This is the accepted manuscript version of the article: Wilkerson, M. H. & Laina, V. (In Press). Middle school students' reasoning about data and context through storytelling with repurposed local data. To appear in *ZDM: Mathematics Education*.

Middle School Students' Reasoning About Data and Context Through Storytelling with Repurposed Local Data

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Abstract. Publicly-available datasets, though useful for education, are often constructed for purposes that are quite different from students' own. To investigate and model phenomena, then, students must learn how to *repurpose* the data. This paper reports on an emerging line of research that builds on work in data modeling, exploratory data analysis, and storytelling to examine and support students' data repurposing. We ask: *What opportunities emerge for students to reason about the relationship between data, context, and uncertainty when they repurpose public data to explore questions about their local communities?* And, *How can these opportunities be supported in classroom instruction and activity design?* In two exploratory studies, students were asked to pose questions about their communities, use publicly-available data to explore those questions, and create visual displays and written stories about their findings. Across both enactments, opportunities for reasoning emerged especially when students worked to reconcile (1) their own knowledge and experiences of the context from which data were collected with details of the data provided; and (2) their different emerging stories about the data with one another. We review how these opportunities unfolded within each enactment at the level of group and classroom, with attention to facilitator support.

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Middle School Students' Reasoning About Data and Context

Through Storytelling with Repurposed Local Data

1. Introduction

Computational tools and cultures are changing the ways in which learners and the general public access, interact with, and make sense of data. Data sharing and the re-use of large, open datasets is now commonplace in a variety of professional and everyday contexts. Insights and models about complex social and scientific issues are often shared with the public via artifacts such as open datasets, data exploration tools, and interactive visualizations. In response to these shifts, there is strong international consensus regarding the importance of data and statistics education throughout the curriculum (Ben-Zvi, Makar, & Garfield, 2018; Franklin et al., 2007); more recently researchers have highlighted a need to consider specifically how complex, public datasets and interactive visualizations may be incorporated into such educational efforts (Gould, 2017; Lee & Wilkerson, 2018).

Helping students learn to reason about and build models using these publicly available datasets and artifacts, however, may not be as straightforward as it seems. To productively engage in data modeling, students should understand how and why a particular dataset was constructed, what might be sources of error or variability in the data, and what questions the dataset was intended to address (Hancock, Kaput, & Goldsmith, 1992; Lehrer & Romberg, 1996). Typically, this is done by engaging learners in their own measurement and data construction activities (Garfield & Ben-Zvi, 2007).

In contrast, publicly-available datasets and visualizations are constructed by others for purposes that are different from students' own. To use those data sources to investigate and model phenomena, students must learn how to *repurpose* the data. This includes considering how their investigations might be informed by data made available by others, evaluating how valid those data are for their goals, and determining how the data may be modified or transformed to better align with those goals. Such repurposing complicates the relationship between data and context. Since learners have at best only partial information about how and why such datasets were created, it is more difficult to reason about the measures and sampling methods used, what might be sources of error or uncertainty, and what inferences can be made (Ainley, Gould, & Pratt, 2015).

This paper reports on an emerging line of research that builds on work in data modelling (Hancock et al., 1992; Lehrer, Kim, & Schauble, 2007), exploratory data analysis (Ben-Zvi, 2006; Cobb & McClain, 2004), and data storytelling (Pfannkuch, Regan, Wild, & Horton, 2010) to study students' data repurposing. Our goal is to design materials and activities to support repurposing as a part of classroom data modeling and statistical practice. The current work represents a first step in this direction to identify whether, and under what circumstances, engaging students in data repurposing activity allows them to think critically about data and context.

Even if students do not have much background knowledge about publicly-available data, it is possible—even likely—that they have other knowledge or experiences that can inform their investigations. A major conjecture driving the current study is that (1) students can provide complementary insights into the types of repurposed data that are of interest to educators and students (e.g., data that are likely to be personally relevant to students, are about well-known social or socio-scientific issues, etc.); and (2) this diversity of perspective can become a valuable resource for collective inquiry as students work to synthesize and build consensus across their findings (Brown & Campione, 1994; Rosebery, Ogonowski, DiSchino, & Warren, 2010). The goal of the current study is to explore this conjecture, by asking: *What opportunities emerge for students to reason about the relationship between data, context, and uncertainty when working with* *repurposed data?* And, *How might these opportunities be better supported through instruction and activity design?* Given our expectation that many such opportunities lie in students' relationships with a given data context, we look at repurposing activities that use publicly available local data about students' cities of residence.

2. Background and Theory

Pfannkuch (2011) introduced the term *data-context* to describe the situation a given set of data reflects, related subject matter knowledge, and knowledge about how those data were constructed. The *learning-experience-context*, in contrast, refers to the specific tasks, social relationships, and statistical knowledge students develop during instruction.

Data repurposing complicates the notion of data context, because this can refer to both the original context of data construction and the new context(s) for which students are now using those data. These more complex relationships between the original and repurposed data contexts may introduce new sources of variation to data as students manipulate it to serve new purposes, or change the representativeness and appropriateness of data for particular questions (Wilkerson et al., 2018). Repurposing also may introduce new tensions between data contexts and the learning experience context, if students are expected to leverage types of knowledge not typically expected for the statistical learning experience context. To encourage students to thoughtfully navigate these multiple contexts, we turn to *storytelling* and *representation*.

2.1 Storytelling

Storytelling is one fruitful way to build coherence across multiple statistical contexts. Pfannkuch and colleagues (2010) argue that "...telling stories, and teaching others to tell stories, about data" (p. 2) is critical for promoting conceptual understanding and communication of statistics. These data stories can help make explicit the connections between the descriptive and inferential statistical methods usually kept separate in the curriculum, help learners integrate new knowledge with what they already know, and highlight the practice of data analysis as a messy, human endeavor. Typically, these stories are conceptualized as embedded within data, to be discovered or unlocked by learners. In an activity exploring data about the Old Faithful geyser in the United States, Shaughnessy & Pfannkuch (2002) ask "What is the story contained in the data?" (p. 257). Chance and colleagues (2007) describe how technology allows "different graphs of the same data [to] provide different pieces of a story… [or] allow the data to tell a (possibly unexpected) story to the student" (p.10).

These characterizations point to a broader literature that suggests learners use narrative to organize and communicate understanding (Bruner, 1991). Rather than attributing story to data, these perspectives suggest stories are the result of students coordinating their prior knowledge and experiences *with* data and the patterns they find during investigation. If we expect students to bring diverse insights and pursue different paths of inquiry, these stories are likely to differ even if they concern the same dataset. Thus we expect students to tell a variety of intersecting stories (Bal, 1997) that illuminate different aspects of the data and related systems under study.

We consider students, then, to be constructing an intersecting set of stories any time they make meaning of a dataset, even if they do not experience this as storytelling in the conventional sense. This interpretation is useful for thinking about the issues likely to emerge when students engage in repurposing. Public datasets often describe complex social or scientific systems. As such, they reflect several interrelated patterns, any subset of which students may uncover during exploration. Indeed, an emerging body of work reveals that students do imbue large, public datasets with deeply personal meaning (Philip, Olivares-Pasillas, & Rocha, 2016).

2.2 Representation

Storytelling and working with data is also tied to issues of external representation; in particular, visualizing data in order to find and communicate patterns. We sought to engage students in storytelling through the explicit construction of hand-drawn or digital inscriptions. Since we expected data repurposing to complicate relationships between data and context, we encouraged students to employ conventional and unconventional representational forms. We expected this would allow students to accommodate new structural information or contextual details about a given situation as needed.

We hoped students would come to treat the representations they were creating as instantiations of *epistemic forms* (Collins & Ferguson, 1993): external structures that, as they are populated with known information, reveal new paths of inquiry. Different epistemic forms tell particular types of stories, and support particular epistemic goals. Scatterplots enable the exploration of bivariate relationships; histograms enable exploration of distributions. Epistemic forms can also help investigators interpret, compare, and synthesize stories and findings. If two students graph two different variables over the same time period, those graphs can be visually juxtaposed to examine whether they change together.

3. Methods

In the spirit of design-based research (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003), we sought to create learning environments that would bring about early versions of data repurposing, in order to study and better support such engagement in the future. Informed by the literature above, we opted to do this by asking students to conduct investigations of local data, and create public representations of their findings. Local data reflect patterns and relationships students see every day in ways that are likely to be at once familiar, complex, and under-examined. Public artifacts offer a way for students to make their reasoning visible as it extends across data, personal, and shared contexts. We did not explicitly ask students to tell stories in either of the activities. Instead, we refer to students' activity as storytelling because they were expected to make sense of repurposed data in terms of their own knowledge and experiences, and to construct public artifacts to share the results of their data investigations.

The analyses we report are drawn from two short, exploratory classroom activities entitled *Rats!* and *Stories of Our City*. Each was designed and conducted in partnership with classroom teachers as an enrichment activity integrated into their curricular plans for the year. Below, we describe these activity sequences in more detail. Both reflected common data investigative cycles described in literature (e.g., Wild & Pfannkuch, 1999) whereby students (1) posed questions about their city; (2) were presented with collections of datasets made available by the local city government; (3) reviewed, selected, and analyzed the data to address their questions; and (4) created visual and/or written artifacts to communicate findings.

Participants. The activities were conducted at two public schools in a densely populated and socioeconomically diverse region of the Northeastern United States. *Rats!* was enacted in one fifth grade class at a grade K-6 school. This was a typical class within a school that served a racially diverse population of students (public records indicate 14% African-American/Black, 7% Asian, 44% Hispanic, 31% White, and 3% Multiracial) with a variety of economic, special education, and language learning needs (21% English language learner, 26% with disabilities, 55% economically disadvantaged). The school's curriculum integrated project-based activities and the arts into school subjects. A total of sixteen students were enrolled in this class, and all consented to participate in the study.

Stories of Our City was enacted in five seventh grade classrooms at a grades 6-8 school. Four were typical classes whose demographics were reflective of the school as a whole, and that served students who required special education services through an inclusion model. The fifth served students who were English language learners, and adapted curricula (including this activity) for this population. This school also served a racially and economically diverse population of students (public records indicate 36% African-American/Black, 15% Asian, 10% Hispanic, 33% White, 1% Native American or Native Hawaiian/Pacific Islander, and 5% Multiracial; with 13% of students English language learners, 21% students with disabilities, and 31% economically disadvantaged). The size of these classes ranged from 15-32 and a total of 45 students consented to participate in the study. As we describe below, only one class was selected for this analysis. That class had 22 students, 16 of whom consented to participate in the study.

Data Collection. Consent for data collection was obtained from students and guardians prior to beginning the enactments. During each activity, we video recorded all classroom discussions and student presentations. We collected additional video and audio data of discussions among selected focal groups of fully consented students. For *Rats!*, the teacher recommended four student groups who were likely to be talkative, and whose performance in class reflected a typical level of attainment in the course. For *Stories of Our City*, video for all consented groups in each class was collected. During each day of the enactments, one or two researchers were present and took field notes. Student written artifacts were collected or scanned for later analysis and, in the *Stories of Our City* study, digital artifacts and screen activity were also recorded for analysis.

Rats! was a three-day (approx. 3 hr) investigation of a recent, well-popularized issue in students' local community—a years-long rodent problem, punctuated by a recent spike in rodent sightings within the past two years. The activity began with a discussion about whether students had observed or heard about the problem. Students then read excerpts from a short news article describing the mayor's recent declaration of "war on rats." The article briefly described a number of factors affecting the problem including weather, food sources, trash management, and construction, but with little reference to quantitative data or trends. At the end of this session, the class held a brief discussion to review the main points raised in the article, and to develop "statistical questions"—a phrase and practice that had already been discussed by the class before our enactment. Students worked together in pairs to write 2-3 questions and identify sources of data that they thought could help them address those questions.

The next day, we introduced datasets available from the city government that in some way reflected the types of data students requested. These included: a table reporting the average monthly temperature of the city during the years of focus; a table of the total number of reported rodent sightings for each month during the years of focus; a table of the total number of reported rodent sightings by geographic ward (region) of the city; a map identifying ward boundaries; and a sheet describing the total population of the city for the three years of focus, and details about the gender and anonymous vs non-anonymous status of people reporting rat sightings.

We were not able to provide everything that students asked for. Information about trash violations in the city proved difficult to obtain, and much of the other data we provided reported different measures or had been collected for different time scales or regions than students identified. We reformatted all data into tables with descriptive parameter names, but otherwise did not modify the data. We made several copies of the tables, maps, and lists available as printouts, and left them on a table in the back of the classroom. Students were invited to revisit their questions from the day before and retrieve the data they expected would be most helpful.

Stories of Our City was a seven-day (approx. 7 hr) investigation of municipal data conducted in partnership with a seventh-grade mathematics teacher who had already designed and enacted a unit called "Designing Data Visuals" in previous years. Students worked to analyze and develop visual and written narratives about their city using demographic and other municipal data provided through the city's website. To begin, students were given a list of approximately 20 general topics for which data were available. They were asked to identify the three topics they were most interested in, and to develop questions about each.

The next day, students were assigned by the classroom teacher to groups of 2-3 based on their chosen topics and collaboration dynamics. Each group was provided with 3-4 datasets related to the topics and questions they had developed. They were invited to refine their questions based on what data was available and what patterns they initially observed. They were also encouraged to request other datasets that they thought may reveal interesting patterns or insights. Most of the datasets provided to students featured a set of tables and descriptive graphical displays (e.g., line graphs, bar charts, etc.).

On Day 3, students were provided laptop computers and introduced to Google Sheets (for analysis and visualization) and easel.ly (for graphic design). However, students were encouraged to use whatever methods they were familiar and comfortable with, and a few chose to make calculations or create data displays by hand. Throughout the unit students were encouraged to analyze and visualize their data, and to refine their questions and intended designs as they investigated. On Day 5, all students participated in a gallery walk to observe one another's progress. On Days 6 and 7, students wrote short narrative descriptions of their questions, analyses, and findings, and gave presentations of their visualizations to the class.

Analysis. Analysis for this paper was conducted in two phases. The first involved repeated viewing of video data (Jordan & Henderson, 1995), field notes and student artifacts from both enactments. We tagged instances that suggested students were engaging with questions about data, context and uncertainty in ways that advanced their inquiry. We focused on moments in which students made sense of the data they had available in terms of the context they had chosen to explore. We also looked for moments where students challenged the *certainty*—reliability, representativeness, or validity—of data based on their experiences of the data and learning experience contexts.

Once several such moments were identified, we reduced our data to focus on video, artifacts, and field notes from the *Rats!* enactment and only one of the four classes that participated in the *Stories of Our City* enactment. Given our interest in the development of classroom norms and our goal of designing instructional activities, this allowed us to focus on the interrelationships between students' investigations and the development of norms in groups and at the classroom level. We selected the *Stories of Our City* focal class that had the most complete set of data, including daily recordings of all four consented groups' interactions, student artifacts, and classroom discussions.

4. Results

We present findings in sections corresponding to the *Rats!* and *Stories of our City* respectively. In each, we organize our results around three foci of analysis. Informed by our initial conjectures, we call these (1) making sense of data, context, and uncertainty; (2) exploring diversity in student stories; and (3) supports for storytelling and synthesis. We strive to balance details of particular groups' navigation of data, context, and uncertainty as they engage in repurposing with a view of how these events unfolded across time and among the classroom community. Throughout the section we use pseudonyms to refer to students and mark researchers and teachers in transcripts with an asterisk.

4.1 Rats!

At the beginning of the *Rats!* activity, students relatively easily developed investigative questions that were germane to the activity and that could be investigated with data. Table 1 provides a summary and examples of student questions. We suspect three factors affected students' success with question posing. First, the introductory activity reminded students about the nature and purpose of statistical questions, a topic they had already dealt with in class. Second, the news article provided to students mentioned several possible causes for the infestation (weather, trash, population density), which informed the questions students posed. Third, many students had already acknowledged they had seen rats and had ideas for what might be attracting them and how they might be controlled.

Table 1. Themes present in questions posed by each group.

		Groups						
Themes	**Example**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Season/Weather	*How does temperature affect rats?* [Group 2]	x	x	x		x		
Recorded Complaints	*What percentage of males and females call to complain?* [Group 4]		x	x	x			x
Geography	*What part of Somerville has the most complaints?* [Group 7]		x	x	x		x	x
Patterns over Time	*Has there been complaints increasing each month?* [Group 3]			x	x	x	x	x
Trash	*How many residents don't take out their trash on their neighborhood's trash day?* [Group 1]	x				x		

4.1.1 Making Sense of Data, Context, and Uncertainty

Regardless of the questions they posed on day 1, nearly all groups started their investigations on day 2 by referring to a city map, looking for their own neighborhoods and schools, and investigating relationships between regions on the map and one particular dataset that described the number of yearly rat sightings per geographic region, as reported through a citywide telephone tip line (Figure 1).

Figure 1. Student groups began their investigation by locating themselves on the city map.

During this initial phase of investigation, we found students considering how issues of sampling and measurement may influence the reliability or utility of provided data. These opportunities emerged as students worked to contextualize, make sense of surprising or unreasonable observations within, or better understand the methods used to construct these most personally proximal datasets. In the following excerpt, one group's curiosity about where their school is located on the map leads a facilitator to point out differences in the sizes of map regions (in terms of area of each ward):

Sam: We have a disagreement. Is our school in Ward 1 or Ward 4? I think it's in Ward 1.
Michelle*: I think it's in Ward 4. It doesn't really matter, I mean this is about [.] well, I mean let's see. I can look [.] here's Broadway.
Fabian: I grew up in Ward 1.
Michelle*: You know what's funny, is, Ward 1 is so much bigger, too, right? So like, that size versus that size [*uses fingers to highlight land areas*].
Fabian: Hmm. I grew up in Ward 1.
Sam: Are there more people there?

These students began with an attempt to locate themselves within the available data, first by finding out where their school was located. In addressing their question, Michelle (an author) highlighted that the geographic wards are not the same size in terms of land area (lines 6-7). This inconsistency in the data led the students to wonder whether each ward had the same number of people. They then began to discuss how both land area and population may influence the number of rat sightings reported, noting that "if there are more people there they might call even if there aren't actually more rats". The group eventually decided not to use this data source for their exploration, because they were unsure whether direct comparisons could be made across wards.

A different group began to question the validity and utility of the same regional rat report data for a different reason. Alyssa and Kathryn first examined patterns of change in rat sighting reports over time in their own ward (4) and wards nearby (1, 2, 3). They quickly noticed these data were quite noisy:

1	Alyssa:	Some have been dropping and some have been going higher.
2	Kathryn:	Or like, some go low here [*gestures to column reporting first year*
3		*of data*] and it goes up here [*moves to next year*]
4	Alyssa:	Or some go low, because like this one [*traces row for Ward 1 over*
5		*time*] went like low and then high, and then low again so they're
6		starting to like help more, and since they're calling and doing
7		something about it, they like [.] in 2013, 1, 2, and 3 had like the
8		most calls, and then the number 7 had the least amount of calls.

This excerpt marks the beginning of a conversation by the pair about the reliability of rat report data. These concerns emerged from the girls' attempts to explain fluctuations across wards over time, as noted by Kathryn in line 2, and geographic ward, as Alyssa highlighted in lines 4 and 5. Working to make sense of these patterns led the pair to engage more deeply with the potential limitations of sighting reports as a data collection method. Alyssa, in lines 6-8, proposed that residents of ward 1 were "calling and doing something about" the rats—which could explain both the high initial sighting reports, and their subsequent reduction. She also noticed an increase in rat sightings in Ward 7, which the pair noted housed many university students in the city. They proposed that college students were messy, and less likely to report rat sightings. These explanations exposed a flaw in the data source: a high number of calls could mark both community investment (in "calling to do something"), and divestment (a lack of care or unsanitary behavior). Eventually, Alyssa concluded that "there are too many reasons that we don't know for why people call" and decided that ward-by-ward sighting reports were not a reliable or helpful data source for understanding the citywide rat infestation.

Across the student groups for whom we had data, many discussed the limitations of phone reported sightings as a measure of rat population. Some questioned the correspondence between sightings and actual rat populations; others the characteristics of callers (age, occupation, gender, etc.) as this relates to who is likely to report a sighting. Of these groups, the two presented above most explicitly used these considerations to question the data's utility for making broader inferences about citywide rat population.

4.1.2 Exploring Diversity in Student Stories

By the third and last day of the activity, most groups had moved from exploring rat sighting trends by ward to evaluating the relationship between weather, time, and rat sighting reports citywide. This revealed a variety of ways of repurposing data, through summarizing and transforming it, to reflect the different mechanisms students suspected drove fluctuations in the regional rat report data. Below, Nikki and Dora explained to the classroom teacher why they decided to calculate the average temperature per *year* for their investigation, rather than seasons like many of their peers.

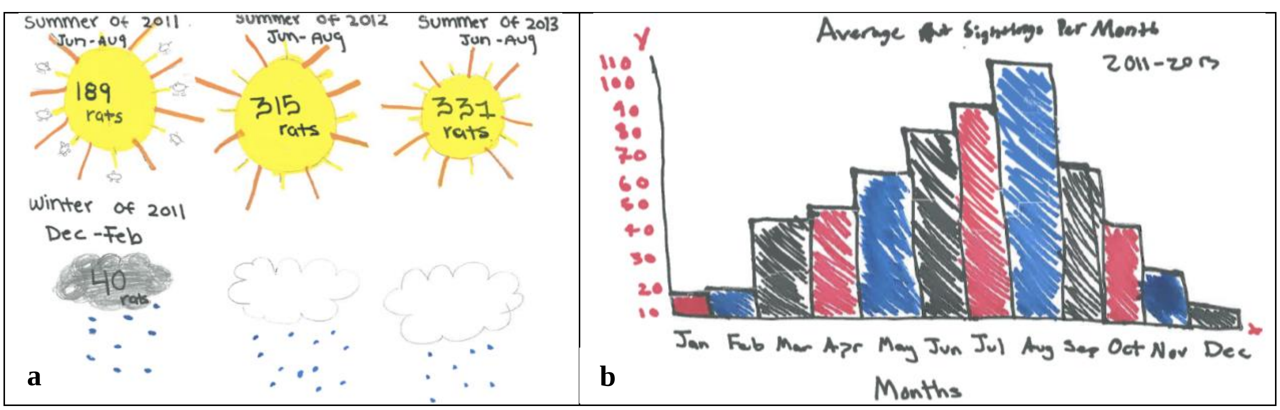
Nikki: So you know that they came the most in 2012, and that 2012 was the hottest year.

Ms. S*: How can you show that with the data?

Dora: We read this [*indicates article from the day before*] and 2012 was the hottest year [*points to calculations of mean temperature per year*], and there were also the most calls were in 2012. So it's probably because of the heat.

Another student group, interested in seasonal rather than yearly patterns, computed average temperatures for the months of December, January and February (winter) and June, July, and August (summer) *across* all three years. When asked to explain their work, Taj cited the regularity of month-to-month changes in temperature to justify the construction of these new means: "The averages in winter are different than in summer. Also you'll see the average here is at seventy [*points to two adjacent columns of monthly average temperatures and slowly indicates each month moving down*], but drops down in winter to like 40."

Overall, there were three structural assumptions that different groups explored. Some sought methods that allowed them to compare seasonal and annual differences by summarizing the data in a way that allowed for both cross-seasonal and cross-yearly comparison (Figure 2a). Others explored whether *season* affected rat populations, and students in this case, like Taj above, sought to find reasonable ways to summarize data across years to emphasize seasonal or monthly comparisons (Figures 2b, 2c). Still others, like Nikki and Dora above, explored *yearly* patterns in rat population change, either because they expected annual temperature fluctuations to affect rat population, or because they expected the rat population problem to become increasingly bad over time (Figure 2d). The first two approaches especially led to many conversations about how temperature can be summarized fairly across seasons. Students wondered whether the number of months included in the definition of different seasons mattered—could winter have 4 months and spring only 2?



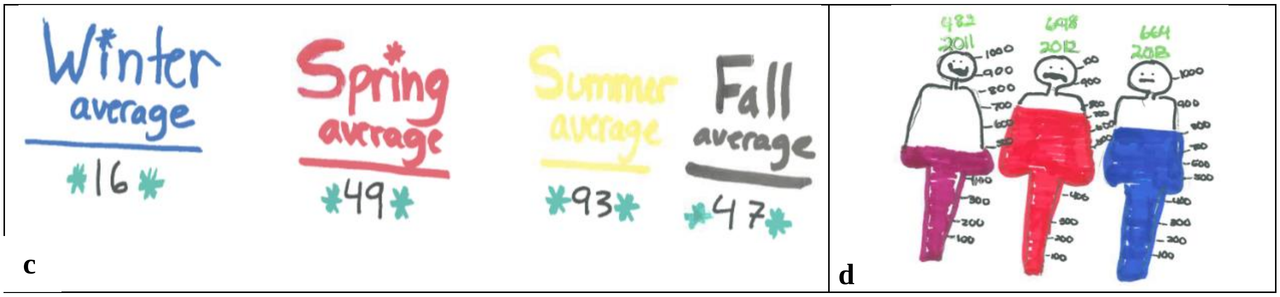


Figure 2. Students emphasized different structures and assumptions in their productions.

Although we did not do so during this enactment, revisiting students' productions suggests that juxtaposing different approaches can highlight the assumptions students make about relationships between data and context, and potential sources of uncertainty. Students who summarized their data across multiple years (as in Figures 2b, 2c) miss important annual differences that other students highlighted (Figures 2a, 2d). Similarly, those who explored monthly, rather than seasonal, patterns (Figure 2b) lent insight into which seasons exhibit more or less variation within-season, and hence more or less reliable summaries, than others (Figures 2a, 2c).

4.1.3 Supports for Storytelling and Synthesis

As noted above, several groups began to question the reliability of the rodent sightings per ward data early on in their investigations. Others, however, moved from maps and ward-specific data to weather data for a different reason: these data were simpler to represent using conventional statistical descriptors and graphs. We suspect this is related both to students' understandings of what was expected in class, and how to communicate findings clearly to others. Consider the exchange below with Fabian, who had earlier explored rat reports by ward with Sam. Here, the group is deciding how to represent total annual rat sightings per year.

Fabian: Do we have to put them in order?
Michelle*: I'd say do whatever —
Fabian: — because I saw this one [*indicates 2011*] is smaller, this one [*indicates 2013*] is bigger, and this one [*indicates 2012*] is biggest.

Michelle*: So, think about the article and what it is you want to make sense of.
Then does it make sense to order it by amount, or by year?
Fabian: By year. I think it'd be easier to say, oh, it's 2013. So I'm gonna do
it in order.

Fabian begins by asking what students "have to" do (line 1) when creating their graphic representations. After Michelle encourages Fabian to consider "what it is you want to make sense of", Fabian turns to consider how others might interpret his production and what it is "easier to say" (line 8). Like Fabian, several students asked whether their stories were required to include "histograms and percents", and whether they could "make something other than a bar chart". We also found several instances in our data of students making decisions about summarizing data in order to simplify the subsequent production of such graphs and charts.

4.2 Stories of Our City

As with the *Rats!* activity, students developed questions that were germane and could be explored using data. Though we did not include an introduction to practice statistical questioning in this case, we did provide sample investigative questions from the municipal website where we obtained the data. We also instructed students to ask questions that could not be answered by simply visiting the website (which featured summary visualizations of many datasets). Popular topic selections among students included birth and death, race, income, language, and poverty. Among the groups we focus on for this paper, two selected income, one public school enrollment, and one housing.

4.2.1 Making Sense of Data, Context, and Uncertainty

Again, we found that students began by working to locate themselves in data, moving between specific values and patterns in the available data and their experiences. When the data and students' experiences were inconsistent, this again led students to evaluate both the relationship between data and context, and whether data were collected and reported in a way that was valid and useful for their own investigations.

Anna and Geoff, analyzing public school trends, noted that enrollment was falling despite their knowledge that the citywide population was growing. To understand this surprising result, they retrieved public school enrollment data from neighboring communities with similar demographics. This allowed them to explore whether the drop in public school enrollment was representative of a broader regional trend, or whether families and students may be moving out of their own city to neighboring areas. It also led them to question why additional data about alternative (e.g., home-based or private) schooling was not collected or made available, despite its relevance to the topic.

Another group, Colin and Phil, explored historical trends in poverty rates in the city. However, the historical data they received only reported the *percent* of individuals and families living in poverty, not absolute values. Like Anna and Geoff, the pair recognized that the city population had been growing, and they were also surprised that the data had not indicated as steady an increase as they expected based on their own understanding of major city issues. They concluded that changes as reported in the data they were provided may not indicate corresponding changes in the absolute value of people living in poverty, masking the trends they were personally most concerned about. They asked the teacher for additional data reporting total population counts for the city. Then, they multiplied these total population values for the decades between 1980 and 2010 by the percent of individuals reported as living in poverty for each decade to calculate absolute number of people living in poverty in their city:

Phil: So in 1980, so this [*points to screen, where he calculated that 1% of the 1980 population is 953.22*] is 1% of the population. It's about a thousand people.

Colin: [*Repeats as he writes on worksheet*] One percent is about a

thousand people.
Phil: And it'll [*calculates 1% of 1990 population*], I think it'll stay about a thousand people for, uh. So if we do, so we could just, um, we could also have, we could use the percent, um, to find out, like we could do um, this, so wait. Are we still gonna use these [*points to human icons on screen*] to represent people?
Colin: Yeah.
Phil: So are they representing percent, or like people [*begins to calculate 1% of 2000 population*]?
Colin: So uh, one percent is about one thousand people. Write it in a key.
Phil: Yea. So if you write, if you write [*looks at Colin's notes*]
Colin: Approximately one thousand.
Phil: Okay, I see what you're saying. Because that'll stay pretty constant, let's see, the other extreme is, uh [*consults 2010 population*], I think it's 105,162. And it's still about a thousand.

By the end of this exchange, although Phil calculated different absolute population values for 1% in each decade they were exploring, Colin and Phil decided that a rough translation of 1% poverty rate = "about a thousand" people was sufficient. However, their initial surprise given the data, and their subsequent investigation, provided several opportunities to consider data and context as it relates to repurposing. Like Geoff and Anna, the group decided that they needed to merge their dataset with another in order to make better sense of the patterns within. The students also questioned, and then more deeply investigated, how the provided data's choice of measure (as percent of population) masked subtle fluctuations in poverty patterns—introducing a type of uncertainty that the students ultimately deemed acceptable for their analysis.

4.2.2 Exploring Diversity in Student Stories

On the last two days of the activity, students presented their results and representations to peers for feedback. Rayna and Julian were the first presenters and described an exploration of income level distribution for different population sectors (families, single individuals, people living together without children). As part of the presentation, Julian pointed out that "Family households have less [people with low income] and more high income." The classroom teacher

Ms. A then asked the group whether there might be an explanation for these differences in distributions. Rayna proposed that "in a family household there are more people who can have jobs," and Julian followed with "well if you don't have a family it might be because you don't have as much financial support yet."

Ms. A's early move to encourage students to develop conjectures to explain the patterns in their data appeared to take root among the student audience, who then began to ask questions and propose explanations for one another's findings. When Anna and Geoff presented their analysis of public schooling enrollment (Figure 3), they made careful distinctions between rates of change for enrollment in each city and absolute enrollment. They pointed out that although enrollment was shrinking in their own city but growing for others, that their city was still "doing better" in terms of total enrollment. Isaiah quickly questioned their use of absolute enrollment as a comparative measure of "doing better" in this way.

Isaiah: This is a large decrease. Do you have any idea why that is? You said we're doing better than [City 1] and [City 2], but… Doing better is the total number of people, even though we're decreasing, we are still high but [City 1] and [City 2] both have smaller populations.
Ms. A*: What else might you want to know to add to this? This group went above and beyond, they compared to other towns. So what else might you want to know?
Isaiah: I would want to compare the number of students to the total populations. And also, I would want to, so is this like, I assume this is —
Rayna: — Actually rather than comparing it to the total population, I'd suggest comparing it to the total population of children. Because one town might have more adults than children and vice versa.

As the session progressed, Isaiah often initiated critiques. Here, Ms. A took his critique as an opportunity to discuss how one might supplement their investigation with a new data source, as Anna and Geoff did (lines 6-8). Students also began to use findings and features from their *own* investigations to extend and challenge peers' findings. Rayna, who had explored income for population sectors including children, suggested that similar sectors might help Geoff and Anna create a fair measure of public school enrollment across cities (lines 12-14).

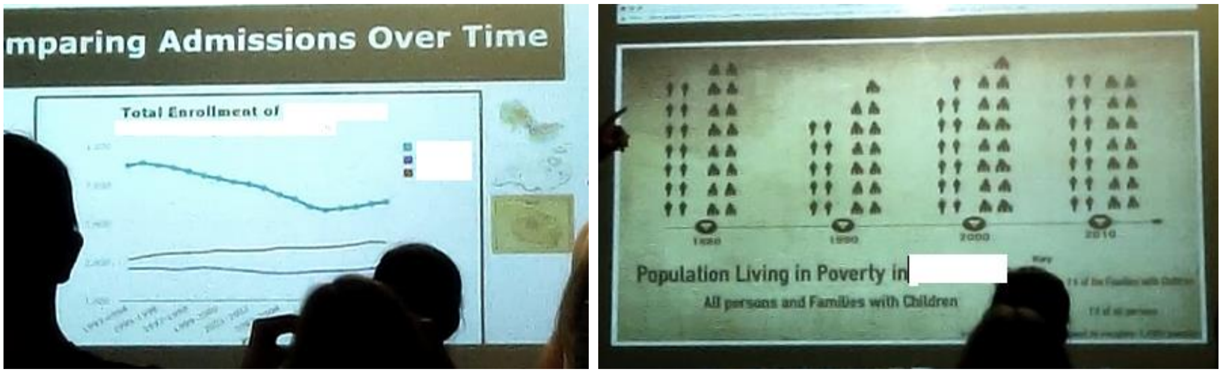


Figure 3. Left, Colin and Phil's investigation of poverty rates. Right, Geoff and Anna's exploration of public school enrollment.

This pattern of questioning and juxtaposing one another's data stories intensified, and an increasing number of students in the class participated. In the last presentation, Colin and Phil presented their investigation of poverty in the city. By this time, the pair had also made predictions about a possible continued decline in poverty rates for 2020, based on their findings from prior decades. Isaiah, again, initiated critique by asking Colin and Phil why they chose to make an argument based on extrapolating from patterns in their data, given their nature:

Isaiah: Why did you choose to extrapolate? Isn't that not a great idea? And also, what does 1% mean?
Phil: We actually checked this, it's about 1000 people, that's pretty consistent across years.
Sam: Do you know how the poverty line had adjusted? Hasn't it changed?
Phil: Maybe it went down and back up, that might explain the drop in the 1980s.
Ms. A*: Sam, can you explain to the group, for those of us who don't know, can you explain why you are asking about the poverty line, what that means?
Sydney: Also, when did rent control start in [this city]?
Colin: We did want to look at government programs.

This last presentation initiated a flurry of questions about the construction and interpretation of data, and about potential sources of uncertainty and paths for further exploration. Isaiah, echoing Colin and Phil's earlier concerns about what information may be lost when reporting percent rather than absolute value, questioned whether it was appropriate to "extrapolate" (line 1) from the data they have, and questioned what 1% of the population represented (line 2). Sam added that the definition of "poverty line" is a socially constructed and dynamic quantity (line 5); this suggests that the data might not be telling them anything useful about the experiences of city residents at all but rather about how poverty has been defined across time. Sydney, who had explored the cost of housing in her own project, began to propose other moderators of poverty, such as rent control (line 11).

4.2.3 Supporting Storytelling and Synthesis

Ms. A worked throughout the activity to renegotiate what counted as data analysis in this classroom. As in the *Rats!* activity, some students were initially unclear about what "counted" as appropriate data analysis in the classroom context. Putting students' stories in conversation offered Ms. A means to encourage them to question and use their own investigations of data to reason about the source, structure, and implications of data. This was apparent in her encouragement for students to seek additional data sources, understand one another's interpretations and explanations for findings, and emphasis on complementary insights gained from different analyses of the same datasets. Toward the end of this class, Ms. A did more explicit work to solidify this orientation toward data analysis as a collective investigative activity, with an emphasis on the bringing together of different student findings:

Ms. A*: Something I'm noticing is when doing these data visuals, people focus on one small piece. But then that's, what happens is people have questions about other things that are going on. Like, what's going on with the economy, or what's, what's the poverty line, how is the poverty line defined? So all, and, like, Emma's main question, about how many kids can actually be enrolled in the schools. So these data visuals, they make us question more, and make us think about things we can extend in our projects.

5. Discussion and Conclusions

The research questions guiding this study were: *What opportunities emerge for students to reason about the relationship between data, context, and uncertainty when they repurpose public data?* And, *How can these opportunities be supported?*

5.1 Opportunities for Reasoning About Data, Context, and Uncertainty

We found that many opportunities for reasoning were similar across both classroom enactments. To begin to build connections between data and context, students first tried to locate themselves in the data. In the *Rats!* activity, almost every group started looking at a map of their city, even when their original questions were not related to geographical information. Once they found where their school or homes were, their experiences in these locations generated discussion about the data available and triggered interesting considerations of sampling, representativeness, trustworthiness and usefulness of the data. In *Stories of Our City*, students compared patterns they found in the data to their own experiences within the city. This led Anna and Geoff to question what types of data were collected to construct the school enrollment dataset (e.g., were private or home schools included?). It also led Phil and Colin to explore whether reporting the poverty rate as percent of the population masked increasing overall numbers of people in poverty. This back-and-forth reflects findings reported in the literature whereby students first negotiate connections between data and context through a focus on specific cases, rather than aggregate patterns (Ben-Zvi & Aridor-Berger, 2015; Konold, Higgins, Russell, & Khalil, 2015).

Opportunities for students to explore the certainty and reliability of data emerged most frequently under two circumstances. The first was when patterns in data did not align with their own experiences of their communities. The second was when students worked to better align the datasets presented with their own questions; or, to understand other students' treatment of datasets in service of different questions. These themes are consistent with other literature on students' statistical reasoning (Ben-Zvi & Aridor-Berger, 2015; Konold et al., 2015; Pfannkuch, 2011), and suggest specific ways in which we might leverage powerful pedagogical models (Brown & Campione, 1994) in future classroom and activity designs.

We also found important differences across the two enactments. Sampling played an important role in *Rats!*, because a main variable—the number of rats in the city—could only be inferred from phoned citing reports. In contrast, *Stories of Our City* involved census and other count data (population and enrollment counts, income reports), and thus did not require the same types of inferences from sample to population. This led students to make sense of surprising or unknown patterns in the data in very different ways. Whereas in *Rats!* students "dove in" to question specific observations (public rat sighting reports, measures of temperature), in *Stories of Our City* they "stepped back" to question the types of measures used, the representativeness of their city relative to others, and causal factors that may extend across broader scopes of analysis.

Rats! was also more limited in scale and scope. This meant that the diversity of investigations that student groups pursued often involved different manipulations and analyses of the same data. *Stories of Our City* was broad to begin with, and further broadened as students sought additional data sources about neighboring cities. Thus, the data and findings in this case did not overlap datasets but rather underlying social and municipal factors (such as economics or migration). These differences led students to manipulate their data in very different ways. Students in *Rats!* often reorganized, summarized, or rejected data to better align them with their goals. Students in *Stories of Our City* recalculated, rescaled, or merged/supplemented data for these same reasons. These differences highlight some of the unique considerations that come from repurposing, rather than constructing, data (Ainley et al., 2015).

5.2 Classroom Supports

Both enactments also shed light on supports for learning data repurposing. One common instructional choice was the public sharing of students' work and findings. Even though the representational forms used across enactments and student groups were different (presentations, visual displays, text, posters), students' perspectives highlighted multiple treatments of the same or related data. These treatments, in turn, exposed issues related to measurement, sampling, representativeness, and appropriateness as they extended across different questions students were interested in. It also offered opportunities for teachers to support practices such as questioning and supplementing the data or understanding how constructs such as the definition of a poverty line might influence interpretations of the data and the phenomena they describe.

Despite the benefits of this public sharing, what students chose to include in these artifacts was limited based on what they expected to do in their classrooms. In the *Rats!* case, even though almost all students started their data explorations looking at the map, none of them included in their presentations how geography influenced the questions they pursued and the data they used. This reflects a tension between students' productive negotiation of data across their personal and data contexts on one hand, and the learning-experience context on the other (Pfannkuch et al., 2011). It also reflects our own need, as facilitators, to better identify, elicit, and take advantage of the emergent opportunities we recognize in student work.

5.3 Limitations and Future Work

These findings emerged from short exploratory studies and represent only a first step toward understanding how data repurposing can be supported in classroom settings. Our analyses focused on single classrooms, which limits the generalizability of our findings. Furthermore, our studies were planned in close collaboration with partner teachers and introduced facilitators into each classroom, offering more support than a typical classroom activity. We do not know many details about participating students' engagements with statistics and data analysis prior to these activities. Such engagements are likely to have influenced students' ways of reasoning about data, context, and uncertainty, as well as what sorts of statistical investigations they recognize as valued in the classroom. In future work, we intend to develop materials and methods that reduce the amount of additional facilitation needed to enact data repurposing activities in classrooms. We also look forward to investigating on a longer-term basis how data repurposing develops alongside and in interaction with other statistics and data modeling instructional trajectories.

5.4 Conclusions

An abundance of large, publicly-available datasets introduces new opportunities and challenges for data explorations and modeling in K-12 classrooms. Students now have access to datasets and data artifacts that would otherwise have been impossible for them to create on their own. This offers opportunities for richer explorations of a variety of topics, including those relevant to students' lives. However, students may know few details about how and for what purposes these data were collected. It is important to consider how students might thoughtfully approach and repurpose these resources, to make sense of persistent issues of measurement, uncertainty, variability, and representativeness in statistics. Repurposing also raises new issues related to data selection and manipulation such as recalculation, summarization, and data merging and purging.

Despite the preliminary nature of these findings, they do illuminate new paths for exploration in data modeling. Our study suggests students are capable of repurposing, and that there is considerable opportunity to study and support it in K-12 classroom instruction. There is still work to be done to understand how such opportunities can be systematically and reliably integrated into curricular materials and instruction. And, it is important to consider how data repurposing may develop over time, in interaction with other statistical and investigative practices. Overall, our findings suggest that putting data in explicit conversation with students' local knowledge; juxtaposing different data stories within and across groups; and explicitly negotiating classroom expectations about the value of personal experience in evaluating data can allow powerful opportunities for such reasoning to emerge.

Acknowledgements

Thanks to participating students, schools, teachers, and Jenna Conversano. This work was supported by a National Science Foundation grant (IIS-1350282) and Tufts University Faculty Research Fund. Recommendations do not necessarily reflect the views of the NSF, UC-Berkeley, or Tufts. We are grateful for feedback from the CoRE writing group and members of the 10th Statistical Reasoning, Thinking, and Literacy Research Forum (SRTL-10).

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