Tensions and synergies in arts-integrated data literacy instruction: Reflections on four classroom implementations

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Statements on open data, ethics and conflict of interest

A. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
B. This research was conducted with approval of, and following ethical guidelines outlined by the Institutional Review Boards at New York University, at the New York City Department of Education, and at Boston Public Schools.
C. The authors have no conflicts of interest to disclose.

Abstract

Data-art inquiry is an arts-integrated approach to data literacy learning that reflects the multidisciplinary nature of data literacy not often taught in school contexts. By layering critical reflection over conventional data inquiry processes, and by supporting creative expression about data, data-art inquiry can support students' informal inference-making by revealing the role of context in shaping the meaning of data, and encouraging consideration of the personal and social relevance of data. Data-art inquiry additionally creates alternative entry points into data literacy by building on learners' non-STEM interests. Supported by technology, it can provide accessible tools for students to reflect on and communicate about data in ways that can impact broader audiences. However, data-art inquiry instruction faces many barriers to classroom implementation, particularly given the tendency for schools to structure learning with disciplinary silos, and to unequally prioritize mathematics and the arts.

To explore the potential of data-art inquiry in classroom contexts, we partnered with arts and mathematics teachers to co-design and implement data-art inquiry units. We implemented the units in four school contexts that differed in terms of the student population served, their curriculum priorities, and their technology infrastructure. We reflect on participant interviews, written reflections, and classroom data, to identify synergies and tensions between data literacy, technology, and the arts. Our findings highlight how contexts of implementation shape the possibilities and limitations for data-art inquiry learning. To take full advantage of the potential for data-art inquiry, curriculum design should account for and build on the opportunities and constraints of classroom contexts.

Keywords: Arts-integrated curriculum, data literacy, middle school, classroom implementation

Structured practitioner notes

What is already known about this topic

- Arts-integrated instruction has underexplored potential for promoting students' data literacy, including their appreciation for the role of context and real-world implications of data, and for the personal and social relevance of data.
- Arts-integrated instruction is difficult to implement in school contexts that are constrained by disciplinary silos.

What this paper adds

- Descriptions of four data-art inquiry units, which take an arts-integrated approach to data literacy.
- Examples of the synergies and tensions observed between data literacy, technology, and the arts during classroom implementation in four different schools.
- Reflections on the role of school contexts in shaping disciplinary synergies and tensions.

Implications for practice and/or policy

- Arts-integration offers opportunities for data literacy learning.
- Consideration of the unique resources and constraints of classroom contexts is critical for fulfilling the promises of data-art inquiry learning.
- There is a need to develop school support specific to arts-integrated data literacy instruction.

Introduction

Whereas data science education prepares learners for careers that require specialized skills in generating, manipulating, and analyzing data; *data literacy* education aims to prepare learners in all roles of an increasingly datafied society (Bargagliotti et al., 2020; Pangrazio & Sefton-Green, 2022; Wilkerson & Polman, 2020). Going beyond the procedures-orientation of traditional K-12 statistics education, data literacy education fosters learners' reasoning about the context in which data is produced and used. Such reasoning engages learners in critiquing the social and environmental contexts and perspectives that shape data (Ben-Zvi & Aridor-Berger, 2016; Lee et al., 2021); questioning data in terms of their non-neutrality, accessibility, and transparency; appreciating the uncertainty of data-claims; and using data to infer implications for the real world (R. Bhargava et al., n.d.; Philip et al., 2013; Rubin, 2020, 2021; Tygel & Kirsch, 2016; Wolff et al., 2016).

Studies on out-of-school programs that weave data literacy into other disciplinary contexts, such as social sciences and the arts, have shown promise in promoting data literacy (Rahul Bhargava et al., 2016; Jiang & Kahn, 2020; Thompson & Arastoopour Irgens, 2022). They also reveal the roles that technology plays in promoting the mutual support of both data literacy and arts learning (Ge et al., 2015; Strycker, 2020; Woodard & Lee, 2021). However, interdisciplinary instruction can be difficult to implement in schools, in which accountability pressures shape subject-specific priorities, as evident in differences in instructional time and technology access and support for cross-subject collaboration. Understanding what is possible within school constraints can support the broader adoption of interdisciplinary curriculum.

We describe a discipline-integrated approach to data literacy education called *data-art inquiry*, and explore how the intersections between data literacy, technology and the arts create synergies that support learning, and tensions that hinder it. In reflecting on our experiences implementing four co-designed, data-art inquiry units in four contrasting school contexts, we explore the data literacy learning opportunities offered by data-art inquiry, and how these are subject to the unique resources and constraints of classroom contexts. This study addresses a need for school-based research on cross-domain curriculum, in which disciplines are mutually instrumental and pedagogical (Mejias et al., 2021).

Background and conceptual framework

Data-art inquiry for learning

Data-art inquiry is a process for building data literacy that draws on inquiry approaches from both data science and the arts. Data scientists engage in a process of generating questions, and collecting, transforming, and visualizing data to make inferences about large, messy datasets. Yet, the computing techniques, decisions, and goals that shape the data are often challenging to communicate to audiences. Drawing on arts-based approaches (Blumenfeld-Jones, 2016), data-

art inquiry engages creators and audiences in thinking critically about context, and in revealing personal or social implications that may otherwise be invisible. This process involves analyzing data in terms of its local and global relationships and significance; problematizing that data in terms of their non-neutrality, transparency, and accessibility; contextualizing data-based inferences in terms of their implications for different people; and communicating those implications using artistic strategies to engage audiences emotionally and intellectually with data. Importantly, data-art is more than presenting graphs in visually appealing ways. It often involves physicalizing data in ways that invite the audience's critical attention to issues through data (Brinch, 2020; D'Ignazio & Klein, 2020; Jordan, 2009; Lupi & Posavec, 2016; Miebach et al., 2022; Willett et al., 2017)). As concerns around data become increasingly socio-political issues, data-art inquiry is becoming a growing professional endeavor ((Brinch, 2020; D'Ignazio & Klein, 2020; Jordan, 2009; Lupi & Posavec, 2016; Miebach et al., 2022; Willett et al., 2017).

Disciplinary synergies and tensions

Data-art inquiry presents both *tensions* and *synergies* in school contexts, as it is enacted through domain-specific beliefs, practices, and outcomes (Peppler & Wohlwend, 2018). By synergies, we refer to the manners in which goals, concepts, and practices of each domain blend to create mutually supportive opportunities for data literacy learning (Mejias et al., 2021; Silverstein & Layne, 2014). In this study, synergies are instances in which technology-enhanced instruction leverages the epistemic alignments between data- and arts-based inquiry processes, including processes for exploration, sensemaking, and critical reflection (Bevan et al., 2019; Costantino, 2018). For example, the intersection of data literacy and the arts can support students' informal statistical inferences by emphasizing the context and implications of data (Makar & Rubin, 2018). It offers opportunities for teachers to incorporate cross-domain instructional strategies (e.g., math-talk (Shaughnessy et al., 2021), studio critique (Litts et al., 2019)) that can effectively support students' justification, feedback, revision, and reflection. It offers more ways to demonstrate learning than can be captured by traditional assessments (Halverson, 2021; Moss et al., 2008). It connects to learners' non-STEM interests and socially relevant issues, inviting more learners to build identities as data producers and communicators (R. Bhargava et al., n.d.), and to view art and data as tools for advocacy and impact (Fam et al., 2018; Gibbs, 2017; Henriksen, 2018; Mejias et al., 2021).

Meanwhile, the intersection of technology with data literacy and the arts can support traditional practices in data science (e.g., data moves, Erickson et al., 2019) and the arts (e.g., creative expression), qualitative data production (e.g., as photos); data re-visualization (e.g., sculpture); audience engagement (e.g., through dissemination and evocative aesthetics; (Brinch, 2020; Lupi & Posavec, 2016)); cross-subject learning and instruction (e.g., by making participation more accessible); and assessment (e.g., by making students' ideas visible).

Tensions, on the other hand, include instances in which disciplinary goals and practices conflict, with some either hindering or rendering the other meaningless. In the context of data-art inquiry, such a tension might result in an artwork inspired by, but not grounded in data-based

evidence. Tensions arise from the unique challenges of implementing arts-integrated curriculum in schools, in which infrastructure determines adoption of new instructional strategies (Peurach & Neumerski, 2015). For example, subject-specific differences in formal organizational structures around standards and accountability, curriculum, and technology priorities, and collaborative work can constrain or support cross-subject curriculum innovations. Similarly, informal structures, such as teachers' professional networks, and their classroom norms and routines, may not address the needs for supporting cross-subject instruction.

This study results from a research-practice co-design partnership, which brought teachers together with researchers to design, implement, and study an arts-integrated data literacy curriculum with attention to aligning institutional and infrastructural contexts (Finch et al., 2021). Specifically, we explore the potential of data-art inquiry by examining the synergies and tensions between data literacy, technology, and the arts, as these are shaped by school contexts during implementation.

Methods

Participants and contexts

We worked with 10 teacher partners in four middle schools across three U.S. states to co-design and implement four data-art inquiry curriculum units: *Dance*, *Photoessays*, *Comics*, and *Collages* (Details on see Supplement A for school demographics).

The 10 teachers each had 5-10 or more years of classroom teaching experience, and were oriented toward student-centered learning. A few teachers had previously taught interdisciplinary curriculum, but none had combined data literacy with the arts. The researchers on our team, all authors of this study, consisted of three university faculty members, two research scientists, and two PhD students.

The implementations occurred during COVID-19 pandemic school restrictions. All classes had a varying mix of in-person and remote students joining via video conference. As the schools differed in terms of student backgrounds, resources and administrative support for interdisciplinary projects, and accountability press, they each presented unique infrastructural challenges and opportunities for data-art inquiry. For instance, the *Dance* school centered all curricula on interdisciplinary project-based learning: the teachers had a decade-long working relationship, and one of the researchers was a former teacher colleague. Similarly, the *Photoessays* school provided flexibility for different subject teachers to collaborate, and the teacher partners were also married. However, the other two schools' adherence to siloed disciplines presented logistical challenges. For instance, the *Comics* math teacher only taught a subset of the art teachers' students. Meanwhile, three of the four *Collages* teachers missed the project's onboarding experience, had to lobby for principal approval to participate, and thereafter had to navigate accountability, testing, and curriculum requirements, rigid class schedules, limited technology infrastructure, and planning time restrictions.

Co-design process

In acknowledgment of the documented challenges of co-design, including partners' limited time, expertise, and different stances on learning (Campbell et al., 2021), our co-design approach sought to balance accommodation for teachers' goals, needs, and contexts, with our goals for generating knowledge about new interdisciplinary approaches. Researcher partners attended to these limitations by establishing a shared investment in a project, and scaffolding routines for design to support practitioners' contributions.

Except for the *Collages* teachers, who joined our project later, the teachers previously attended a 1-day co-design workshop in both Years 1 and 2 of our project, which our research team organized to establish common understandings of data literacy, and to elicit ideas for curriculum designs based on teachers' instructional goals. Implementations for the current study began after the Year 2 workshop, when we formed four teams, each consisting of 2-4 researchers (a subset of the authors, some of whom were members of two different co-design teams) and 2-4 teachers from the same school. Approximately one school term before the implementation, co-design teams met regularly via Zoom on a mutually agreed-upon schedule, which varied from once per week to once per month. While teachers' involvement in the design process differed between teams, researchers in all teams were largely responsible for creating lesson materials to serve as discussion starters at co-design meetings, while teachers gave feedback based on knowledge of their students' interests and challenges, and on logistical considerations for implementation.

Unit designs

Each unit was designed according to varying contextual considerations and teacher goals, and so differed in terms of the specific data literacy competencies targeted, the inquiry processes emphasized, the medium and form of artwork produced, the technology integrated, and the distribution of instruction between math and arts classes (~45-60 minutes per session). While the units had subject-specific goals that included learning particular art forms (e.g., modern dance, comics), each had overarching goals that included promoting students' appreciation for real-world applications of math and the arts (e.g., advocacy); and abilities to engage with different aspects of data inquiry. Specific data literacy learning objectives included understanding that: data can be both qualitative and quantitative; biases in operationalization and sampling decisions have implications for the people described by data; and artistic representations of data can be crafted to provoke reflection and reactions from audiences. Additionally, teachers sought to foster specific disciplinary practices and knowledge, such as applying an understanding of central tendency to real-world questions.

Each unit consisted of: (1) a personally- and socially-relevant driving question based on (2) a real-world dataset, (3) a prompt to critically analyze and interpret data by articulating a data-based claim through an artistic medium and/or form, and (4) an artists' statement, in which students would explain the data-based message they aimed to communicate, the impact they sought to evoke in their audiences, and their arts-based strategies for eliciting that impact. While we did not

require students to incorporate statistical findings into their final artwork in the way that an infographic would, for example, data analysis and inference-making were integral to their processes of sensemaking and art creation.

Data and analysis

Our approach draws on the design case (Boling, 2010), which offers a description of an experience or design to disseminate specialized knowledge, including the decisions made that resulted in an existing design, and that can serve as precedent to inform future designs. Rigor in a design case is primarily determined by its usefulness to others, and can be achieved by, among other things, prolonged engagement with a phenomenon, data triangulation, description of salient elements, and peer debriefing (Smith, 2010).

Here, we describe our experiences implementing four units co-designed with teachers over two years. To elicit our insights, we iterated on a shared narrative of our experiences by triangulating between classroom data, participant interviews, and co-design meeting notes.

Classroom data varied based on school-specific IRB permission, and included student artifacts (artworks, written responses to reflective prompts), classroom observations, pre-post surveys, and student interviews. Further detail, and unit-specific findings based on these data are reported elsewhere (Amato, Matuk, et al., 2022; Desportes et al., 2022; Vacca et al., 2022).

Individual 1-2-hour long post-implementation interviews with teachers prompted reflections on the co-design process and implementation, observations of student learning, and ideas for improvement. Researchers took detailed notes during interviews, which were recorded and transcribed with Zoom's automated transcription feature. Meanwhile, researchers' notes during co-design meeting notes documented teachers' emerging questions and issues, and the teams' design decisions.

To synthesize our experiences and findings from these data, researchers individually wrote responses to prompts (Supplement B) created by us to elicit reflections on our experiences with implementing a unit for which we were part of the co-design team; how we operationalized the main aspects of our data-art inquiry framework; and the extent to which we observed students meeting our intended learning goals. We referred to all our data sources in writing these reflections, and ultimately produced 10 individual reflections (1-4/unit, 1-4 pages each). Next, we read and compared one another's reflections, and iteratively confirmed, questioned, clarified, and elaborated them through weekly discussions over several months.

This process led to our identification of, and consensus on synergies and tensions between data literacy, technology, and the arts—that is, instances in which one seemed to either support, or to be in contention with another—that were salient in our experiences. Our findings, summarized in Table 5, describe how these synergies and tensions played out, and the contribution of the unique contextual factors of the implementations.

In our Findings, we present individual analyses of each unit, illustrating participants' experiences and supporting our points through quotes from student work and teacher interviews. In our Discussion, we then highlight broader themes apparent across units.

Findings

Dance

Unit description

Dance (Table 1) had students use dance to communicate the implications of data patterns and trends about topics of their choice. The unit consisted of 6 Math lessons (1-2 sessions/week, 3 weeks) embedded within a sequence of 72 Dance lessons (4 sessions/week, 18 weeks). In math, students learned to ask statistical questions, reviewed applications of measures of central tendency, and interpreted data visualizations. Data and dance were integrated in all the dance lessons, which first involved students in exploring connections between data and dance through analysis and discussion of professional dances (Weeks 1-8), then working as a class to choreograph a dance based on a jointly interpreted, given data visualization (Week 9). In small groups or individually, students then choreographed dances based on topics of their choice (e.g. climate change, labor, economics), based on their analyses of researcher-curated graphs (Weeks 10-16). Finally, students performed their dances and artist statements at a live-streamed, interactive exhibition attended by the school community (Week 17), and reflected on their experiences as a class (Week 18).

Table 1. Overview of the *Dance* unit design and implementation

School	Public charter, midwestern United States
Co-design team	4 researchers 2 female teachers (1 math + 1 dance)
Schedule	Math was taught in the midst of Dance. ● **Math:** 6 sessions over 3 weeks (1-2 sessions/week) ● **Dance:** 72 sessions over 18 weeks (4 sessions/week)
Driving question	How can dance be used to communicate meaning behind data?
Learning objectives	● Analyze, interpret, and contextualize real-world data and its implications. ● Apply contemporary dance techniques to communicate about data to an audience.
Data	● Researcher-generated and curated graphs based on existing data sets on various topics, from which students could choose.
Technology	● Collaborative slide decks for articulating links between data findings and planned dance movements. ● Video streaming of dance performances (handled by teachers).

Artifact	● Original dance choreography and performance. ● Artist statement, associated slide deck.

Tensions and synergies

Data reasoning through embodiment

As a movement-based art, dance synergized with data literacy, enabling students to use space, time, and shape to describe and reason about data characteristics, context, and implications (Desportes et al., 2022). For example, students contrasted data values and category differences by varying the positions of their bodies in space, and relative to one another (Figure 1). They developed movements to represent qualities of data categories. For example, in dancing about animal population trends, one student conveyed birds through "graceful sweeping movements like a front walkover to a jump at the end" while her partner conveyed a fish by "flexing and contracting their body and spreading out." Additionally, students used movement to convey implications interpreted from data. For example, to represent the statistic that "16% of LGBT youth did not get mental health care because their parents did not allow them to go," one team invented the move "'Shampoo' to express the feeling of being caged in, unable to move." Another conveyed trends in perceptions of women's roles by "doing movements lower and work[ing] toward higher levels to show women working up toward their goals over time (...)." (Figure 1).

Thus, students recognized helpful metaphoric connections between dance and math, with the dance teacher noticing their "use statistical vocabulary as a way to describe their moving sequences," and the math teacher explaining that "all the modeling that we did within their dance class, we could then relate that back when they're working on their own [in math class] or remember how we used this movement to represent a trend of the data."

Balancing aesthetics with accuracy

A tension arose with students' struggles to attain desired dance aesthetics while also grounding their choices in data. As one team described, they "wanted to do movements that didn't always go with the graphs," and ultimately decided to include a particular move that "just kinda looked cool." Additionally, students reflected on the challenges of communicating particular messages through an otherwise subjective art form ("we just really hope that people understood it."). These reflections highlight a tension between the goals of data literacy and the arts, and the need to guide students in finding disciplinary alignments that balance aesthetics with accuracy.

Dis/connections through technology

While live-streaming students' final performances showed the value of data-art for engaging broader audiences with data, we experienced tensions in our attempts to integrate technology into the unit itself. To maintain a focus on dance foundations, we limited technology's role to connecting students and their teacher in their hybrid class format, and to audiences through performance. However, dance instruction over videoconferencing was difficult given the

importance of space and embodiment. As the dance teacher described of one student, “It was hard for her to interpret the movement [over Zoom] because she's new at dancing.” Additionally, the text-based template we provided for students’ to communicate their data-aligned choreography limited their ability to convey the emotional qualities of their planned movements.

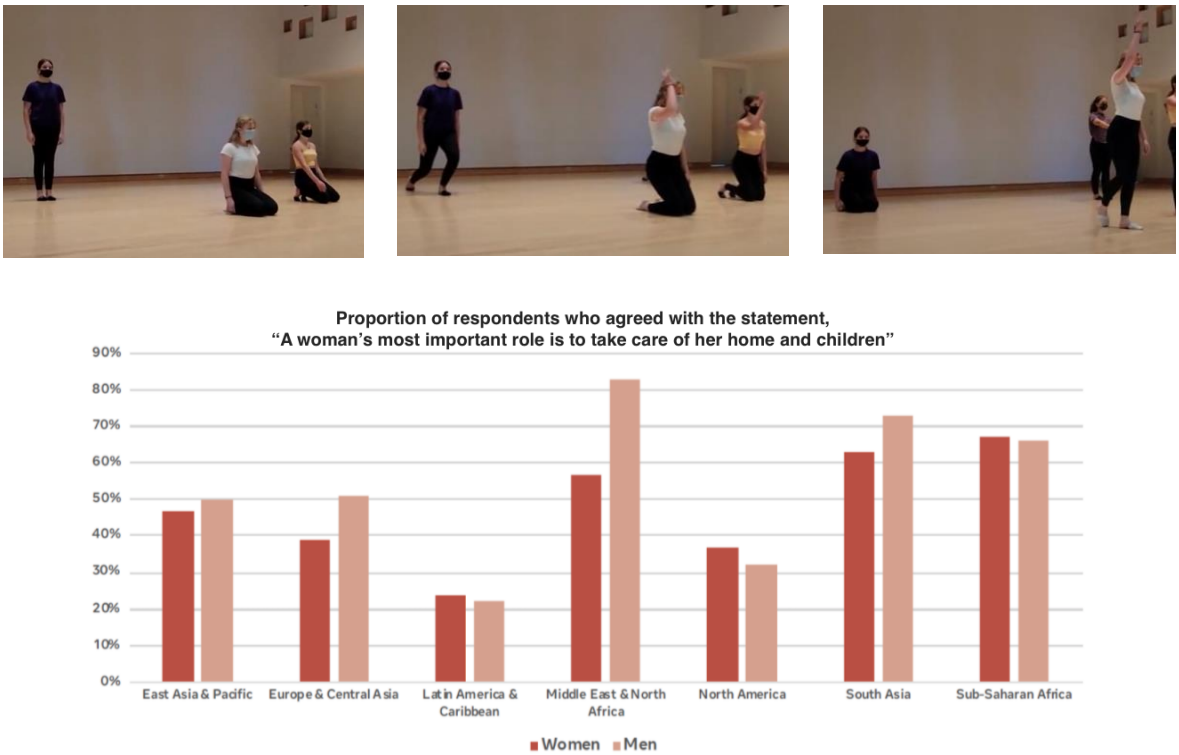

Figure 1. Three moments (top) from a *Dance* student team’s dance based on a graph of women’s rights (Facebook, 2021) (bottom).

Photoessays

Unit description

Photoessays (Table 2) engaged students in exploring ‘What contributes to a healthy place?’ through photography and creative writing about their neighborhoods. They first identified focal inquiry topics by exploring map-based visualizations of public data (Data2Go.nyc; (Anti-Eviction Mapping Project, n.d.; Maizlish et al., 2019) and making scatterplots in the Common Online Data Analysis Platform (CODAP). They then planned and conducted neighborhood walks to photograph how these indicators of health appeared in their everyday routes. Each student then reflected on the perspectives that their photography added to other data-based representations of their neighborhoods, and wrote accompanying letters—in prose or poetry—to introduce their neighborhoods to external audiences. A display of students’ collected works was made by researchers using ArcGis Storymaps (storymaps.arcgis.com), and was a centerpiece when students read their letters in a salon-like exhibition.

Table 2. Overview of the *Photoessays* unit design and implementation

School	Private Catholic, urban, Eastern United States
Co-design team	3 researchers 2 teachers ● 1 male, Math and English Language Arts (ELA) ● 1 female, Visual Art and Physical Education (PE)
Schedule	9 lessons across subjects were taught in tandem. ● **Art & PE:** 4 sessions over 3 weeks ● **Math:** 3 sessions over 2 weeks ● **ELA:** 2 sessions over 3 weeks
Driving question	How can we use photography to engage critically with public data around the question, 'What contributes to a healthy neighborhood?'
Learning objectives	● Think critically about how neighborhood health is measured and represented. ● Practice interpreting data visualizations and making scatter plots. ● Understand that data can include both numerical and non-numerical forms. ● Engage in storytelling with data through photography.
Data	● NYC data from Data2Go.nyc ● Student-generated neighborhood maps ● Photography documented during neighborhood walks
Technology	● Public data visualizations: Data2Go.nyc, healthyplacesindex.org, antievictionmap.com ● CODAP (codap.concord.org) ● Digital photography
Artifact	Digital photo essays consisting of photography accompanied by creative writing.

Tensions and synergies

Relatability of data visualizations afforded different data insights

While The Oakland Community Power Map (OCPM) and Data2Go.nyc are both map-based tools, each created different kinds of synergies between technology and data literacy. For example, Data2Go.nyc, which aggregates public data relevant to well-being (e.g., housing, safety, environment, education) from across multiple community districts, sources, and years, allows visualization of trends and comparisons (e.g, histograms, scatterplots) while highlighting corresponding data between graphs and maps. According to the math teacher, these contextually integrated tools for exploring relationships between variables allowed students to appreciate the personal and social impact of their environment on health. As one student reflected in their interview, "your life expectancy can be lowered, just because of the quality of your community and area. That's something I didn't notice before."

Meanwhile, the OCPM, a project that crowdsourced photography and writing about places important to community members, "clicked right away" with students, according to the art teacher. Seeing a community through data that they might themselves have produced, and about

neighborhoods similar to their own, prompted students to infer implications of these data to their own experiences. They reflected on how outsiders tend to perceive their neighborhood as dangerous, although they knew that kind, family-oriented people also lived there.

Students' final artifacts created a synergy between the data literacy and the arts, which allowed them to express critical, data-based perspectives on community issues (Amato, Matuk, et al., 2022). One student interviewed explained how her poem addresses stereotypes about her neighborhood, which "has that reputation of being like a bad ghettoish community…but it's more like a kind of family." Her map and photography further supported her perspective by representing community assets (e.g., her movie theater and lakeside hangouts), and linking city infrastructure to well-being by highlighting the safety issue in her neighborhood's sidewalk cracks (Figure 2).

Challenges and opportunities with integrating numeric and photographic data

Photo walks presented a synergy between each of technology, the arts, and data literacy. Using observational practices of photography, students could examine street-level evidence of health statistics, like high crime rates and air pollution. These real-world experiences moreover prompted questions over why their neighborhood observations contrasted with their analyses of community-level data.

At the same time, tensions emerged from contextual constraints. Students were limited to take photos at times and places that were accessible and safe, with some students being limited to locations near their school. In addition, school-related events delayed photo walks, and prevented a second class photo walk, which would have allowed iteration and deeper investigations through photography.

For some students, experiencing these constraints made it challenging to draw on their data-based findings to inform or explain their photography For example, some students investigated the relationship between education and average life expectancy but did not represent these findings in either their photography or letters. One student, in describing her initial data exploration, explained that "I did it because I was told to," and did not refer back to that data while taking photos. Among other reasons, it may be that students were constrained in what they could access and observe through photography.

Other students, however, responded to these constraints by thinking critically about the implications of sampling decisions; the importance of using multiple variables, and the need to measure under-represented indicators through data. In reflecting back on the project, the same student quoted above explained that the value of combining data, photography, and writing is to "show your community," and "emphasize how much there is to improve. Without one, we wouldn't understand the other," demonstrating her appreciation for using multiple approaches to understanding and representing issues.

Students' artist statement: "For this project, I chose to indicate life expectancy in my community with the quality of our sidewalks. Since sidewalks are used quite often, it is important to take care of them and make sure they function without issue. People that use walking aids, such as canes and scooters, have to watch sidewalks more carefully in case of cracks that can cause them to fall. In my community, cracks in sidewalks are quite common; it's easy to trip if your [sic] aren't paying attention. Although it is a small detail, having nice sidewalks improves a place's appearance while keeping its members happy and healthy."

Figure 2. A *Photoessays* student's photographic investigation of sidewalk quality as an indicator of their community's health. The student-drawn map (far left) highlights resources in the artist's community.

Comics

Unit description

Comics (Table 3) had students make comics to convey data-based inferences by relating personal experiences to nationally representative data. We chose the theme of friendship in response to teachers' desire for direct applicability to students' lives, and given its importance in middle school-aged youth's socio-emotional development. Meanwhile, comics connected to students' existing interests in the genre, and the art teacher's prior comics unit. Students learned about the features of sequential art, analyzed national survey data from the PEW Research Center on teens and technology use, and analyzed researcher-generated graphs of their own and their peers' responses to a researcher-designed survey about friendship beliefs and experiences (e.g., "How many of your close friends are online/nonbinary/male?" "Which best describes you?: I can count on my friends when things go wrong," etc.). Finally, each student created a comic to communicate claims and inferences based on these data (Figure 4).

Table 3. Overview of the *Comics* unit design and implementation

School	Public, urban, Eastern United States
Co-design team	4 researchers 2 female teachers ● 1 Math ● 1 Visual Art
Schedule	Math began in the midst of Art ● **Art**: 1 session/week for 6 weeks ● **Math**: 3 sessions over 2 weeks
Driving question	How can we use comics to reflect on our own friendship experiences in relation to others?

Learning objectives	● Relate broader data trends to personal experiences. ● Use data to reflect on personal friendship behaviors and understandings. ● Make comics that communicate data-based inferences.
Data	● Researcher-generated visualizations of class responses to a researcher-designed survey about friendship experiences and beliefs.
Technology	● Pixton (pixton.com), a digital comics creation platform.
Artifact	Comics that reflect on a personal relationship to the friendship data analyzed.

Tensions and synergies

Reasoning about data through comic narratives

We observed multiple synergies in the combination of comics and friendship data for promoting students' reasoning about implications of observed data trends (Vacca et al., 2022). Often, their comics featured themselves as characters, situating their own friendship experiences within broader trends. In one comic, for example (Figure 3), a character addresses the reader as she reflects on her class's responses to the question "Do you find it easy to make friends?" She questions the significance of the 2.2% difference between people's "Yes" and "No" responses. As she no longer remembers how her own friendships began, she asks whether the age at which people made their friends would change their perceptions of how easy it is to make friends. In this case, the dialogic format of comics, combined with friendship data, supported reflections on this student's personal experiences with respect to broader trends, and on the role of context in the meaning behind data.

Affordances of digital comic-making tools to support all learners

We found multiple synergies between technology, the arts, and data literacy. For example, the art teacher initially described herself as being on "team stick-with-tradition," implying that under normal circumstances, she would have had her students create hand-drawn comics. However, remote teaching "pushed [her] to be more open" to technology-based art, and ultimately she adopted the free online comic-making tool Pixton (pixton.com). As well, whereas Pixton's ready-made assets and templates limited students' aesthetic control, the templates also allowed all students to experiment with visual storytelling techniques such as contexts and character gestures and expressions, which would have otherwise been time consuming and limited by students' skills. Pixton's digital format also supported students in iterating on and sharing their work. It furthermore enabled the math teacher to bring students' artwork into her lessons as she guided students in integrating math into their comics.

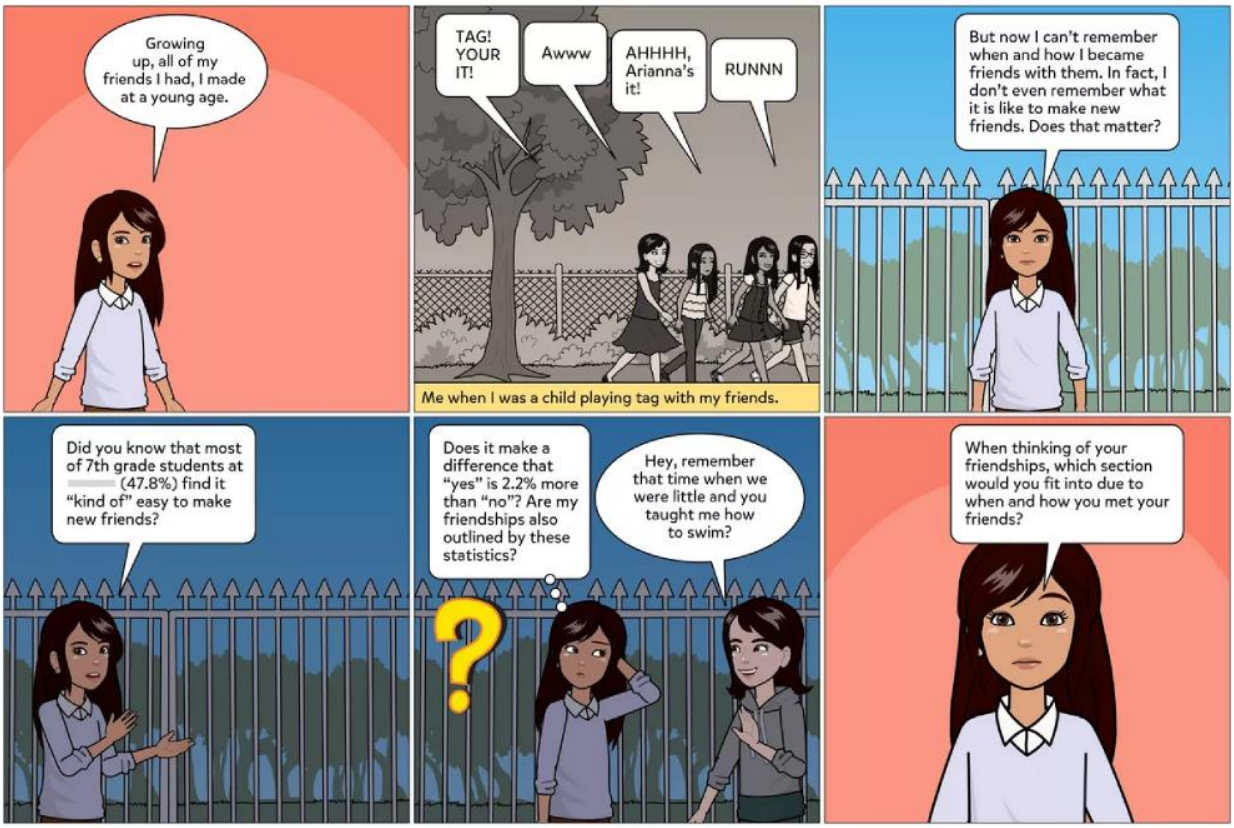

Figure 3. A *Comics* student's data comic, which demonstrates how they are placing themselves in the data, and using percentages to reason about significant differences.

Collages

Unit description

In *Collages* (Table 4), students explored, 'How might the way we use our time affect our well-being?' by interpreting visualizations of American Time Use Survey data (ATUS, bls.gov/tus), and graphing dot plots using TUVA (tuvalabs.com). In then collecting their own time use data, students were challenged to critique typical time use categories, and to reflect on effective sampling strategies.

Initially, we planned for students in math class to sample and represent their time use through photography; and in ELA class, to use their photos to construct a visual data story that would counter misperceptions of teens' time use (Amato, Silander, et al., 2022). However, several challenges arose during implementation, including a sudden testing requirement that prevented the synchronization of classes, and unanticipated limitations in students' computer and camera access. Teachers therefore decided to disband and adapt the materials to be standalone, single-subject units. Thus in math, data collection was reduced to a one-time retrospection on prior time use, with limited time to analyze and discuss results. Meanwhile, in ELA, students discussed and responded

to news articles and photo essays about time use by creating collages with found imagery to counter personally-experienced stereotypes.

Table 4. Overview of the *Collages* unit design and implementation

School	Public, urban, Eastern United States
Co-design team	3 researchers 4 female teachers ● 1 Library ● 2 Math ● 1 English Language Arts (ELA)
Schedule	**Subjects taught in sequence** ● **Library:** 1 session ● **ELA:** 5 sessions over 1 week ● **Math:** 5 sessions over 1 week
Driving question	How can we counter stereotypes of teens through photography of their time use?
Learning objectives	● Practice interpreting and making data visualizations (e.g., heatmaps, histograms) ● Compare and apply sampling strategies in data collection. ● Understand the value of photographic data for revealing contextual variation otherwise hidden in aggregated data. ● Make data-based arguments.
Data	● Subset of American Time Use Survey (ATUS) data on teens and well-being. ● The Most Common Day (flowingdata.com/2017/10/19/american-daily-routine) ● Articles based on data from ATUS (Horrigan & Herz, 2004) and on well-being data from Pew Research Center, TIME, Edweek, The Atlantic, CNN, NY Times. ● Student-collected data on personal time use.
Technology	● TUVA (tuvalabs.org) ● Found digital imagery from Google Images.
Artifact	A collage of existing images to represent relationships between personal time use and well-being

Tensions and synergies

Contrasting classroom cultures constrained and afforded data reasoning

The lack of coordination between Math and ELA created both synergies and tensions between data literacy and the arts, while also revealing affordances and constraints of subject-specific instructional routines.

For instance, the ELA teacher spent much of the previous months cultivating classroom discussion routines, such that her "students would lead their own discussion," and "listen and respond" respectfully." While she initially lacked confidence in addressing topics such as data sampling, insisting that these be covered in the math class, she reported that students' critiques of different sampling methods and of the nature of data as evidence, emerged organically from their discussion. She found that the topic of time use "was really real-world connected (…) because we talked about how we used to spend our time [before the pandemic] vs. now, during lockdown. (…)

Sometimes there are some students who are disengaged, this wasn't the case this time." Students reflected on relationships between time use and well-being, and how values assigned to time use are personally and contextually determined ("One kid might spend their time on the phone, another harvesting crop. Is one more valuable than the other?").

Meanwhile, the math teachers, under the pressure of state assessments, typically spent class supervising students' work on problem sets. Lacking coordination with the ELA lessons, which were originally intended to provide social context to the data, the math teachers felt that students "needed to see some idea of an end goal. I didn't have that for them." In contrast to the ELA teacher's observations, the math teachers felt that students' recognition of the personal relevance of time use data was: "kind of off," reporting how one student commented, "My mom doesn't do this [leisure activity]. She just goes to work all day."

The contrast in routines for completing vs. critically reflecting on problems were echoed in teachers' technology choices. Whereas the Math teachers incorporated lesson content into Desmos (desmos.com) and monitored students' work through the dashboard. the ELA teacher had students document reflections in digital notebooks. Had we drawn strategies from ELA to support similarly critical discussion in math, we may have been able to guide students' consideration of data bias, and how national surveys could better capture the diversity of people's experiences.

Exploring photographs and found images and data

The school's limited infrastructure created tensions between technology and data literacy that stifled our intended goals, while also pushing teachers to create alternative routes toward their instructional goals. For example, the math teachers, excited for their students to use TUVA (tuvalabs.org) to explore a public data set, found that the platform lagged with multiple simultaneous users, and that they lacked sufficient familiarity with it to provide proper guidance.

Meanwhile, teachers surmounted other technology barriers that enabled students to think critically about the nature of data and of sampling with photographs as data. For instance, faced with a lack of student cameras for gathering personal time use data, the math teachers had students design sampling strategies that they would pursue to accurately represent their own time use (e.g., "If we take photos of a teenager's day every hour…"). The ELA teacher led discussions of how social media images represent and misrepresent celebrity time use; and rather than have students create individual photo essays, she had them create collages with found imagery to represent their time use and well-being. Through these activities, students became curious about "how else you can collect data" and "how would photographic data look different if you presented it as numbers?"

Table 5. Summary of synergies and tensions between data literacy, arts, and technology

Comics & Friendship	**Synergies** ● 'Friendship' data was relatable, encouraged inference-making about oneself in relation to broader data patterns, and encouraged data-based socioemotional reasoning. ● Pre-made components lowered the bar for all students to make comics. ● The digital format facilitated iteration on comics, and incorporation into both the art and math instruction.

	Tensions ● Aesthetic choices sometimes conflicted with intuitive strategies for making data-based claims. ● Pixton's premade assets limited students to referencing percentages, rather than, for example, incorporating graphs or exploring 1:1 mapping between visual and data properties.
Dance & Data	**Synergies** ● Movement encouraged sensemaking through embodiment, and visual communication of data patterns, comparisons and trends. ● Dance allowed enactment of inferred implications of data interpretations. ● Metaphoric alignments with dance supported reasoning about data science concepts. ● Video conferencing supported collaboration and feedback in the class's hybrid format. ● Live streaming allowed broader audiences for students' performances, and gave their work consequentiality. **Tensions** ● Choreographic choices were sometimes aesthetically-based rather than data-based. ● Students were challenged to express dance ideas through the text-based scaffold used to support the hybrid class.
Photoessays & Healthy Neighborhoods	**Synergies** ● Photography facilitated documentation of community assets and problems not typically captured by neighborhood health indices. ● Photography highlighted contextual variability behind aggregated data. ● Through photography and creative writing based on photo walks, students made personal connections to public data about their neighborhoods. **Tensions** ● Photo walks were constrained by time, accessibility, and observability, with some students limited to school surroundings, rather than personally important locations farther afield. ● Students were challenged in synthesizing ideas across graphs, photography, and creative writing.
Collages & Time Use	**Synergies** ● Analyzing collages helped students connect personally to the importance of representing teens' time use. ● Existing digital imagery allowed art-making without cameras. ● ELA discussion routines supported critical reasoning about the nature and uses of data. **Tensions** ● Lack of cameras limited students' full exploration of photography for collecting time use data. ● Lack of Math discussion routines, and challenges with using TUVA, limited students' abilities to personally relate to existing time use data.

Discussion and conclusion

Data-art inquiry has various opportunities for data literacy learning in school contexts. In adapting to each school's contextual constraints and affordances, we explored different ways to emphasize and coordinate subjects, and a range of data-art forms, from data-informed art (*Comics*), to data-driven art (*Dance*), to data-as-art *(Photoessays).* Here, we highlight broader patterns observed across implementations in how disciplinary synergies and tensions were contextually shaped.

In terms of synergies between data literacy and the arts, we found different media to offer unique ways of supporting informal statistical reasoning (Makar & Rubin, 2018). For example, narrative-based media (comics and creative writing) supported students' introspection on their personal experiences relative to broader data trends. Movement-based art (dance) supported embodied sensemaking of the shape and meaning of data. Meanwhile, photography highlighted how data should be interpreted within the limits of operationalization and sampling decisions, and how images can reveal contextual details that tend to be hidden in statistics. However, there were also tensions in using arts-based approaches to convey data claims as students struggled in making artistic choices based on data vs. aesthetics.

Arts-based practices and routines furthermore encouraged students' engagement with critical issues about data, through the language of data science. In *Collages* for example, the ELA teachers' reflective discussion routines created space for students to question decisions made in categorizing people's time use, and the values that these decisions imply. Meanwhile, the practice of verbally describing dance movements, when applied to dances about data, encouraged students' adoption of data science vocabulary.

Technology also created multiple synergies with data literacy and the arts through its various roles in data-art inquiry. For instance, arts-integrated technologies served to link subject-specific practices by serving as a model, or as a data-art-making tool. In *Photoessays*, for example, students' use of a digital participatory mapping artwork prompted critique of issues in data, and served as a model for their own neighborhood maps. Additionally, students used digital photography to capture qualitative data from their communities, and visualize data-based perspectives on them.

Meanwhile, in *Comics*, the easy-to-use, web-based nature of Pixton allowed the math teacher to guide students in building math into their artwork during math class. While its highly scaffolded nature limited students' creative control, it also allowed students— regardless of their art identities—to participate in data-art making.

Tensions with the integration of technology largely stemmed from time and infrastructural constraints. For example, *Dance* and *Comics* resisted integrating new data analysis tools, aware of limitations on teachers' abilities to prepare, and on their school's technology infrastructure (Fernández-Batanero et al., 2021). This meant foregoing student-collected data in favor of existing data. It also meant that the burden was on researchers to find, clean, and visualize data with which students would engage. Meanwhile, *Collages* and *Photoessays* chose to experiment with new data

analysis tools (i.e., CODAP and TUVA), but the already limited time for students and teachers to learn and work with the tool left less time for discussion. Further work might consider ways that technologies can balance disciplinary authenticity with feasibility in classroom-based data-art inquiry.

Recommendations for research and practice

Although all teachers were committed and enthusiastic about the project, we were variously challenged to navigate constraints around cross-subject integration, including subject-specific differences in curriculum flexibility, accountability, and instructional time, and administration-level priorities on interdisciplinary instruction. Our experiences across contexts highlight the following recommendations to mitigate unforeseen challenges in implementing arts-integrated data literacy curriculum.

(1) Build on synergies between domains. The synergies identified in this study show value in drawing on arts-based practices to support data literacy, including discussion routines, personally-oriented reflection, and exhibitions to external audiences. Other research similarly points to the value of studio critique in STEM (Litts et al., 2019). Thus, resonant with calls to better prepare educators across disciplines to teach data literacy related to their field (Finzer, 2013; Lee et al., 2021), teachers might be specifically supported in learning and adopting effective instructional practices from other subject areas.

(2) Establish shared, flexible goals for arts-integrated data literacy curriculum. With common curriculum goals and expectations, any necessary in-the-moment adaptations that teachers may make when encountering unexpected implementation challenges will more likely adhere to the curriculum's original goals. Our experiences with scheduling challenges during *Collages* showed that teachers, who had overall less time to co-design with us, resorted to planning within familiar disciplinary silos rather than pursue solutions that would prioritize subject integration. Other teams, however, who had had the time to more fully internalize the data-art inquiry process (e.g., by making their own data-art as part of our planning process, and establishing roles and routines through regular co-design meetings) coordinated with researchers when curriculum adjustments were needed. These experiences highlight some teachers' unfamiliarity with co-design, and the need to actively address institutional hurdles for cross-subject collaborations. For example, teachers might be given time and incentives to collaborate on cross-subject curriculum—both with researchers, and among cross-subject colleagues. Additionally, arts-integrated curriculum materials might be designed to be flexible and responsive to emergent needs across subject contexts, and beyond a co-design partnership.

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Statements on open data, ethics and conflict of interest

D. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
E. This research was conducted with approval of, and following ethical guidelines outlined by the Institutional Review Boards at New York University, at the New York City Department of Education, and at Boston Public Schools.
F. The authors have no conflicts of interest to disclose.

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