Mathematizing Middle School: Results From a Cross-Disciplinary Study of Data Literacy

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Introduction

“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.” –Rubin (2005)

Much has been written about the importance of understanding quantitative data in today’s society (Briggs, 2002; Madison, 2002; Scheaffer, 2001; Steen, 2001). Unfortunately, the realization of this importance has not translated into changes in classroom practice. While there has been significant research on the teaching and learning of data analysis and probability (e.g. Konold & Higgins, in press; Lehrer & Schauble, 2002) and while we have seen the inclusion of data analysis in mathematics education standards (NCTM, 2000), data analysis is still too often relegated to calculating measures of central tendency and reading graphs and tables. Indeed, Rubin (2005, p 22) writes, “‘Numerical literacy’ is woefully incomplete without ‘data literacy,’ yet we shortchange most students by leaving these topics out of the common series of math courses.”

While unfortunate, this situation is perhaps inevitable. Mathematics textbooks are already “a mile wide and an inch deep” (Schmidt, 1999), and data literacy takes significant time to develop. Data literacy includes the ability to: formulate and answer questions using data as part of evidence-based thinking; use appropriate data, tools, and representations to support this thinking; interpret information from data; develop and evaluate data-based inferences and explanations; and use data to solve real problems and communicate their solutions. As such, true data literacy is neither a single discipline nor a subdiscipline of mathematics (Briggs, 2002; Madison, 2002; Scheaffer, 2001; Steen, 2001).

To experience true data literacy, students must be deeply anchored in context. This context is required to inform the types of arguments and analyses that are relevant to solving important problems. Whereas in most mathematics “the context is part of the irrelevant detail…in data analysis, context provides meaning” (Cobb & Moore, 1997, pg. 801). We cannot expect this context to come solely from the mathematics classroom. Furthermore, the importance of data literacy has been recognized across the disciplinary standards (see Table 1), providing a basis for an interdisciplinary treatment of data. True data literacy requires contributions from across the curriculum.

This requirement conflicts with the organization of our school system, which continues to treat the disciplines as separate, 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., in press; Wineburg & Grossman, 2000). Most math classes, for example, limit students to approaching mathematics as exercises in number manipulation (see Cobb & Bauersfeld, 1995), rather than opportunities to think about real problems or push for evidence to back up claims (Kuhn, 1999). Consequently, students often fail to transfer and apply mathematical reasoning to understanding scientific content (Aldridge, 1994; Akatugba & Wallace, 1999) or exploring societal problems. In social studies and English language arts, argumentation is rhetorical rather than quantitative (Stodolsky & Grossman, 1995). The divisions between these cultures interfere with students’ building data literacy specifically because they fail to engage students in rich, realistic interdisciplinary contexts that require them to use diverse analytical approaches for evaluating different forms of data and evidence.

In this paper we discuss a pilot study in which we investigate bridging the disciplines of social studies and mathematics to help students learn important aspects of data literacy. We view this pilot as an important step in a larger research program that investigates the learning progression, and the concomitant learning mechanisms required to increase the data literacy of our students from the early years through High School while meeting standards related to analysis of data and evidence across the disciplines (Table 1).

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<tr>
<th>Data Literacy Requirement</th>
<th>Middle School Math Standards (NCTM)</th>
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<tbody>
<tr>
<td>Formulate and answer data-based questions</td>
<td>“Formulate questions, design studies, &amp; collect data about a characteristic shared by two populations or different characteristics within one population.”</td>
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<tr>
<td>Use appropriate data, tools, and representations</td>
<td>“Select, create, &amp; use appropriate graphical representations of data; discuss &amp; understand the correspondence between data sets &amp; their graphical representations.”</td>
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<tr>
<td>Develop and evaluate data based inferences and explanations</td>
<td>“Use observations about differences between two or more samples to make conjectures about the populations; use conjectures to formulate new questions &amp; studies to answer them.”</td>
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<th>Middle School SS Standards (NCSS)</th>
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<td>Formulate historical questions, obtain historical data, question &amp; identify gaps in data, &amp; construct sound historical interpretations.”</td>
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<td>Use appropriate geographic tools such as atlases, data bases, systems, charts, graphs, &amp; maps to generate, manipulate, &amp; interpret information.”</td>
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<td>“Use observations about differences between two or more samples to make conjectures about the populations; use conjectures to formulate new questions &amp; studies to answer them.”</td>
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<th>Middle School Science Standards (NSES)</th>
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<td>“Identify questions that can be answered through scientific investigations. Develop the ability to refine &amp; refocus broad &amp; ill-defined questions.”</td>
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<td>“Use appropriate tools &amp; techniques to gather, analyze, &amp; interpret data; the use of which, including mathematics, will be guided by the question asked &amp; the investigations students design.”</td>
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<td>“Encourage increasingly abstract thought as learners use data &amp; apply skills in analyzing human behavior in relation to its physical &amp; cultural environments.”</td>
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<td>“Students can learn to formulate questions, design &amp; execute investigations, interpret data, use evidence to generate explanations, propose alternative explanations, &amp; critique explanations &amp; procedures.”</td>
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<th>Middle School ELA Standards (NCTE)</th>
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<td>“Students conduct research on issues &amp; interests by generating ideas &amp; questions, &amp; by posing problems.”</td>
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<td>“They gather, evaluate, &amp; synthesize data from a variety of sources (e.g., print &amp; non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose &amp; audience.”</td>
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<tr>
<td>“Students use spoken, written, &amp; visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, &amp; the exchange of information).”</td>
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Table 1: Aspects of data literacy found across the curriculum

Our Approach and Research Questions

We take an approach to teaching data literacy that attempts to bridge disciplinary divisions by applying and investigating the Preparation for Future Learning framework (PFL; Bransford &
Schwartz, 2000). PFL is based on a reconceptualization of transfer: instead of expecting that students can directly transfer skills from one situation to another, PFL suggests that instruction should actively prepare students to learn in new settings and contexts. PFL introduces students to a concept by having them investigate a set of problems that highlight the structure of the concept. Instead of creating complete solutions in this activity, students come to understand the structure of the concept, and internalize key dimensions of the situation. Later, in a formal learning activity, students are introduced to a standard solution, which they practice and apply in a variety of contexts. This prescription reverses the traditional lecture-and-apply process (Klahr & Nigam, 2004) and aligns with research that shows that students are more likely to learn when they have recognized the existence of a problem before being presented with a solution (Lehrer & Schauble, 2000). It is also consistent with the conceptual change literature, which shows that students must first understand that there is a problem with their current thinking, and then realize that their existing concepts are not adequate for creating a solution, before they are fully ready to learn scientific concepts (Strike & Posner, 1992).

In our study students conducted investigations using quantitative data in social studies (the preparation activity) and then learned the appropriate data analysis techniques in mathematics class (the learning activity). By preparing in the context of social studies, students understand the meaning of the investigations and come to understand the need for a mathematical solution, all while investigating important societal phenomena. In addition, the social studies teacher is not responsible for teaching the math concepts: the quantitative reasoning that is employed in social studies is consistent with social studies standards. We expect that, by engaging in the formal learning activity in mathematics, students will develop not only a deep understanding of the relevant data literacy techniques, but also will develop a stronger capacity to transfer their understanding to other situations.

Our PFL-based approach is consistent with the mathematics education literature on teaching data analysis. Data analysis instruction is most productive when it is embedded in contexts of genuine inquiry (Feldman et al., 2000; Lehrer & Schauble, 2002), promotes reflective discourse (Feldman et al., 2000; McClain et al., 2000), and fosters students’ understanding that data can be queried to help them make informed decisions about relevant problems and situations (Lehrer & Schauble, 2002).

This pilot project set out to lay the groundwork needed to test the following research question:

- Will the PFL approach, implemented in a public school setting, result in increased data analysis skills in mathematics and increased data literacy in social studies?

To inform our understanding of the effectiveness of the PFL framework, we also considered the following:

- How do variations in implementation affect learning outcomes?
- Can students prepare to learn mathematics in social studies activities?

**Classroom Content**

Our classroom implementation, which lasted 3 weeks, included all three sixth-grade mathematics and all three sixth-grade social studies teachers in a public middle school in Ohio.
This school uses a team-based teaching approach, so all students who have the same social studies teacher also have the same math teacher.

In creating classroom materials, we integrated research on data literacy, data analysis, and proportional reasoning. The social studies context focused on problems of water availability in the Middle East and required that students make sense of measures such as *per capita* water availability, as well as use appropriate representations (maps with legends, pictographs, and bar charts) in argumentation. We adapted to the mathematics teachers’ data literacy goals by drawing links between *per capita* measures to the more foundational area of *proportional reasoning* in mathematics. Our learning goals in designing the inter-disciplinary PFL activities were to give students opportunities to:

**Investigate real problems.** Teachers introduced complex societal problems to students in social studies class. Students were to imagine that they worked for an international organization and had to decide if the water in the Middle East is divided “fairly” among countries. Students were instructed to create a method that allowed a fair comparison across countries. Students were presented authentic descriptive information about each of the countries, including measures of water availability and population. This was the preparation activity. Throughout, the students did not receive explicit instruction about the concept of *per capita* or the necessity to include population in their solution. Students also shared their methods, further preparing them for the learning activity (see Schwartz & Martin, 2004). As it has been found productive in prior PFL studies (Schwartz & Martin, 2004), the teachers were told to prompt students to reflect on the generalizability of their solution.

**Formulate and answer data-based questions.** Students formulated and later answered questions based on their investigation of water availability data in social studies. These questions were deeply linked to core disciplinary content knowledge, and data analysis techniques learned in mathematics are applied to support student investigations.

**Use appropriate data, tools, and representations.** Students learn in mathematics that data from social studies contexts often requires transformation from raw values (such as the amount of water used by a set of countries or their gross domestic products) to measures that combine two quantities such as a *per capita* measure (Thompson & Thompson, 1992). While the notion of transforming data to make it more meaningful is a key understanding in its own right, central to the work of creating common measures is the role of 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).

**Communicate solutions.** Students used the results of their investigations in projects designed to explain the problem and their proposed solutions. A key aspect of this was understanding important characteristics of different graphical representations, such as maps with legends, pictographs, and bar charts, and the importance of scale when using such representations.

Figure 1 shows a schematic of our approach: students moved from understanding the overall context in social studies, to a preparation activity in social studies that used quantitative data in investigating an important question, to a learning activity in mathematics. After this learning activity, students then applied their new mathematical understanding in the investigation of a
new social studies question. Figure 2 shows the progression of events across mathematics and social studies classes.

A description of the key social studies lessons follows.

“Intro and water use units” lesson. This unit was designed to introduce students to the notion of water use, the issues facing the middle east, and have students develop a baseline for thinking about how to compare water use across people, towns, and countries. The goal was to discuss how individuals use water, and how a city uses water as a whole, leading to a conversation of “how much water each person uses”. This is an idea that is revisited throughout the unit, and is key to our introduction of proportional reasoning.

Map Lessons. In these lessons students filled in maps of the target countries by using icons to represent agriculture, industry, population, and water availability. After students made their own maps, they then compared theirs with other students. The teachers were instructed to focus students on key quantitative aspects of the representations, including number and size of icons, the scale used in the creation of icons, etc. This comparison of different maps, with different icons, different scales, and different location of icons, was the preparation activity that led to the use of pictographs, and then bar graphs, in mathematics class.

“Comparison of water use” lessons (“countries” and “household”). These classes were designed to prepare students to learn about proportional reasoning. Students were asked to make a fair comparison of the water use within different countries, and represent this graphically. A standard bar graph of the country data is shown in Figure 3.

“Prediction of future water use” lesson. In this lesson students predicted future water use based on current conditions. This was a preparation activity that used the per capita measure previously learned in mathematics class. In this lesson students prepare to learn the notion of
prediction by scaling, that is, prediction by multiplying the current per capita water use by the expected future population.

A description of key mathematics lessons follows.

“Maps and Pictographs” Lesson. In this lesson, students worked in pairs to review their individual maps and compare the quantitative aspects (such as number of icons to represent a particular aspect of the data). This was followed by a class discussion in which the importance of using the same scale was brought into focus. Students then discussed the relative merits of icon placement when comparing a particular data value across countries. This led directly to the notion of a pictograph. In a pictograph the scaling of icons is made important, as is their placement. By having all icons represent the same value, and by stacking icons, it is a simple perceptual task to compare relative values. This ease of comparison was not present in the original maps students had created.

“Bar graphs” Lesson. In this class students reviewed their pictographs, and a class discussion revealed a key limitation of pictographs: they do not permit comparing “parts of numbers” (i.e., if the data values are not exact multiples of the scaling factor). Bar graphs are introduced as a “solution” to this representational problem. Students then created bar graphs of their social studies data, with a focus on scaling and labeling.

“Per Capita” Lesson. After a review of the graphing homework from the prior class, the teacher reads a story about a gradually increasing number of people dividing up some cookies. This is related back to the social studies context of people having to divide the amount of water that is available to them. This allowed the students to bring in ideas of “fair sharing”, and understand how dividing the amount of water by the number of people would result in a fair comparison. In this lesson the teacher also showed a comparison of a graph of the raw data (Figure 3), and a graph of the per capita data (Figure 4).

“Prediction of future water use” lesson. In this lesson students used the per capita measure previously created to extrapolate the future water use based on predictions of future populations.
Methods and Data Sources

**Design:** Due to the design-based nature of our work, we used a one-group pretest-posttest research design across a 3-week curriculum intervention. We administered pre- and posttests to all students in mathematics. We also administered interim assessments to track the developing knowledge of students. These interim assessment items were first used as a pretest in social studies, and then were individually administered between the social studies preparation activity and the mathematics learning activity.

**Participants:** 118 students in a middle school in suburb in Ohio. These students were distributed among three distinct teacher teams. Each teacher team was comprised of four content-matter teachers (math, science, social studies, language arts). In this study we only worked with the social studies and mathematics teachers.

**Instruments:**

- **Mathematics Assessments:** These were the same for pretest and posttest. The assessment consisted of 20 items, predominantly short answer and constructed-response items. These items were modified from NAEP, TIMMS and Ohio standardized tests, as well as items created specifically for this project (Zalles and Vahey, 2006). They measured the constructs of graph reading, making comparisons using proportional reasoning, and creating and using unit rates.

- **Interim Proportional Reasoning Readiness Assessments:** These included 6 items that were designed to measure the formative knowledge students constructed through social studies preparation and invention activities. Students answered the interim assessments before the unit started and then answered individual items after the relevant social studies preparation activity but before the relevant mathematics learning activities. (See Figure 5 for a sample item). A sample interim assessment item, given during the PFL cycle designed to teach the idea of proportional comparisons, is shown below.

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Stacey finds out that New Mexico has 50,000 acres of national parks, and Maine has 45,000 acres of national parks. Based on this data she says that New Mexico has more of its land covered by national parks than Maine. Do you agree with her reasoning? Explain your answer. If you disagree, then what else would she need to know?
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**Figure 5. Example Interim Assessment Item**

To be answered correctly, these interim assessment items do not require a full understanding of the target mathematics. For instance, in the question above, although one could
agree with Stacey’s reasoning, a more sophisticated answer would recognize the need for some baseline data on the states, such as the total area of each state, without requiring that students fully understand proportional comparisons. By understanding the need for baseline data, even without knowing how to use it, a student will be prepared to learn about proportional comparisons. That is, she will be able to transfer her formative knowledge about how to make a fair comparison in a social studies context into mathematics class, where the computation of proportions becomes an elegant solution to a known problem.

Classroom Observation Protocols: Researchers observed each class during the 3-week lesson. The protocol focused on the quantitative preparation activities in social studies classes and the learning activities in mathematics classes. Observers identified the key content addressed during the lessons, cross-references to the partner class (either mathematics or social studies), the time devoted to key learning activities, implementation quality of the preparation and learning activities, the level of student engagement, the graphic representations used, and a tally of key behaviors relevant to important aspects of PFL.

Teacher logs: Teachers completed short daily logs. In these logs they noted aspects of the days’ lesson that they felt went well, those that went poorly, aspects of student behavior that surprised them, and their overall attitude toward the project.

Results

Can students prepare to learn mathematics in social studies activities?

We found a significant difference in students’ performance on interim assessment items. In the item shown in Figure 5 there was a significant gain in the number of students mentioning the need for baseline data on this item between the pretest and interim test ($n = 96, t = 3.82, p < .01$). This finding provides preliminary evidence that the preparation activities (invention and sharing) enabled the students to be ready to learn about proportional procedures in mathematics class. In particular, students were able to transfer their emergent and pre-formal understanding of proportional comparisons to a situation in which they could recognize an incomplete solution to a complex problem. This preparation is key to developing a deep understanding of the importance and uses of proportional comparisons.

Will the PFL approach, implemented in a public school setting, result in increased data analysis skills in mathematics and increased data literacy in social studies?

While we do not have the data to fully answer this question, our pre- to post-test gains can begin to shed light on the effectiveness of using PFL to increase data analysis skills in mathematics class.

A paired sample t-test was used to analyze student learning gains. Our analysis found a significant gain from pretest to posttest, with an effect size of 0.4. The pre- and posttests were scored by raters who were blind to assessment type (pre or post) and achieved an inter-rater reliability of 90%. This provides preliminary evidence that our approach has the potential to increase students’ cross-disciplinary data literacy.

How do variations in implementation affect learning outcomes?

A closer look at the assessment data, as seen in Figure 6, shows that students started out with different levels of knowledge, and differential gains were seen across teacher teams.
Figure 6. Raw score pre/post test results and effect size, by teacher team and aggregated

This breakout by teacher team points to an interesting phenomena: while there were substantial differences between both pretest and posttest scores for students across teacher teams, the two standard explanations of differences in student achievement do not hold. The first standard explanation is *regression to the mean*, which is based on the notion that students with high pretest scores have no place to go but down, and students with low pretest scores can only get better. However, we see that this does not hold true: while the students with the lowest pretest scores did indeed have the highest gains, students with the highest pretest scores also had high gains: it was students who started in the middle who gained the least. The second standard explanation is an *aptitude-achievement interaction*, which is based on the notion that that “the rich get richer,” and the highest achieving students tend to gain the most from a new instructional method, simply because they are predisposed to being the high-achieving students. The fact that the students who scored lowest on the pretests gained the most shows that this explanation also does not hold true. We look to the observation notes to see if there was something different in the instruction received by these different groups of students that could explain this result.

Our observations reveal that there indeed were important differences in the ways that teachers implemented the PFL activities and these could correlate with student learning gains. A quantitative analysis of the observation data shows that the teacher team with the highest student gains exhibited, on average, twice the number of key PFL behaviors as the teacher team with the lowest student gains (such behaviors include comparing approaches to highlight key dimensions of the problem).

Analyzing Differences in Implementation

We selected a pair of high-gain teachers in mathematics and social studies (Group 2) and the low-gain teachers in mathematics and social studies (Group 1), and then we closely compared how much time (in minutes) these teachers devoted to specific quantitative learning activities (e.g., preparatory activities in social studies and formal instruction activities in mathematics). We also tallied how many specific instances of effective PFL instruction or learning behaviors were observed and counted in each class. These behaviors included: (1) Students asking follow-on questions and application questions; (2) Students or the teacher raising interesting critical questions about the solutions invented/told/ or presented; (3) Teacher
mentioning interesting related examples and cases; (4) Students identifying misunderstandings and asking each other questions to solve these misunderstandings; (5) Students quietly absorbing information and showing in their work that they are productive; (6) Students checking with teacher to see if they’re on the “right track;” and, (7) Teacher points out contrasts between critical cases during inventions and sharing. We used observers’ short field notes for additional interpretation. In all our analyses, we focused on comparisons between teachers who taught the same exact lessons in the same subjects.

We found that the high-gain social studies teacher engaged in specific practices more than the low-gain teacher. For example, the high-gain teacher devoted 50% more time to quantitative reasoning activities than the low-gain teacher. We found the high-gain students showed 75% more occurrences of “understanding” behaviors than the low-gain students. We found the high-gain teacher used the “contrasting case” instructional method 100% more than the low-gain teacher.

In reviewing field notes, we identified specific discussion features that varied between the high-gain social studies teacher and the low-gain. For example, during the map-making preparation activity, the high-gain teacher asked students questions that focused on quantitative computation of the scale and units of measurement, such as: “How did you come up with 8?” and “How did you decide the number of icons to put on your map?” Students responded with quantitative reasoning such as: “Cause I divided it by 3. I have 3 icons for urban, but only 2 for rural.” “I divided by 8, so I have 8 for agriculture, industry…” The teacher would ask “Why did you choose the scale that you did?”

By contrast, the low-gain teacher in the same lesson asked questions that asked students to interpret their quantitative data rather than critique or justify it, such as: “Looking at the map, do more people live in urban or rural areas?” Students responded with non-quantitative reasoning such as there were more people in urban areas because “the icon is bigger” or that they “chose more icons for urban because there were more people in urban areas.” The teacher did not focus the discussion on quantitative computation or reasoning at these points in the lesson. Instead of pressing students to demonstrate their computations, the teacher left it up to a democratic vote: “How many think it doesn’t matter if you have more icons for urban if more people live in urban areas?” Votes were taken but the teacher did not provide feedback about effective quantitative decision strategies.

We noted similar differences across all the preparatory activities compared between the high-gain and low-gain social studies classes.

The differences between high-gain and low-gain mathematics teachers were similar. Focusing on those lessons where the mathematics teachers guided students through review of data generated in social studies class, we found consistent patterns. The high-gain teacher focused on fewer concepts and devoted more time to them, while the low-gain teacher covered more concepts with less time for each. The high-gain students demonstrated 72% more instances of “understanding behaviors” than low-gain students. The high-gain teacher showed 100% more use of the “contrasting cases” instructional method than the low-gain teacher.
As noted in the social studies classes, we also noticed key differences in the ways these teachers pressed for student quantitative reasoning across these lessons. The high-gain teacher pressed students for critical and conceptual reasoning, asking them to engage in extended student-led critiques and prompting them to focus on quantitative features of the social studies materials they were reviewing. The low-gain teacher did not involve students in focused and extended critique, but instead asked them a series of questions in rapid succession on a varied range of concerns. For example, during the presentations, the teacher asked students to focus on quantitative, aesthetic, and representational concepts within a few minutes’ time without allowing extended discussion or reflection in any one of these.

Conclusions

This work has taken the first key steps in helping us to understand how students can become more data literate by engaging deeply in a particular social studies context, and using that context (as well as the important problems raised in that context) as the basis for building mathematical understandings. We have seen that it is possible for students to transfer their emerging and incomplete understandings from social studies, and build a more complete and formal understanding in mathematics class.

While we have preliminary evidence that the PFL approach, when implemented in a public school setting, can result in increased data analysis skills in mathematics and increased data literacy in social studies, this study is far from conclusive. Because we did not have a control group, we cannot claim increased learning as compared to another classroom intervention. Additionally, it is not clear that PFL itself was the cause of the student learning that we did see, or if there are other, more simple explanations, such as time on task working with quantitative data. Finally, we found that our PFL approach required more than simply “telling” students the appropriate mathematics in math class: To be effective, the PFL math teacher needs to use the social studies context as an opportunity to inject more focused reflection and conjecture and problem solving into mathematics class.

To interpret these findings from both social studies and mathematics, we found that two common concepts from mathematics education research into effective instructional discourse that were useful for explaining the differences in learning outcomes between the high-gain and low-gain teachers: cognitive demand and consistency of conceptual focus (Hufferd-Ackles, Fuson, Sherin, 2004; Kazemi, 1998). Cognitive demand focuses on whether or not a task -- or a teacher’s question -- demands quantitative reasoning from students. Consistency of conceptual focus refers to whether or not a task or teacher’s question maintains consistent student attention on quantitative reasoning. In both social studies and mathematics classes, the high-gain instructors made higher cognitive demands on students for engaging in, justifying, and explaining their quantitative reasoning. In a similar way, the high-gain instructors devoted more time to single key quantitative concepts than the low-gain instructors.

Nonetheless, this study provides compelling insight into how we may transfer quantitative reasoning from social studies into mathematics to increase the data literacy of our students. In particular, we note our high-gain mathematics teacher was able to leverage existing social studies standards to aid in the creation of a mathematics classroom environment consistent with best practices of classroom instruction (NCTM, 1991). Teachers implementing these best practices (a) view classrooms as mathematical communities rather than collections of individuals; (b) use logic and mathematical evidence to verify results rather than relying on the teacher as the authority; (c) emphasize mathematical reasoning rather than memorizing...
procedures; (d) focus on conjecture, inventing, and problem solving rather than mechanical answer finding; and (e) make connections among the ideas and applications of mathematics rather than seeing them as isolated concepts and procedures (McCaffrey et. al, 2001).

For our high-gain mathematics teacher this was enabled, at least in part, to students engaging in quantitative reasoning in social studies class (and this reasoning was, we note, consistent with social studies standards). The social studies context allowed students to become deeply engaged in a meaningful investigation, and begin to investigate quantitative data in a context that was far more realistic and compelling than typically possible in mathematics class. While we cannot say precisely what was transferred from social studies to math class, the results of the interim assessment shows that students were becoming more sophisticated in their quantitative reasoning as a result of their social studies investigation.

Our study also provides some starting ideas for helping social studies teachers to effectively infuse quantitative reasoning into their lessons (as required by the latest NCSS standards, as seen in Table 1). Social studies teachers may need encouragement in giving time to helping students think about the quantitative reasoning inherent in activities such as map-making; and, design issues need to be separated from the quantitative strategies (such as deciding on units or scale). While social studies teachers are trained to build democratic processes into their classroom instructional strategies, taking votes and polls should not be the only techniques used in building quantitative reasoning skills: appropriate quantitative justifications must become a key part of the classroom culture. For instance, it may help to adopt the strategy of the teacher who characterized the students’ data sheet as a critical source of evidence to support their argument.

With respect to our instructional framework, this research confirms prior PFL research, which shows that not just any invention activity will result in learning gains. Instead, the invention must be directed precisely toward the learning goal, and highlight important aspects of the problem situation for students. We also discovered that, in our cross-disciplinary context, a successful formal learning activity may require surprisingly subtlety. The high-gain mathematics teacher did not simply engage in a straightforward lecturing exercise (as is common in single-discipline PFL activities), but instead built up to this exercise by first making explicit links to the social studies materials, having students present their social studies work in the mathematics context, and focusing on the important mathematical properties of the situation. Only after students engaged in this exercise did he engage them in a lecturing activity. In contrast, the low-gain mathematics did not engage students in as much mathematical thinking about their solutions. As a result she may not have allowed students to appropriately build upon any pre-formal understandings they had been developing in social studies.

We have also shown that there is great potential for interim assessments that can help teachers (and researchers) determine if students have created the pre-formal knowledge that will prepare them for a telling experience. The potential for these assessments transcends the PFL framework, and can be useful in a wide variety of educational settings. More work needs to be done on these interim assessments, both to refine our particular items, and to better understand the potential use of such items across a wider variety of educational settings.

As we collaborated with teachers to create and pilot the PFL treatment, we discovered that some aspects of PFL were more “robust” than others in the real world of cross-disciplinary curricular units. In particular, our PFL implementation appeared to be particularly sensitive to (a) Teacher and student expectations in terms of classroom norms. This was particularly evident when the activities ran counter to established classroom norms. Such established norms

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include the teacher giving feedback as to the “correctness” of student responses, and the teacher providing the correct answer after a small number of student responses.

(b) Teacher implementation of appropriate scaffolding while students were involved in the preparation activity. While they were provided with clear examples of prompts to provide during the preparations (such as “will your solution work with the data from all the countries?”), they occasionally found such prompts difficult to administer as they wanted to provide students with more directed feedback.

(c) The subtle differences between providing guiding questions and “giving away the answer”. As we saw in our analysis of social studies teachers, the low-gain teacher chose to steer away from guiding questions, worrying that he would unintentionally give away the answer. For PFL to be productive, we must help teachers build a robust understanding of these subtle differences.

(d) The requirement of close coordination between mathematics and social studies classes. In our unit a preparation activity in social studies was closely followed (within the next day or two) by a learning activity in math class. This coordination was difficult to maintain, as not only did such normal middle school experiences as fire drills and band practice throw cross-curricular articulation into a tailspin, but articulation requirements resulted in classroom teachers curtailing important student inquiries to meet the strict scheduling constraints. In future work we will find ways to create more modular units, that don’t require such close coordination.

Importance of this study

By making progress in the important problem of cross-disciplinary transfer and learning, we are advancing the fields’ knowledge of how to infuse mathematics throughout the curriculum. It is generally recognized that cross-disciplinary thinking is key to current advances in science and mathematics, so findings ways to infuse mathematics throughout the curriculum is key to helping students in becoming mathematicians, scientists, or simply well-informed citizens.

More specifically, we are beginning to provide a scientific basis for conducting school-based data literacy activities that cut across disciplines. Just as the notion that we cannot separate literacy in reading from comprehension in science is becoming commonplace (Armbruster, 1991; Armbruster et al., 1989; Baker 1991; Casteel & Isom, 1994; Levitan, 1991; McNamara et al., 1996), we expect that it will soon become generally accepted that one cannot separate data literacy into the distinct compartments of social context and mathematics. This research will contribute to our ability to enhance STEM education and increase the range of students both interested in and capable of analyzing data as a basis for thinking about societal issues.

In doing so, we are actively advancing knowledge of an important new framework of instruction, Preparation for Future Learning. As shown above, moving PFL into a new context may require a refinement, or even rethinking of some of the key tenets of the framework. Furthermore, in our use of interim assessments, we are beginning to formalize the notion of what it means to be “prepared” to learn a new concept. This formalization may have implications far beyond that of the PFL framework.

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