Research: Creating a Teacher Dashboard Application. *IxD&A*, *19*, 63-76.

Albuquerque, D., Cafeo, B., Garcia, A., Barbosa, S., Abrahão, S., & Ribeiro, A. (2015). Quantifying usability of domain-specific languages: An empirical study on software maintenance. *Journal of Systems and Software*, *101*, 245-259. https://doi.org/https://doi.org/10.1016/j.jss.2014.11.051

Aldunate, R., & Nussbaum, M. (2013). Teacher adoption of technology. *Computers in Human Behavior*, *29*(3), 519-524.

Bain, R. B. (2000). Into the breach: Using research and theory to shape history instruction. In P. N. Stearns, P. C. Seixas, & S. S. Wineburg (Eds.), *Knowing, teaching, and learning history : national and international perspectives* (pp. 331-352). New York University Press.

Baker, A. D. (2019). Open educational resources in teacher preparation programs: Teacher candidates' perceptions of open textbooks. *International Journal of Teacher Education and Professional Development (IJTEPD)*, *2*(1), 52-65.

Ball, D. L., & Forzani, F. M. (2009). The work of teaching and the challenge for teacher education. *Journal of teacher education*, *60*(5), 497-511.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389-407.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. W.H. Freeman and Company.

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. In: Taylor & Francis.

Bausmith, J. M., & Leinhardt, G. (1998). Middle-school students' map construction: Understanding complex spatial displays. *Journal of Geography*, *97*, 93-107. https://doi.org/10.1080/00221349808978834

Blow, F., Lee, P., & Shemilt, D. (2012). Time and chronology: Conjoined twins or distant cousins? *Teaching History*, *147*, 26-34.

Börner, K., Maltese, A. V., Balliet, R. N., & Heimlich, J. (2016). Investigating aspects of data visualization literacy using 20 information visualizations and 273 science museum visitors. *Information Visualization*, *15*, 198-213. https://doi.org/10.1177/1473871615594652

Boyatzis, R. (1998). *Transforming Qualitative Information: Thematic Analysis and Code Development*. Sage Publications, Inc.

Brugar, K. A., & Roberts, K. L. (2017a). Elementary students' challenges with informational texts: Reading the words and the world. *The Journal of Social Studies Research*. http://dx.doi.org/10.1016/j.jssr.2017.02.001

Brugar, K. A., & Roberts, K. L. (2017b). Seeing is believing: Promoting visual literacy in elementary social studies. *Journal of teacher education*, *68*, 262-279. https://doi.org/d0o.i.1o1rg7/71/00.10127274/080721214877619167268960280

Carlson, J. R., Fosmire, M., Miller, C., & Nelson, M. R. S. (2011). Determining data information literacy needs: A study of students and research faculty. *Libraries Faculty and Staff Scholarship and Research*. http://docs.lib.purdue.edu/lib_fsdocs/23

Carroll, J. M., Smith-Kerker, P. L., Ford, J. R., & Mazur-Rimetz, S. A. (1987). The minimal manual. *Human-computer interaction*, *3*(2), 123-153.

Charalambous, C. Y., Philippou, G. N., & Kyriakides, L. (2008). Tracing the development of preservice teachers' efficicacy beliefs in teaching mathematics during fieldwork. *Educational Studies in Mathematics*, *67*, 125-142.

Council for Economic Education. (2010). *Voluntary national content standards in economics* (2nd ed.). Council for Economic Education.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3-14.

Davis, E. A., Palincsar, A. S., Smith, P. S., Arias, A. M., & Kademian, S. M. (2017). Educative curriculum materials: Uptake, impact, and implications for research and design. *Educational Researcher*, *46*(6), 293-304.

Davis, F. D. (1993). User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. *International Journal of Man-Machine Studies*, *38*(3), 475-487 %@ 0020-7373.

DiSalvo, B., Yip, J., Bonsignore, E., & DiSalvo, C. (2017). *Participatory design for learning*. Taylor & Francis.

Druin, A. (2002). The role of children in the design of new technology. *Behaviour and information technology*, *21*(1), 1-25.

Duke, N. K., Martin, N. M., Norman, R. R., Knight, J. A., & Roberts, K. L. (2013). Beyond concepts of print: Development of concepts of graphics in text, preK to grade 3. *Research in the Teaching of English*, *48*, 175-203.

Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education*, *42*(3), 255-284.

Fingeret, L. (2012). *Graphics in children's informational texts: A content analysis* (Publication Number 3524408) [Doctoral dissertation, Michigan State University]. Proquest Dissertations Publishing. East Lansing, MI.

Finholm, C. E., & Shreiner, T. L. (2022). A lesson in missed opportunities: examining the use of data visualizations in online history lessons. *Social Studies Research and Practice*.

Finzer, W., & Damelin, D. (2016). Design perspective on the Common Online Data Analysis Platform (CODAP). Paper presented at American Educational Research Association (AERA) conference, Washington DC.

Forte, A., & Guzdial, M. (2005). Motivation and nonmajors in computer science: identifying discrete audiences for introductory courses. *IEEE Transactions on Education*, *48*(2), 248-253.

Friel, S. N., Curcio, F. R., & Bright, G. W. (2001). Making sense of graphs: Critical factors influencing comprehension and instructional implications. *Journal for Research in Mathematics Education*, *32*(2), 124-158.

Goodwin, N., Nelson, J. A., & Harris, J. M. (2017). Useful economic tools and concepts. http://www.ase.tufts.edu/gdae/education_materials/modules/Useful_Macroeconomic_Tools_and_Concepts.pdf

Harsh, J. A., Campillo, M., Murray, C., Myers, C., Nguyen, J., & Maltese, A. V. (2019). 'Seeing' data like an expert: An eye-tracking study using graphical data representations. *CBE Life Sciences Education*, *18*(3), 1-12. https://doi.org/https://doi.org/10.1187/cbe.18-06-0102

Holden, H., & Rada, R. (2011). Understanding the influence of perceived usability and technology self-efficacy on teachers' technology acceptance. *Journal of Research on Technology in Education*, *43*(4), 343-367.

Irgens, G. A., Knight, S., Wise, A. F., Philip, T. M., Olivares, M. C., van Wart, S., Vakil, S., Marshall, J., Parikh, T., Lopez, M. L., Wilkerson, M. H., Gutiérrez, K., Jiang, S., & Kahn, J. B. (2020). *Data literacies and social justice: Exploring critical data literacies through sociocultural perspectives* 14th International Conference of the Learning Sciences: The Interdisciplinarity of the Learning Sciences, ICLS 2020, Nashville, TN.

Kalathas, P., Parham-Mocello, J., Elliot, R., & Lockwood, E. (2022). Exploring Math+ CS in a Secondary Education Methods Course.

Kosar, T., Mernik, M., & Carver, J. C. (2012). Program comprehension of domain-specific and general-purpose languages: comparison using a family of experiments. *Empirical software engineering*, *17*(3), 276--304.

Kosar, T., Oliveira, N., Mernik, M., Pereira, M. J., Crepinsek, M., Cruz, D., & Henriques, P. (2010). Comparing general-purpose and domain-specific languages: An empirical study. *Computer Science and Information Systems*, *7*(2), 247-264.

Krajcik, J. S., & Blumenfeld, P. C. (2006). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences*. Cambridge University Press.

Lee, Y., Kozar, K. A., & Larsen, K. R. T. (2003). The technology acceptance model: Past, present, and future. *Communications of the Association for information systems*, *12*(1), 50.

Maltese, A. V., Harsh, J. A., & Svetina, D. (2015). Data visualization literacy: Investigating data interpretation along the novice-expert continuum. *Journal of College Science Teaching*, *45*, 84-90.

Marshall, T. (2016). *Prisoners of geography: ten maps that explain everything about the world* (Vol. 1). Simon and Schuster.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., Fishman, B., Soloway, E., Geier, R., & Tal, R. T. (2004). Inquiry-based science in the middle grades: Assessment of learning in urban systemic reform. *Journal of Research in Science Teaching*, *41*(10), 1063--1080.

Maslin, M. (2019). The beautifully macabre cartoons of Gahan Wilson. *The New Yorker*. Retrieved November 15, 2021, from https://www.newyorker.com/culture/postscript/the-beautifully-macabre-cartoons-of-gahan-wilson

Miles, M. B., Huberman, A. M., & Saldaña, J. (2020). *Qualitative Data Analysis: A Methods Sourcebook* (4th ed.). SAGE.

Naimipour, B., Guzdial, M., & Shreiner, T. (2019). Helping Social Studies Teachers to Design Learning Experiences Around Data: Participatory Design for New Teacher-Centric Programming Languages.*ICER '19* Proceedings of the 2019 ACM Conference on International Computing Education Research, New York, NY, USA.

Naimipour, B., Guzdial, M., & Shreiner, T. (2020). *Engaging Pre-Service Teachers in Front-End Design: Developing Technology for a Social Studies Classroom* 2020 IEEE Frontiers in Education Conference (FIE),

Naimipour, B., Rauch, I., Shreiner, T., & Guzdial, M. (2021). From Guided Exploration to Possible Adoption: Patterns of Pre-Service Social Studies Teacher Engagement with Programming and Non-Programming Based Learning Technology Tools. In *Proceedings of the 2021 Society for Information Technology and Teacher Education (SITE) Conference* (pp. To appear). AACE.

National Assessment Governing Board. (2018a). *Civics Framework for the 2018 National Assessment of Educational Progress*. U.S. Department of Education.

https://www.nagb.gov/content/dam/nagb/en/documents/publications/frameworks/civics/2018-civics-framework.pdf

National Assessment Governing Board. (2018b). *Geography Framework for the 2018 National Assessment of Educational Progress*. U.S. Department of Education. https://www.nagb.gov/content/dam/nagb/en/documents/publications/frameworks/geography/2018-geography-framework.pdf

National Assessment Governing Board. (2018c). *U.S. History Framework for the 2018 National Assessment of Educational Progress*. U.S. Department of Education. https://www.nagb.gov/content/dam/nagb/en/documents/publications/frameworks/history/2018-history-framework.pdf

National Council for the Social Studies. (2013). The college, career, and civic life (C3) framework for social studies state standards: Guidance for enhancing the rigor of K-12 civics, economics, geography, and history. In. Silver Spring, MD: NCSS.

Newton, K. J., Leonard, J., Evans, B. R., & Eastburn, J. A. (2012). Preservice elementary teachers' mathematics content knowledge and teacher efficacy. *School Science and Mathematics*, *112*(5), 289-299.

Norman, R. R. (2012). Reading the graphics: What is the relationship between graphical reading processes and student comprehension? *Reading and Writing*, *25*(3), 739-774. https://doi.org/10.1007/s11145-011-9298-7

Ottenbreit-Leftwich, A. T., Brush, T. A., Strycker, J., Gronseth, S., Roman, T., Abaci, S., Shin, S., Easterling, W., & Plucker, J. (2012). Preparation versus practice: How do teacher education programs and practicing teachers align in their use of technology to support teaching and learning? *Computers & Education*, *59*(2), 399--411.

Ottenbreit-Leftwich, A. T., Glazewski, K. D., Newby, T. J., & Ertmer, P. A. (2010). Teacher value beliefs associated with using technology: Addressing professional and student needs. *Computers \& Education*, *55*(3), 1321-1335.

Özgün-Koca, S. A., Meagher, M., & Edwards, M. T. (2010). Preservice teachers' emerging TPACK in a technology-rich methods class. *The Mathematics Educator*, *19*(2).

Philip, T. M., Olivares-Pasillas, M. C., & Rocha, J. (2016). Becoming racially literate about data and data-literate about race: Data visualizations in the classroom as site of racial-ideological micro-contestations. *Cognition and Instruction*, *34*(4), 361-388. https://doi.org/10.1080/07370008.2016.1210418

Philip, T. M., Schuler-Brown, S., & Way, W. (2013). A framework for learning about Big Data with mobile technologies for democratic participation: Possibilities, limitations, and unanticipated obstacles. *Technology, Knowledge and Learning*, *18*, 103-120.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, *29*(1), 4-15.

Roberts, K. L., Norman, R. R., & Cocco, J. (2015). Relationship between graphical device comprehension and overall text comprehension for third-grade children. *Reading Psychology*, *36*, 389-420. https://doi.org/10.1080/02702711.2013.865693

Roberts, K. L., Norman, R. R., Duke, N. K., Morsink, P., Martin, N. M., & Knight, J. A. (2013). Diagrams, timelines, and tables – oh, my!: Fostering graphical literacy. *The Reading Teacher*, *67*, 12-23. https://doi.org/10.1002/trtr.1174

Satyanarayan, A., Moritz, D., & Wongsuphasawat, K. (2017). Vega-lite: A grammar of interactive graphics. *IEEE Transactions on Visualization and Computer Graphics*, *23*(1), 341-350.

Schnotz, W., & Kurschner, C. (2008). External and internal representations in the acquisition and use of knowledge: Visualization effects on mental model construction. *Instructional Science*, *36*, 175-190. https://doi.org/DOI 10.1007/s11251-007-9029-2

Shah, P., & Hoeffner, J. (2002). Review of graphic comprehension research: Implications for instruction. *Educational Psychology Review*, *14*, 47-69. https://doi.org/10.1023/A:1013180410169

Shah, P., Mayer, R. E., & Hegarty, M. (1999). Graphs as aids to knowledge comprehension: Signaling techniques for guiding the process of graph comprehension. *Journal of Educational Psychology*, *91*, 690-702. https://doi.org/10.1037/0022-0663.91.4.690

Shreiner, T. L. (2018a). Data literacy for social studies: Examining the role of data visualizations in K-12 textbooks. *Theory & Research in Social Education*, *46*, 194-231. https://doi.org/https://doi.org/10.1080/00933104.2017.1400483

Shreiner, T. L. (2018b). Preparing social studies teachers for the challenges and opportunities of disciplinary literacy instruction in a changing world. In C. Martell (Ed.), *Research in social studies teacher education: Critical issues and current perspectives* (pp. 47-68). Information Age Publishing.

Shreiner, T. L. (2019). Students' use of data visualizations in historical reasoning: A think-aloud investigation with elementary, middle, and high school students. *The Journal of Social Studies Research*, *43*(4), 389-404. https://doi.org/https://doi.org/10.1016/j.jssr.2018.11.001

Shreiner, T. L. (2020). Building a data-literate citizenry: How U.S. state standards address data and data visualizations in social studies. *Information and Learning Sciences*, *121*(11/12), 909-931. https://doi.org/https://doi.org/10.1108/ILS-03-2020-0054

Shreiner, T. L., & Dykes, B. M. (2021). Visualizing the teaching of data visualizations in social studies: A study of teachers' data literacy practices, beliefs, and knowledge. *Theory & Research in Social Education*, *49*(2), 262-306. https://doi.org/10.1080/00933104.2020.1850382

Shreiner, T. L., & Zwart, D. E. (2020). It's just different: Identifying features of disciplinary literacy unique to world history. *The History Teacher*, *53*(3), 441-469.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14.

Smarkola, C. (2011). *A Mixed-Methodological Technology Adoption Study : Cognitive Belief-Behavioral Model Assessments in Predicting Computer Usage Factors in the Classroom*. SensePublishers. https://doi.org/10.1007/978-94-6091-487-4_2

10.1007/978-94-6091-487-4

Spinuzzi, C. (2005). The methodology of participatory design. *Technical communication*, *52*(2), 163-174.

Strobel, B., Lindner, M. A., Saß, S., & Köller, O. (2018). Task-irrelevant data impair processing of graph reading tasks: An eye tracking study. *Learning and Instruction*, *55*, 139-147. https://doi.org/https://doi.org/10.1016/j.learninstruc.2017.10.003

Taylor, S., & Todd, P. A. (1995). Understanding Information Technology Usage: A Test of Competing Models. *Information Systems Research*, *6*(2), 144-176.

Tondeur, J., Van Braak, J., Ertmer, P. A., & Ottenbreit-Leftwich, A. (2017). Understanding the relationship between teachers' pedagogical beliefs and technology use in education: a systematic review of qualitative evidence. *Educational Technology Research and Development*, *65*(3), 555--575.

Tondeur, J., Van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, *59*(1), 134--144.

Tschannen-Moran, M., & Hoy, A. W. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education*, *17*, 783-805.

Tschannen-Moran, M., Hoy, A. W., & Hoy, W. K. (1998). Teacher efficacy: Its meaning and measure. *Review of Educational Research*, *68*(2), 202-248.

Uttal, D. H., & Sheehan, K. J. (2014). The development of children's understanding of maps and models: A prospective cognition perspective. *Journal of Cognitive Education and Psychology*, *13*(2), 188-200.

Vosniadou, S., De Corte, E., Glaser, R., & Mandl, H. (2012). The use of multiple, linked representations to facilitate science understanding. In *International perspectives on the design of technology-supported learning environments* (pp. 51--70): Routledge.

Wallace, J., McCarthy, J., Wright, P. C., & Olivier, P. (2013a). Making design probes work. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,

Wallace, J., McCarthy, J., Wright, P. C., & Olivier, P. (2013b). Making Design Probes Work. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,

Wilkerson, M. H. (2017). Teachers, students, and after-school professionals as designers of digital tools for learning. *Participatory Design for Learning*, 125-138.

Wolters, C. A., & Daugherty, S. G. (2007). Goal structures and teachers' sense of efficacy: Their relation association to teaching experience and academic level. *Journal of Educational Psychology*, *99*(1), 181-193.

Zhao, Y., & Cziko, G. A. (2001). Teacher adoption of technology: A perceptual control theory perspective. *Journal of Technology and Teacher Education*, *9*(1), 5-30.