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Thinking with Data: A Cross-Disciplinary Approach to Teaching Data Literacy and Proportionality

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Abstract:

The Thinking with Data project (TWD) takes seriously the fundamental requirement that data literacy bridge disciplinary domains. The TWD project has designed and evaluated a set of four 2-week, integrated modules for cross-disciplinary implementation in 7th grade social studies, mathematics, science, and English language arts. We leveraged disciplinary standards in choosing the particular topics addressed with each module, with the goal of increasing student learning in the disciplines while also increasing cross-disciplinary data literacy. In this paper we describe our theoretical approach to designing and implementing these modules, report on our student learning gains in mathematics, and report on teacher reactions to the materials. Our quasi-experimental study provides strong evidence that the TWD approach builds data literacy while also allowing students to learn the core discipline-based content standards.

"We use data every day—to choose medications or health practices, to decide on a place to live, or to make judgments about education policy and practice. The newspapers and TV news are full of data about nutrition, side effects of popular drugs, and polls for current elections. Surely there is valuable information here, but how do you judge the reliability of what you read, see, or hear? This is no trivial skill—and we are not preparing students to make these critical and subtle distinctions." -- Andee Rubin, 2005

Introduction

Much has been written about the importance of understanding quantitative data in today's society (Briggs, 2002; Madison, 2002; Scheaffer, 2001; Steen, 2001). As implied in the quote above, understanding of most of today's societal concerns requires the use and interpretation of data (to the list above we can add concerns such as water and food scarcity, global warming, the use of genetically modified crops, etc.). Unfortunately, while data analysis has been included in mathematics education standards (NCTM, 2000) for a decade, it is too often relegated to calculating measures of central tendency and reading simple graphs and tables, without aiming for true data literacy.

This situation is perhaps not surprising. Mathematics textbooks are already "a mile wide and an inch deep" (Schmidt et al., 1999), and data literacy takes significant time to develop. In addition, true data literacy is neither a single discipline nor a subdiscipline of mathematics. This is most obvious in considering the role of the context of investigation: whereas in most mathematics "the context is part of the irrelevant detail…in data analysis, context provides meaning" (Cobb & Moore, 1997, 801). We cannot expect the context for data literacy to come solely from the mathematics classroom: true data literacy requires contributions from across the curriculum, preferably integrated across it.

Alas, integrating data literacy across the curriculum is not so easy, as this requirement conflicts with the current organization and culture of our school system, which continues to treat

the disciplines as separate and unrelated topics to be "covered" in 45-minute periods. The separation results in pedagogical cultures that miss opportunities to build on each other (Stevens et al., 2005; Wineburg & Grossman, 2000). Most math classes, for example, limit students to approaching mathematics as exercises in number manipulation (see Cobb & Bauersfeld, 1995), without thinking about real problems or pushing for evidence to back up claims (Kuhn, 1999). Unsurprisingly, students often fail to transfer and apply mathematical reasoning to understanding scientific content (Akatugba & Wallace, 1999; Aldridge, 1994) or exploring societal problems. Moreover, in social studies and English language arts, argumentation is often rhetorical rather than quantitative (Stodolsky & Grossman, 1995). As a result, the divisions between these cultures interfere with students building data literacy.

The Thinking with Data project (TWD) takes seriously the fundamental requirement that data literacy bridge the disciplinary domains. The TWD project has designed and evaluated a set of four 2-week, integrated modules for cross-disciplinary implementation in 7th grade social studies, mathematics, science, and English language arts. We have found that standards in all four subject areas address three broad categories of data literacy: formulating and answering data-based questions; using appropriate data, tools, and representations; and developing and evaluating data-based inferences & explanations. We have leveraged these similarities in choosing the overarching context as well as the particular topics addressed with each module, maintaining the goal of increasing student data literacy throughout.

In this paper we will describe our view of data literacy, describe the cross-disciplinary modules, discuss student learning gains, and report on how teachers across the disciplines responded to the requirement of using data across the curriculum. Our quasi-experimental study provides strong evidence that the TWD approach builds data literacy while also allowing students to learn standards-based mathematics content. Our teacher interview data shows that, given certain conditions, teachers from across the core disciplines are willing and able to integrate complex data into their teaching. We will then present conclusions and implications for future work.

Data Literacy

The goal of increasing student data literacy through a cross-disciplinary approach has two immediate, and somewhat obvious, implications in terms of teaching and learning mathematics. The first implication is that the relevant context should come from outside math, as mathematics teachers do not have the resources to devote to exploring important societal issues in a deep and meaningful way. In our analysis we have found that social studies is the most logical choice for supplying the context. The second implication is that mathematics learning should then infiltrate the other core disciplines, for instance by increasing the amount of data-based argumentation in English Language Arts. This approach allows us to increase the available time for data literacy (as it would no longer be constrained to only mathematics class), as well as increase the relevance of what students learn in mathematics class. There was one less-obvious implication, however: the content of the mathematics class now has to meet the needs of the other disciplines.

In analyzing how mathematics class could meet the needs of other disciplines, we had to reconsider what was meant by data literacy. Whereas the phrase *data literacy* often connotes images of students immersed in large volumes of data (and this is what we had in mind at the outset of the program), we have found that there is another view of data literacy that can help students make sense of the data encountered both in school and in "real life". In this view the creation of common measures, which can be used for comparison and argumentation, are at the

center of data literacy (Vahey et al., 2006). We have found that the analysis of many social studies contexts (as well as many contexts encountered through news reports, advertising, etc.) requires a transformation of data, from raw values (such as the total amount of water used by a set of countries, and the populations of those countries) to a measure that combines two quantities (Thompson & Thompson, 1992), such as a per capita measure (such as per capita water use). In this paper we take the perspective that this data transformation, and the arguments such a transformation enables, is a core aspect of data literacy.

While the notion of transforming data is a key understanding in its own right, we have found that data transformation can also provide a context for investigating proportional reasoning. That is, we do not focus on just any data transformation, but on those transformations that engage students in proportional reasoning. Proportionality is an essential middle-grades concept that can be used to make sense of a variety of mathematical, scientific, and societal situations, and is a key element in thinking with data (Rubin, 2005). When embodied in authentic situations, proportionality entails multiple entry points for children's reasoning (Kaput & West, 1994; Lehrer, Strom, & Confrey, 2002), and is fundamental to productive growth in mathematical reasoning (Lamon, 1994).

Overview of the Modules

We have found that world water issues provides a timely and compelling context for our building students' data literacy. In our unit students investigate the fair distribution and use of water in the Tigris/Euphrates watershed, and then investigate issues surrounding several watersheds in the US. This context is timely because issues surrounding water availability and quality are growing in urgency locally, nationally, and internationally. This context is compelling as all students can understand the importance of water, and this context bridges investigations in far-flung places with local concerns. Our unit also aims to be compelling by being based on the overriding theme of *fairness*. In particular, the social studies and mathematics modules focus on the fairness of measures as they relate to fair allocation and fair comparison, as well as the fairness of data representations. Evaluating fairness is a productive activity for middle school students when engaged in data analysis (Hancock et al., 1992; Lajoie et al., 1995; Vahey et. al, 2000), and fairness is almost always deeply related with proportionality. The question of fair allocation of resources, such as water, almost always drives toward the notion of an allocation that is proportional, such as the amount of water per number of families or people in a region. Similarly, fair comparison, such as in comparing water quality or use, rests on the development of proportional measures.

Figure 1: Water Distribution across Turkey, Syria, and Iraq

Country	Population in millions	Surface area in thousand km^2	Total renewable water resources In million $meters^3$
Iraq	25.1	438.3	75,420
Syria	16.8	184.2	26,260
Turkey	68.3	784.3	213,610

Students begin the TWD unit in the social studies module, where they use real-world data to explore water availability and use in Turkey, Syria, and Iraq, and to devise and defend fair ways of sharing available water resources between them (see Figure 1). We are aided in this goal by a

United Nations resolution that states, in part: "Watercourse States shall in their respective territories utilize an international watercourse in an **equitable and reasonable manner**."

Students next engage in the mathematics module, which is described in more detail below. In the mathematics module students investigate techniques of proportional reasoning and data analysis to expand on their social studies work and their data-based arguments for fair use. They also apply proportional reasoning in science-related contexts (such as salinity), and engage in data-based argumentation. In science, students analyze data to defend and/or dispute various hypotheses concerning water availability and quality in the Tigris/Euphrates basin, then apply similar approaches to understanding water issues in US watersheds. In science they also used the context of the Middle East to explore issues around water salinity and crop growth, and conducted an experiment in which they grew their own plants in soils with different salinity levels. The unit culminates in English language arts, where students use their research on US watersheds to identify major water issues and develop persuasive arguments around possible data-based solutions. In this context mathematics is a useful tool in helping to understand and solve a significant societal problem, in stark contrast to most students' perceptions of mathematics as disconnected from the problems of everyday life. While this description may indicate that each module was designed solely to serve students' mathematics learning, disciplinary experts designed the modules such that each addresses relevant disciplinary content standards, and teacher reports indicate that the modules achieved success in doing so.

We note that students begin their investigation in Social Studies, *before* they have engaged in mathematics class. This is in contrast to an approach in which the mathematics is taught first, and then this mathematics is applied in Social Studies. The decision to begin in Social Studies was a direct implication of the instructional framework that we chose for our unit, called Preparation for Future Learning (PFL) (Bransford & Schwartz, 1999).

Theoretical Framework: Preparation for Future Learning

In the PFL framework, students first *prepare* to learn an important concept by investigating a set of problems that are designed to highlight its structure. Instead of creating complete solutions, students come to understand the structure of the concept and internalize key dimensions of the situation. Students then engage in a formal learning activity in which they are introduced to a standard, generalized solution to their specific problem. This provides students the opportunity to reflect on both the context-bound solution and the abstracted knowledge. Students then practice and apply this new solution in a variety of contexts, again aiding in abstraction and reflection. PFL reverses the traditional lecture-and-apply process (Klahr & Nigam, 2004), and instead has students investigate a complex problem, and then learn the canonical solution. The PFL approach is consistent with the conceptual change literature, which shows that students must first recognize the existence of a problem, and then realize that their existing understandings are not adequate for creating a solution, before they are fully ready to learn difficult concepts (Lehrer & Schauble, 2002; Strike & Posner, 1992).

We applied a novel PFL approach across the modules. The social studies module, the first the students encounter, has two related goals. The first goal is to provide the deep context that is necessary for students to engage in true data literacy activities. The second is to provide the *preparation* for the mathematics module. In TWD, this preparation occurs by having students explore issues of fair allocation of water in the Tigris/Euphrates watershed. They manipulate real world data in charts and graphic representations, consistent with important social studies process standards, (NCSS, 1994). It is difficult, however, to create a fair solution without recourse to

per-capita-type measures, something students rarely generate spontaneously in social studies. Students thus students come into the mathematics module with an understanding of the need for proportional measures—that is, they are "prepared" for instruction in proportional reasoning.

Description of the mathematics module

After the social studies module students engage with the math module. The math module relies on the *preparation* activities from social studies, as students are prepared both affectively (that is, there is an answer to the question "why are we doing this?") and cognitively (that is, student recognize that simple, intuitive approaches don't lead to satisfactory solutions). The math module, like all the TWD modules, took 10 days of class time. In this section we describe three of they key activities in detail (an overview of the entire module is provided in Appendix A).

Day 1 Activity. On the first day students revisit the notion of fair allocation, through a simplified situation that is analogous to the water situation in the three countries. Students break into unequal size groups (in a class of 20, the suggested group sizes are 10, 6, and 4), and each group is given a number of tokens (50, 40, and 10, respectively). Each group first discusses how to distribute the tokens among the students in their group. Students typically decide to "deal" the token out individually to each person in the group (as if they were playing cards), and then find some way to split or ignore the remaining token(s). This is analogous to finding a way to distribute the water *within* a country.

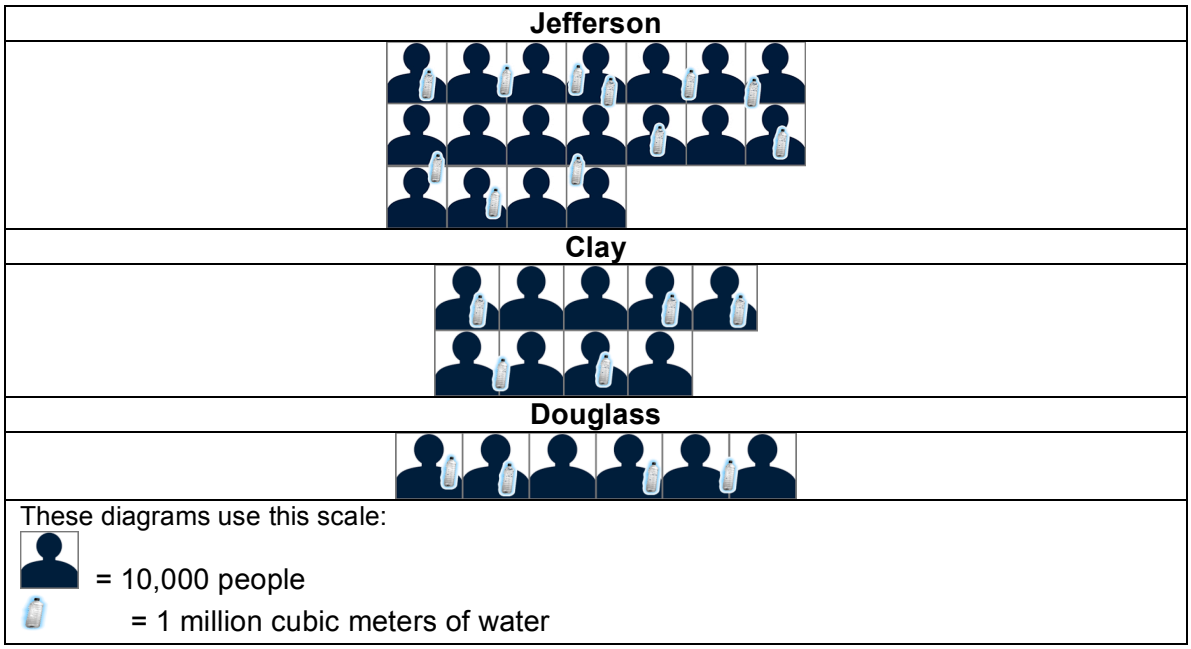
This is followed by a class discussion in which the distributions across different groups are compared. Through this activity students come to see that, although their group may have created a fair distribution, and there are intuitive reasons to think that the original distribution was fair (the largest group receives the most token, and the smallest group receives the fewest: this is analogous to the social studies situation), the people in some groups received far more tokens than the people in other groups. This activity reinforces the importance of creating a fair measure that takes into account the number of students and tokens in a formal manner. The class culminates in a discussion in which the goal is to have students use their experiences in social studies and in this activity to begin derive a measure that can allow for fair comparisons in this context. While some students arrive at the notion of a *per capita* measure of water distribution (that is, amount of water divided by the number of people), it is not necessary for the class to agree on this measure in this first day.

Day 2 Activity. On the second day students dive deeper into situations that are analogous to, but simpler than the social studies context, this time with the goal of coming to an understanding of the importance of formal *per capita* measures in making fair comparisons. Students are asked to compare water allocation across three fictional counties, and are given a graphic representation of the number of people and amount of water (Figure 2). To make this comparison, students are first asked to make a quick, non-quantitative judgment (they are not provided the legend shown in the figure).

Students are then asked to determine a way to quantitatively determine the relative allocations (again, without the legend). During this activity the teacher leads students to using a per capita measure. We note that, because the students are not provided a legend, they typically use the count of water bottles and people to derive their measure. Because of this, they cannot "deal" water bottles the way they dealt out tokens previously, as there are fewer water bottles than people. This further pushes students toward the necessity of the *per capita* measure. Students are then provided with the legend, and again calculate the *per capita* measure. This

time, however, they also must deal with different magnitudes in units, which is another requirement in using data found in the real-world.

Figure 2: Water Distribution across fictional counties



In lessons 3 – 8, which are not described in detail in this paper, students apply per capita measures to the actual data from social studies (Figure 1), discuss related measures such as salinity to compare the saltiness of samples of water of different sizes, and investigate the role of percents in making proportional comparisons. The module also has students consider instances when quantitative comparisons are not as relevant as political or social considerations (for instance, if Turkey claims that the water falls on their land, and so nobody else is entitled to it, no amount of quantitative reasoning will help: in order to counter such arguments one needs bodies like the United Nations, which created the watercourse agreement!).

Day 9 Activity. On the ninth day of the module, students use their understandings of proportional comparisons to investigate data based arguments. Students are provided with a table of data (Figure 3), and are asked to evaluate a set of arguments, all of which claim that the proposal is fair (Figure 4).

Figure 3: Proposed water allocation across three fictional counties

	Population (in thousands)	Surface Area (in sq km)	PROPOSED ALLOCATION Total Renewable Water Resources (in millions of cubic meters)
Richland	**150**	**250**	**30.5**
Putnam	**75**	**100**	**25.0**
Orange	**60**	**50**	**5.5**

Figure 4: Arguments claiming the above proposed water allocation is "fair".

Argument 1: This is fair because the county with the most land has the most people. Richland has the most people and it has the most land. Putnam has the second most people and the second most land. Orange has the least people and the least land.

Argument 2: This is a fair distribution of resources because Richland has the most people and it has the most water, Putnam has the second most people and second most water, and Orange has the least number of people and the most water.

Argument 3: This is a fair distribution of resources because Richland has the most land and it has the most water, Putnam has the second most land and the second most water, and Orange has the least land and the least water.

Argument 4: This is a fair distribution of resources because the per capita water distribution is the same in all three counties.

In this activity students apply three aspects of arguments: Is the argument factual (all arguments except 4 are factual); Does the argument use relevant data (assuming students agree that the most relevant data is number of people and amount of water, then arguments 1 and 3 do not, arguments 2 and 4 do); Is the argument complete (only argument 4 is complete, although it is inaccurate). By analyzing these arguments students recognize that arguments that have intuitive appeal may not be the strongest quantitative arguments. We argue that this recognition is a key aspect of becoming a data literate citizen. In Day 10 students then create their own proposal for these counties, and create an argument to describe why they have a "fair" solution.

Student Learning: Methods and Results

The TWD unit was tested in a quasi-experimental study that took place in the 2008-2009 school year. We chose a quasi-experimental study instead of a fully-powered randomized experiment due to the exploratory nature of this project: the primary goal of this project was to design materials and investigate the potential efficacy of our approach to determine if the approach is worthy of further study. In future research we may investigate the possibility of scaling up to a larger randomized experiment.

The TWD materials were tested with seventh grade students in two middle schools in northeast Ohio (School 1 and School 2). Both schools used a team teaching approach, which allowed us to have one teacher team in each school (social studies, mathematics, science and English language arts teachers) implement the unit. The other teams in the school then provided a natural comparison group. There were four seventh grade teams in School 1 and three seventh grade teams in School 2.

Data Sources:

The primary data sources collected in this study are:

1. A data literacy assessment that was administered at the beginning of the year and at the end of the year to all seventh grade students in both schools. This assessment was designed to measure students' (a) interpretation of complex tables of data and synthesis across tables; (b) understanding of arguments that used the tables of data; and (c) ability to create their own proportional measures.

2. A mathematics pre- and post-test and a science pre- and post-test, both of which were only administered to students in the TWD condition. While these assessments were not administered

to the comparison group, an analysis of learning gains can provide insight into the effectiveness of the materials in helping students to learn core disciplinary concepts.

3. Observation and interviews: At least one instance of every TWD lesson by every teacher was observed by an experienced classroom observer (81 total observations), using a semi-structured observation format. All TWD teachers were interviewed at the end of the unit.

Results:

An analysis comparing pre- post-test gains on the data literacy assessment yielded a t-statistic of $t(156.273) = 10.750$, $p < .001$, with an effect size of Cohen's $d = 1.24$ (very large effect). Both schools showed a statistically significant difference in gain scores between the TWD and non-TWD conditions. When considering questions individually, student scores improved the most on those items that required higher order thinking skills such as data interpretation across multiple tables and calculation of proportional data. This provides support for the argument that the TWD materials and the PFL approach aid in the development of data literacy skills among middle school students.

As an example of the type of learning exhibited by the data literacy assessment, students were provided with a textual description of changes to the High Plains (Ogallala) Aquifer (note that aquifers, and the concerns surrounding depleting an aquifer, were investigated in Science class). Students were provided the table found in Figure 5 as part of the context, and were asked to complete the table in Figure 6 and discuss the benefits of analyzing the data on a *per year* basis. Students in the TWD unit were able to better complete the table, as well as discuss the benefits of accurate *per year* comparisons.

Our analysis also shows statistically significant gains in learning disciplinary content in math and science. Due to inconsistencies in test administration, only two items could be scored on the Math test for School 1; both items were based on argumentation, and showed statistically significant gains ($Z = 3.16$ and $Z = 4.70$ respectively). Students in School 2 showed statistically significant gains across the Math test, $t(24) = 4.899$, $p < .001$, $d = .56$ (medium effect). In Science, students in both schools showed statistically significant gains with large effect sizes.

Figure 5: Table provided in Data Literacy assessment showing aquifer changes

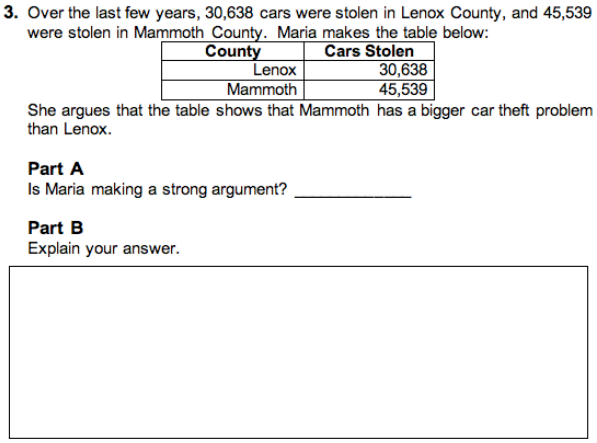
	Percentage of aquifer water	1950-1980 water level change in ft	1980-1995 water level change in ft	1996 water level change in ft
Colorado	3.7	-4.2	-5.9	+0.15
Kansas	9.9	-9.9	-8.0	+0.23
Nebraska	65.5	0.0	+2.3	+0.58
New Mexico	1.5	-9.8	-4.0	-0.65
Oklahoma	3.4	-11.3	-2.7	+0.70
South Dakota	1.8	0.0	+3.1	+0.82
Texas	12.0	-33.7	-7.4	-0.98
Wyoming	2.2	0.0	-1.5	-0.24
High Plains Aquifer	**100**	**-9.9**	**-0.33**	**+.08**

Figure 6: Table provided in Data Literacy assessment for per-year analysis

State	1950-1980 water level change in feet	1980-1995 water level change in feet	1950-1980 Change PER YEAR in water level in feet	1980-1995 Change PER YEAR in water level in feet
Colorado	-4.2	-5.9		
Kansas	-9.9	-8.0		
Nebraska	0.0	+2.3		
New Mexico	-9.8	-4.0		
Oklahoma	-11.3	-2.7		
South Dakota	0.0	+3.1		
Texas	-33.7	-7.4		
Wyoming	0.0	-1.5		

An example of an argumentation question is found in Figure 7. For this question the students had to analyze a data-based argument in which they are not provided with an adequate amount of data. That is, in order to make the required comparison a *per capita* measure is needed, but the population (or any other reasonable baseline number) is not provided.

Figure 7: Data-based argumentation question



3. Over the last few years, 30,638 cars were stolen in Lenox County, and 45,539 were stolen in Mammoth County. Maria makes the table below:

County	Cars Stolen
Lenox	30,638
Mammoth	45,539

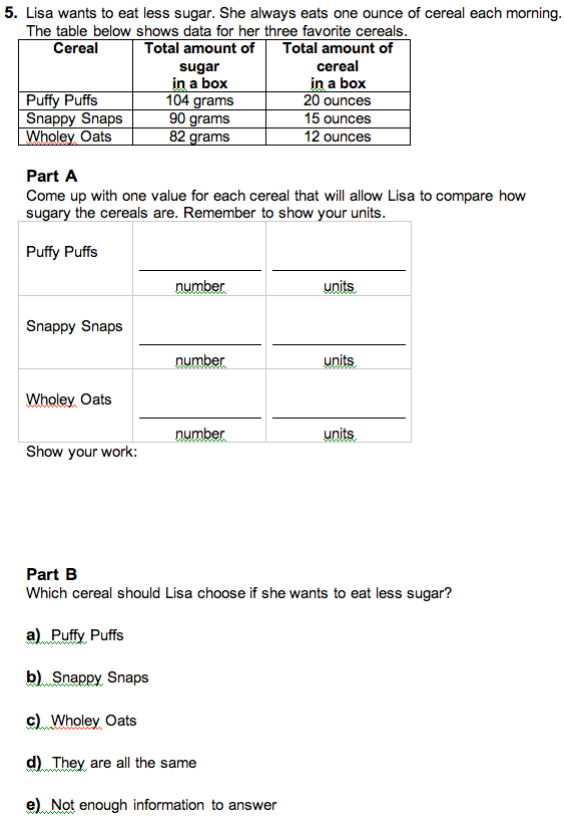
She argues that the table shows that Mammoth has a bigger car theft problem than Lenox.

Part A
Is Maria making a strong argument? _____

Part B
Explain your answer.

Figure 8 shows a question in which Part A requires the calculation of a proportional measure. In this questions students must either calculate the amount of sugar per ounce of cereal, or amount of cereal per ounce of sugar. While either calculation is acceptable, the students must then show that they can use their calculated measure by answering Part B of the question.

Figure 8: Calculate a proportional measure question



5. Lisa wants to eat less sugar. She always eats one ounce of cereal each morning. The table below shows data for her three favorite cereals.

Cereal	Total amount of sugar in a box	Total amount of cereal in a box
Puffy Puffs	104 grams	20 ounces
Snappy Snaps	90 grams	15 ounces
Wholey Oats	82 grams	12 ounces

Part A

Come up with one value for each cereal that will allow Lisa to compare how sugary the cereals are. Remember to show your units.

Puffy Puffs	_____ number	_____ units
Snappy Snaps	_____ number	_____ units
Wholey Oats	_____ number	_____ units

Show your work:

Part B

Which cereal should Lisa choose if she wants to eat less sugar?

a) Puffy Puffs

b) Snappy Snaps

c) Wholey Oats

d) They are all the same

e) Not enough information to answer

Based on these results we can confidently state that students in the TWD condition were able to engage in more sophisticated data literacy activities as a result of the TWD unit, while also learning important discipline-specific content.

Teachers and Data Literacy: Reactions to math across the curriculum

Given the successful student learning, we next investigate the teacher perspective on using the TWD materials. In order to understand how our approach to cross-disciplinary data literacy could become more widely implemented, we must understand the reactions of the teachers who would be responsible for implementing the materials. Through an analysis of our teacher interviews we report on the key benefits and drawbacks of using data across the curriculum. In our analysis four key themes emerged: connections across the curriculum; the content and timing; the use of data; and the organization of school.

Connections across the curriculum:

Teachers were generally enthusiastic about the cross curricular connections. Teachers stated that students were able to apply their understandings from the prior classes to their own discipline, and the depth of knowledge was useful. This seemed especially valuable in English Language Arts. One exception is the social studies teacher: because social studies was the first module, and the goal was to *prepare* students for other modules, the social studies teacher was not sure that the students were going to learn what he wanted them to. We also note that some teachers felt that the connections were valuable, but were not absolutely necessary: the module could have been done in math with only a short introduction to the context.

Social Studies Teacher:
I think the initial, the central idea is wonderful, the overall theme is great. They walked away saying, "Yes, there's an issue with water," they need to share it, you know, it's not a simple problem and not a simple solution.

Social Studies Teacher:
They got some things, like the big picture, that there was a limited amount of water that you needed to distribute between three countries and they got that… at this point I felt like they didn't have a clear, concise picture and the last questions on the water summit worksheet that they had to fill out was, okay, now, based on everything you've learned, how would you allocate this water fairly, how would you divide it up fairly? And the kids still had no clue… I mean, that was the problem, the kids didn't see the solution to this problem in the social studies unit, it was kind of left hanging, you know, you're going to understand this in math.

Math Teacher:
[In social studies] they created a treaty and what they felt was fair, and then they brought it to math and we looked at their treaty and once we did their calculations, we were able to see that 'maybe it wasn't fair...And transfer from social studies, that was definitely used in a couple of the lessons.

Math Teacher:
It was good that I understood what they did in social studies... I think the social studies gave them a good background of it. But um if we just did the math part, I think the kids would have been fine if I would have just had to explain or maybe pull down the map. [Social Studies and Math] didn't have to be together but it was beneficial that they were.

Science Teacher:
Iit was interesting because we started off in the Middle East and then we moved to the United States and I think it just...learning what they are going through in the Middle East and what does a damn do to the environment and how does salinity effect growth in plants. Like it was interesting because it was both hands on because they were able to plant their seeds and actually work with the salt waters versus the fresh waters so we were always going back to that hands on experiment. That was a good reference. I don't think that they really understood, they would say 'mine isn't growing as much as hers.' Well, why is that? And like, it kind of got the wheels turning right from the get-go. And as we started to get the informational stuff, I think they started to make some connections

English Language Arts Teacher:
After having so many weeks on the watersheds, these kids knew much more than I ever did on watershed, so the knowledge base was there so I think that helped them…I always try to teach them that whenever you write or whenever you speak, you have to assume that the listener or the reader knows nothing, and in this case it was pretty much true. So when they would write on this, I would say to them that "I don't know what an aquifer is" or, "I don't know what this is" or, " I don't know what this means. What does this mean?" And so I was able to point out their weaknesses and get them to expound more.

Content and Timing:

Overall, the teachers felt that the materials addressed important topics in their grade level standards. The one exception again was Social Studies, in part because the social studies standards had changed from the time the project began to the time it was implemented in these classrooms. However even for those teachers who felt that the standards were appropriate, the precise timing of the materials in the school year was often problematic. Timing issues may prove to be a major obstacle for this project, as the sequence of modules (first social studies, then math, then science, then ELA) is assumed in the materials, and this sequence puts significant

constraints on when in the school year each module can be taught. The one (perhaps surprising) area in which timing didn't seem to be an issue was in English Language Arts. The data-based argumentation seemed to fit in well with their end-of-year plans, and the overall timing of the unit seemed appropriate.

Social Studies Teacher:
I should have already been done with Greece at the end of this grading period and the grading period's ending on Halloween and we haven't started Greece yet… Overall, I just wouldn't teach it next year or the following year because it doesn't meet my historical standards, it's not what I need to teach and it's put me behind

Math Teacher:
It fit in my curriculum... I had to split my algebra material in half. So it would be beneficial if I was actually teaching this stuff, decimals, percentages, per capita…Or have this as an intro to that unit or after that unit. Like a post thing like 'we just learned a whole unit of this, here is a real world example'.

Science Teacher:
I would probably put it after my environmental science unit, not in the middle… I like stopped, started this, stop again and continue what I was teaching

Science Teacher:
And no, I mean, I...how do I explain that...for example I had to explain what the process of osmosis is. Which I do later in the year, but to have them understand how the salt water is effecting the plants, I had to fit that in now.

English Language Arts Teacher:
I was surprised. I thought it would take over two weeks and it took ten days to the day... I think because they came to me with so much knowledge, it went much quicker. It was perfect, because when I do a writing essay, it is always a week. It is graphic organize, write the rough draft, topic sentence, prepositional phrase, peer edit, use your thesaurus--that is always a week and this [writing the essay] was exactly a week.

English Language Arts Teacher:
Well we are all realistically OAT [Ohio Achievement Test] driven and I think it is perfect for that...You are really getting to think on one topic about the social studies, about the science, about the math aspect, about the presentation aspect--on one topic about watersheds--you are getting them to think in four different arenas and boy is that training the mind. We did really well. I am real curious to see what our results would be. When we met with the class, we were like 'holy cow.'

The use of data:

The use of data was widely acknowledged as a significant benefit to this project. Teachers in all the disciplines discussed the benefits to using data, and with the most enthusiasm in English Language Arts. While the Social Studies teacher noted that data use is part of their standards, there was still concern about having "a lot of math", and not being rooted in the historical standards for the grade level.

Social Studies Teacher:
I felt like it was a lot of math, too, in social studies, although working with graphs and whatnot can be social studies related. And for the standards aspect, I understand where it hits the standards, but it's not so much the historical standards in my class, like, we don't

teach about that region, and if they did - we actually learn about that region in 6th grade, and they learn about it as Mesopotamia and not the current region.

Math Teacher:
We have struggled to get to [data interpretation] by the end of the year because I try to get everything done before the state test and then the after the state test you still have a lot of the curriculum left about 25% and data is always last. I don't know why.

Science Teacher:
The OAT has a ton of graphs in the science part of it. There are tables and graphs and they have to look at the table and graph and the picture and decipher what is going on in it. And that is what the whole program was...So they really had to look at the map and read it and then figure out what the question is asking and then answer it.

English Language Arts Teacher:
It was content-based, like data based, that I had not done. I had never done data-based writing, it was geared towards another subject, so this was so valuable. That if we don't do this project again, which I hope we do, I would probably would replicate it with another thing. So if you guys are doing a big thing in science or social studies, let's switch the classes for two weeks and let me do the writing and speaking on the topic. Yes. ***This is really the best set of essays I've ever got and this is probably one of the lowest sets of students I've ever had…Sixteen years, I don't think I ever got an essay that good****.*

The organization of school:

While only mentioned by English Language Arts teachers, the organization of the school day presents a significant challenge to the program. The program was only implemented in schools that were already committed to a team teaching schedule, so, for instance, all students who had Teacher X for Social Studies would have Teacher Y for math. This choice was made to minimize conflicts with traditional school organizational issues. However, we found that even within the bounds of team teaching, there could be conflicts with students in specialized pull-out classes, and having students in different classes, even within one teaching team, could be problematic for cross-disciplinary projects. We also found that some teachers found a way to work around these obstacles.

English Language Arts Teacher:
They are not in the same classes together all day. Like the group that they had in science class, when they came to language they weren't with the same people. They might have one group member in here. Then they didn't even have group members to back up the information that they had worked with in science. Some of our math kids in math class go to different math teachers during the day. So they miss out on the math part of the module.

English Language Arts Teacher:
In science, she made the groups who had to use the findings in social studies and math and look up future stuff in science. So she and I literally for two weeks traded classes because there was no way they had to work with their science group. So whenever she taught science, they came to me and whenever I taught language arts, they came to her.

Conclusions

While the importance of a cross-disciplinary approach to data literacy instruction is widely recognized, a theoretically sound approach to providing such instruction is still lacking. This study provides a theoretically and empirically grounded basis for increasing the use of real-world

data and developing students' data literacy across the curriculum, providing a benchmark against which other such efforts can be measured.

This study is also significant in that we created and investigated the effectiveness of a curriculum based on the PFL framework of teaching and learning. We found that *preparing* students can occur in one curricular context with the *learning* activity occurring in another, strengthening the plausibility of claims that PFL uncovers a general mechanism of transfer (Bransford & Schwartz, 1999).

We also found that, while there may still be some obstacles to implementing this approach on a wide scale, teachers experience many benefits to this cross disciplinary approach. Perhaps surprisingly, the biggest impact on to creating a cross disciplinary approach to data literacy may be in the area of argumentation within English Language Arts. With further work on refining these materials to minimize some of the obstacles, our approach may be one that can scale to a wide range of teachers and students, and impact student learning across the disciplines.

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Appendix A: Overview of the Math Module

Day 1	Day 2	Day 3	Day 4	Day 5
1. Share the Water Fairly **Topics:** • Introduction to fairness • Link to SS **Activities:** Students break into 3 unequally sized groups, determine how to share beans (representing water), then determine if the allocation was fair both within their group and within the class.	**2. Who Has the Most Water?** **Topics:** • Per capita • Ratios, fractions, and decimals **Activities:** Students investigate which of 3 counties has the most water per capita, first without a legend, then with a legend, and compare the results.	**3. Which Is Saltier?** **Topics:** • Evaluating the saltiness of water **Activities:** Students investigate which of 6 water sources are least/most salty. This is done by creating a salinity measure, which is similar to our per capita measure from previous classes.	**4. What Is Fair?** **Topics:** • Per capita as a fair or equitable measure **Activities:** Students develop per capita measures to evaluate the fairness of the current water allocation in Iraq, Syria, and Turkey, then compare it to a fictitious proposal of water allocation.	**5. Regional Per Capita** **Topics:** • Regional per capita **Activities:** Students find an equitable solution for the region by using total water and total population to create a regional per capita (relates to Day 1)
Day 6	**Day 7**	**Day 8**	**Day 9**	**Day 10**
6. Dealing with Change **Topics:** • Percents (review, assumes students have already had exposure to percents) **Activities:** Students revise water allocations from per capita to percent to anticipate changing conditions.	**7. Sharing with Percents** **Topics:** • Percents **Activities:** Students use percents to share water under changed conditions and share resources other than water.	**8. Ears in the City** **Topics:** • Per capita • Percent **Activities:** Students use census data to compare the (1) corn production and (2) proportion of people living in urban areas in different states.	**9. Evaluating Arguments** **Topics:** • Evaluating the validity of mathematical arguments **Activities:** Students determine if mathematical arguments are factual, complete, and use relevant data.	**10. Creating an Argument** **Topics:** • Creating valid mathematical arguments **Activities:** Students use per capita or percent to fairly divide water for an imaginary region, and determine the safety for this region given tourist mugging data. They support the math with valid written arguments.