Challenges to Cross-Disciplinary Curricula: Data Literacy and Divergent Disciplinary Perspectives

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> *“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

Data literacy is the ability to ask and answer meaningful questions by collecting, analyzing and making sense of data encountered in our everyday lives. In our increasingly data-driven society, data literacy is arguably an important civic skill and one that we should be developing in our students. In addition, using data to connect school subjects with real-world events makes learning a richer and more meaningful experience. It can move students beyond simply learning facts to beginning to acquire skills in inquiry, critical reasoning, argumentation, and communication.

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 classroom practice. While there has been significant research on the teaching and learning of data analysis and probability (e.g. Konold & Higgins, 2003; Lehrer & Schauble, 2002), and 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 simple graphs and tables, without aiming for true data literacy. 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.”

Although unfortunate, this situation is perhaps inevitable. Mathematics textbooks are already “a mile wide and an inch deep” (Schmidt et al., 1999), and data literacy takes significant time to develop. Data literacy includes the ability to formulate and answer data-based questions; use appropriate data, tools, and representations; 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). 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, p. 801). We cannot expect the context for using the skills of data literacy to come solely from the mathematics classroom, where it is perceived as artificial. 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.

Our research takes seriously the fundamental requirement that data literacy bridge the disciplinary domains, as is the case in the real world, and finds commonalities that can be used to cross these divisions (Table 1). In our NSF-funded Thinking with Data (TWD) project we developed a cross-curricular unit designed to cultivate middle school students' deep understanding of data literacy. The TWD unit consists of four, 2-week replacement modules for interdisciplinary implementation in seventh grade social studies, mathematics, science, and English language arts. The modules address issues of data representation, common measure, and proportional reasoning, using real data accessed from real world media sources in discipline-specific, problem-solving contexts and aligned with relevant subject area standards.

Data Literacy Requirement	Middle School Social Studies Standards (NCSS)	Middle School Mathematics Standards (NCTM)	Middle School Science Standards (NSES)	Middle School English Language Arts Standards (NCTE)
Formulate and answer data-based questions	"Formulate historical questions, obtain historical data, question & identify gaps in data, & construct sound historical interpretations."	"Formulate questions, design studies, & collect data about a characteristic shared by two populations or different characteristics within one population."	"Identify questions that can be answered through scientific investigations. Develop the ability to refine & refocus broad & ill-defined questions."	"Students conduct research on issues & interests by generating ideas & questions, & by posing problems."
Use appropriate data, tools, and representations	"Use appropriate geographic tools such as atlases, data bases, systems, charts, graphs, & maps to generate, manipulate, & interpret information."	"Select, create, & use appropriate graphical representations of data; discuss & understand the correspondence between data sets & their graphical representations."	"Use appropriate tools & techniques to gather, analyze, & interpret data; the use of which, including mathematics, will be guided by the question asked & the investigations students design."	"They gather, evaluate, & synthesize data from a variety of sources (e.g., print & non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose & audience."
Develop and	"Encourage increasingly	"Use observations	"Students can learn to	"Students use spoken, written,

evaluate data based inferences and explanations	abstract thought as learners use data & apply skills in analyzing human behavior in relation to its physical & cultural environments.”	about differences between two or more samples to make conjectures about the populations; use conjectures to formulate new questions & studies to answer them.”	formulate questions, design & execute investigations, interpret data, use evidence to generate explanations, propose alternative explanations, & critique explanations & procedures.”	& visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, & the exchange of information).”

Table 1: Common Data Literacy Process Standards across Disciplines

In this paper, we report on the development and field testing of our TWD materials, focusing on an unanticipated discovery we made in the course of our materials development – the revelation that even though the various disciplines have very similar data literacy standards for middle school students (Table 1), the perspectives they adopt are quite different, in particular the perspectives they take on data-based argumentation. It is our expectation that similar epistemological challenges may confront all attempts to design interdisciplinary curricula, especially curricula, like ours, that are grounded in authentic media and real world data.

In the first sections of the paper we analyze the aspects of data literacy and argumentation across the four school disciplines of social studies, mathematics, science and English language arts that were the focus of our cross-disciplinary modules, describe the theoretical approach guiding the pedagogy of the modules, and report on learning gains realized from their implementation in two public middle schools in northeast Ohio. We then discuss some of our key design challenges in helping students to coherently use data and analyze and construct arguments across the curriculum, report on how we met those challenges, and reflect on those features of our intervention that most likely resulted in learning gains. We end with a discussion of remaining challenges and implications for cross-disciplinary curricula and media literacy in general.

Data literacy across the school disciplines

The Thinking With Data unit consists of four modules, one module for each of the school disciplines of social studies, mathematics, science, and English language arts. Each module was designed to take two weeks of classroom time. The modules were designed to be taught in sequential order, but no other coordination was required across modules.

The context for the TWD unit is a compelling one: world water issues. Specifically, the modules were designed around students’ investigations of fair distribution and use of water in the Tigris/Euphrates watershed and several watersheds in the US. In social studies, students 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. In mathematics, they learn techniques of proportional reasoning and data analysis to expand on their social studies work and their data-based arguments for fair use. In science, students explore 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 English language arts, they use their research on US watersheds to develop persuasive arguments around identifying major water issues in the watersheds and proposing solutions for them.

The data literacy focus for the TWD unit is the creation of common measures as key to the use of appropriate data and numerical representations. In our prior research (Vahey et al., 2006), we discovered that data analysis in many social studies contexts required a transformation of data, from raw values (such as the amount of water used by a set of countries, or their gross domestic products) to a measure that combined two quantities (Thompson & Thompson, 1992), such as a per capita measure. 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). We also note that an understanding of proportionality is vital to understanding water quality data. For instance, the amount of sodium in a sample of water from a well is less important than its concentration in parts per million.

Central to building students' data literacy in the TWD unit is 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. Fairness in representation – representing a complex group by a single individual, a complex situation by a single quantity, or a group of data points in a visual image – also hinges on proportionality. However, it reveals an additional, implied aspect of the utility of proportion: simple prediction by scaling. We would expect that a fair representation would allow, for example, doubling of some key aspect of the representation if the phenomenon under investigation is also doubled, and violation of this is often cited as a misleading use of representations (Tufte, 1990).

In the science and English language arts modules, fairness is also evoked in the context of understanding water issues fairly and developing fair solutions to them. In science the use of proportional reasoning to analyze *fairness* translates to an equal basis of comparison. Embedded within the foundational structure of science is the ability to make measurements that are comparable. Without standard units of comparison, there would be no meaningful communication amongst scientists about any variables that are measured. This fundamental understanding is ubiquitous in our daily lives; whether it is using the foot/pound system to measure body weight or the metric system to buy a liter of soda. These are measurements and use that we take for granted. To explicitly pull out the unit comparison aspect of our everyday experience, and extend it into yet other arenas of content and thought, is an important part of developing data literacy. The science unit includes several opportunities for students to think about units of measurement as they apply to conducting a cross-comparison of climatic conditions between specific areas, water pollution and salinity measures, and water distribution figures. Students are given opportunities to think fluidly about the information they access and comparisons they are asked to make throughout the science unit. Students are developing the tools in science with which to structure their arguments with supportive evidence in English language arts. In science, students also begin Internet research on US watersheds that culminates in the development of persuasive arguments in English language arts. In English language arts students are asked to use data and data representations to support their arguments in both written and oral form, and their oral arguments are judged fair or not by their classmates.

Theoretical approach

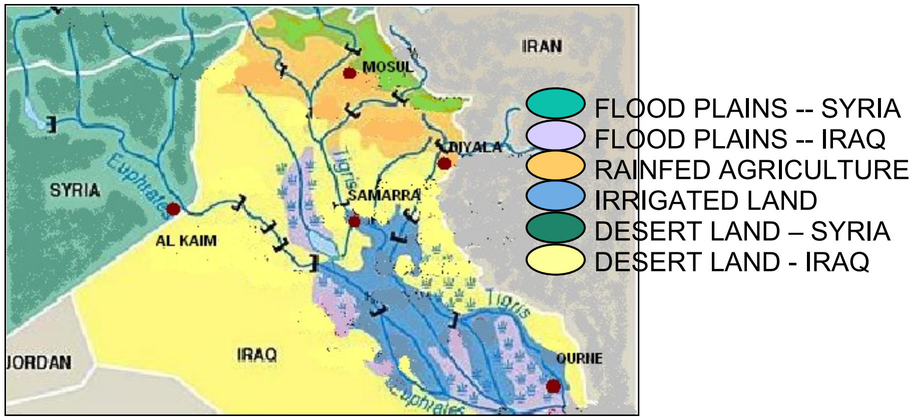
Our theoretical approach is grounded in a novel application of the Preparation for Future Learning (PFL) framework (Bransford & Schwartz, 1999). In this framework, students first prepare to learn an important concept by investigating a set of problems that are designed to highlight its structure. Instead 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 solution, and which they then practice and apply in a variety of contexts. PFL reverses the traditional lecture-and-apply process (Klahr & Nigam, 2004) and is consistent with the conceptual change literature, which shows that students must first understand that there is a problem and realize that their existing understandings are not adequate for creating a solution, before they are fully ready to learn scientific and/or mathematical concepts (Lehrer & Schauble, 2002; Strike & Posner, 1992).

We apply the PFL approach both across and within modules. Our application across modules is based on the social studies context of water availability and use as a preparation context that also provides the contextual support required to engage students in data literacy (Yager & Lutz, 1996). In social studies, students explore issues of fair allocation of water in the Tigris/Euphrates watershed through the manipulation of real world data in charts and graphic representations, which are important social studies process standards, (NCSS, 1994). It is difficult, however, to fairly divide the water without recourse to per-capita-type common measures, thus students come into the mathematics module with an understanding of the need for proportional measures. They are "prepared" for instruction in proportional reasoning, which is what they get, culminating in a revisiting of the fair allocation of the Tigris/Euphrates water. Mathematics in turn continues the *prepration* of students by introducing students to the notion of salinity, which is studied in greater depth in science, and by introducing students to formal argumentation methods, which are studied in greater depth in English language arts. In science, geospatial representations of data are introduced and added to the (by now) more familiar charts and graphs, as students are asked to uncover the scientific explanations for water problems. They also begin research on water issues in US watersheds, using government data and real media reports, which leads to the development of persuasive arguments concerning these issues and watersheds in English language arts. In science and English language arts, then, students apply and expand upon their growing understanding of data literacy.

PFL is used within modules through a common lesson format. Throughout the TWD unit students are introduced to ideas through data-based activities in which they are provided with data and then explore focused questions based on the data. In many cases, the focused questions take the form of argumentation for or against particular positions. For example, in science students are asked to decide whether irrigation increases soil salinity by synthesizing information from three data sources, a data table, a GIS-type map, and a chart (Figure 1). Student groups are asked to develop arguments for or against the position, using evidence from the sources. Teachers do not provide answers, but rather direct students' attention to particular aspects of the data representations, such as that the data in the chart might be best understood proportionally, after the groups have presented their arguments to the class for discussion.

	amount of agricultural land (km^2)	**amount of irrigated land (km^2)**	**amount of irrigated land w/ salty soil (km^2)**	**amount of irrigated land w/ severe salinity problem (km^2)**
Iraq	60,190	33,050	24,457	978

Syria	54,210	12,670	5,320	1,011
Turkey	260,130	41,860	15,000	0



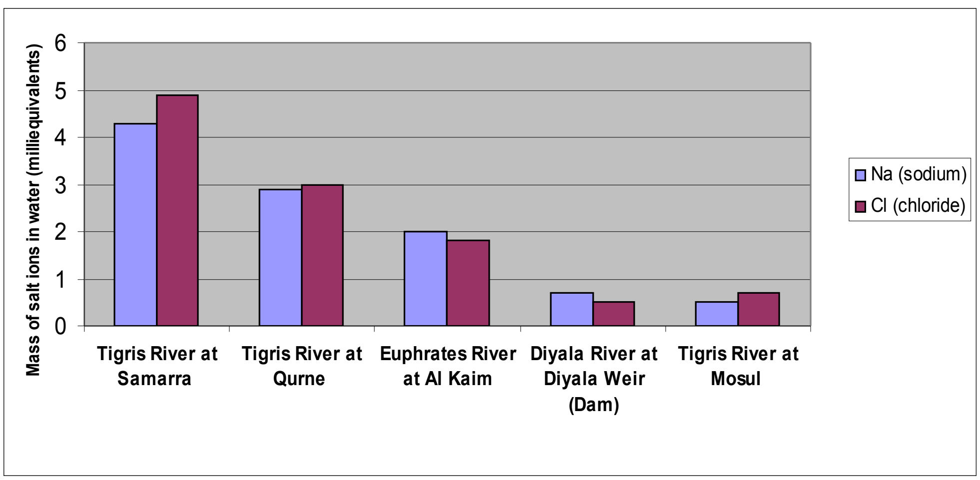


Figure 1: Science Salinity Challenge

This PFL-based approach is consistent with the mathematics and science education literature on data literacy. 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 make informed decisions about relevant problems (Lehrer & Schauble, 2002). Furthermore, this approach is consistent with recent findings on the most effective ways to teach social studies, science, and mathematics (National Research Council, 2005), which recommend that students work with evidence, and that instruction engage students' prior knowledge (key to the preparation activities), engage students in metacognition (key in recognizing that existing knowledge is insufficient), and engage students in both factual and conceptual knowledge (key to the learning activity).

School Context and Quantitative results

In this section we address the core question of our research: "did students learn?" We do this by presenting the context for the study, followed by the results of a series of assessments. We then discuss epistemological challenges to creating a coherent argumentation framework, and finally reflect on implications and remaining challenges.

In the 2008/2009 school year, we tested the Thinking with Data unit with seventh grade students in two middle schools in northeast Ohio (which we shall call School 1 and School 2). Both schools used a team teaching approach which allowed us to have one team (social studies, mathematics, science and English language arts teachers) implement the unit. We could then test its efficacy by comparing data literacy gain between students in the TWD (experimental) team and all other seventh graders in the school. There were four seventh grade teams in School 1 and three seventh grade teams in school 2. In both schools, the TWD unit was implemented with a team involving lower achieving students. In School 2, the number of students in the TWD team was about half that over the other seventh grade teams to provide the students with greater support.

In the state of Ohio, schools are ranked for accountability purposes on a five point scale -- Excellent, Effective, Continuous Improvement, Academic Watch, and Academic Emergency – based on a combination of academic indicators, a performance index score, and adequate yearly progress. In the 2008/2009 school year, School 1 was rated Excellent and School 2 was rated Effective. The ethnic breakdown for students in School 1 was 92% Caucasian/White, 3.5% African American, 2.5% Asian, 2% Multiracial, 0% Latino/Hispanic, and 0% Native American. In the 2008/2009 school year, 21% of the students in School 1 received free or reduced lunch. The ethnic breakdown for students in School 2 was 78.5% White/Caucasian, 12% African American, 3% Asian, 6% Multiracial, .3% Latino/Hispanic, and . 2% Native American. In the 2008/2009 school year, 33.5% of the students in School 2 received free and reduced lunch.

In both School 1 and School 2, four teachers taught each of the four TWD modules. Table 2 below gives the teaching experience, academic achievement, and gender for each of these four.

school	module taught	years teaching	highest degree	gender
1	SS	10	Masters	female
	Math	5	Bachelors	male
	Science	15	Masters	female
	ELA	16	Masters	female
2	SS	9	Masters	female
	Math	4	Bachelors	male
	Science	7	Bachelors	female
	ELA	4	Bachelors	female

Table 1: TWD Teachers' Experience by School

The primary assessment used in this study was a test of overall data literacy. In particular, this assessment measured if students could (a) interpret complex tables of data; (b) understand arguments that used the tables of data; and (c) create their own proportional measures, which provided a more complete understanding of the data and arguments than one would have without the proportional measures. The assessment was administered to all students in the TWD condition, as well as students in comparison conditions (other seventh grade students in the same schools who did not use the TWD materials). An analysis comparing pre/post test gains yielded a t-statistic of $t(156.273) = 10.750$, $p < .000$, 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. The mean difference at School 1 was 3.135, at School 2 the mean difference was 2.270. Effect sizes amounted to 1.27 (School 1) and 1.00 (School 2). 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.

Epistemological Challenge: Argumentation across the Disciplines

In developing the cross-disciplinary TWD curriculum, we found that identifying a common theme and standards-based content for social studies, mathematics, science and English language arts was challenging. Through considerable work, however, we were able to identify world water issues as being sufficiently challenging and as having enough available real world data and news stories to satisfy our contextual needs. We also identified process standards in all four disciplinary areas that seemed to address common data-literacy skills (Table 1). Although similar data literacy processes – formulating appropriate data-based questions, employing suitable data, tools, and representations to answer them, and developing and evaluating defensible data-based arguments and explanations -- are addressed in the national K-12 standards for all four subject areas, we quickly realized that the disciplines approach these processes from fundamentally different epistemological perspectives. This is especially true with regards to argumentation.

As previously noted, the instructional approach we adopted for our unit was grounded in Preparation for Future Learning (PFL). Such an approach leads to scenarios in which students develop positions on particular issues and then defend those positions in whole class discussions. In our opinion, such an approach also leads students to a richer understanding of the concepts being learned, as well as encourages them to "do" social studies, mathematics, and/or science. The approach also fit well with our culminating English language arts module, which was focused on persuasive arguments, and, we thought, could provide another unifying theme across the unit.

However, as we began to develop and implement the modules, we realized that, although they all made argumentation a central feature, the perspectives through which the different disciplines approached argumentation were quite different. Indeed, we noted that while there is one commonality across all the argumentation-based process standards, it is an unfortunate one -- each is a caricature of the argumentation used in the field; in particular:

- in social studies all argumentation is context-dependent;
- in mathematics argumentation is proof of absolute truth;
- in science argumentation is a search for the most parsimonious explanation;
- in English language arts argumentation uncovers a horizon of possibilities (Langer, 2000).

These are described in more depth and in the context of the Thinking with Data curriculum below.

Social Studies

One of the most important goals of social studies is to develop "critical analytic abilities that will enable citizens to make informed decisions" about societal issues (Hahn, 1996, p. 30). In order to do so, social studies teachers need to create a context for learning that includes real-world data, information, and issues (Engle & Ochoa, 1988; Shaver, 1977). This need is reflected in the NCSS (1994) standards, which emphasize the collection, analysis, and interpretation of data "in relation to its physical and cultural environments" (see Table 1). Moreover, the kind of context that social studies teachers create in their classrooms is different from other subject areas, because "different disciplines are organized differently and have different approaches to inquiry" (Bransford, Brown, & Cocking, 2000, p. 155; see also Shulman, 1987).

In the Thinking with Data project, the social studies module is the first module for exactly this reason: to provide a real-world context. In our case, students make a first attempt at analyzing data in order to come to a decision about dividing the water in the Tigris-Euphrates watershed between Syria, Turkey, and Iraq. Students argue the case for each of the three countries based on (incomplete) statistical data and historical and geographic information. They soon find that this is a difficult exercise, as the issue of water allocation is not as clear-cut as it may seem on the surface, and there is a need for information and skills that go beyond what they might learn in social studies alone. Consequently, students will not arrive at a satisfactory solution to the issue, but that is not the point. In fact, it is more important that students formulate an answer to the main question

> *that seems best supported by relevant data, […] because we assume that well-informed people may continue to disagree on the best answer. What is important is that the disagreements entail increasingly sophisticated debates about the quality and relevance of evidence as well as the logic employed in coming to a particular conclusion.* (Lockwood, 1996)

Finally, as Wraga (1993) has argued: "because societal problems are complex and they transcend conventional subject divisions, civic competence depends upon integrating knowledge from a variety of subjects." Therefore, while the struggle to find an answer to the water allocation problem in social studies is frustrating because it was made messy to make it real, this struggle has a purpose. It prepares students for learning in math, science, and English language arts, which is exactly what the underlying PFL (Preparation for Future Learning) framework is supposed to do.

Mathematics

Mathematical argumentation is the investigation of whether a mathematical statement is true based on evidence. This includes constructing conjectures and articulating and defending these conjectures through explanation and justification (NCTM, 2000; Shechtman, Kim, and Knudsen, 2008). While this view or argumentation is consistent with social studies, mathematics argumentation requires an epistemic shift from belief about the world to reasoning with abstract axioms (Lehrer and Lesh, 2003). That is, a primary goal of mathematics argumentation is to abstract from real-world contexts to more general understandings that transcend such real-world contexts.

In the Thinking with Data project, the mathematics module uses the real-world context provided by social studies in two ways: first, as a context to motivate the learning of proportional reasoning; and second, as an application of using proportional reasoning in argumentation. However, in order to support the epistemic shift to abstract mathematical reasoning, the learning of proportional reasoning uses a multiplicity of contexts, each of which are designed to highlight the abstract mathematical notion of creating proportional measures (Lamon, 1994).

While some of these contexts are directly related to water distribution, the situations were simplified to make draw attention to the key aspects of proportional reasoning. For instance, in the first activity in mathematics class, students were divided into unequal sized groups, and each group received unequal amounts of tokens. Once the distribution of tokens was shared with the entire class, students were asked to determine if their group received a "fair share" of tokens. Through this activity students soon came to realize the importance of a measure of fairness that could take into account both the number of students and the number of tokens. This became the basis for investigating proportional reasoning in a variety of contexts (including water distribution, salinity, and corn production, to name a few).

As students came to a more formal understanding of proportional reasoning, and, in particular, *per capita* measures, they employed these measures in data-based argumentation about the real-world context introduced in social studies: water distribution in the Middle East. This data-based argumentation was then tied directly to the argumentation forms that were used in English language arts. The argumentation goals included making mathematically appropriate arguments based on data, as well as recognizing when they did not have the data required to make an appropriate argument (e.g. they knew the amount of water available to different regions, but not the populations of the regions, and so could not construct the *per capita* measure).

Science

The National Science Education Standards (NSES, 1995) emphasizes the importance of developing students' understanding and abilities associated with major science conceptual and procedural schemes. Of particular importance are unifying concepts and processes of science that transcend content boundaries, especially the argumentation-related abilities to understand evidence, use models, and make explanations using scientific evidence and concepts. Within the seventh grade these abilities are grounded in the content areas of energy transfer, populations and ecosystems.

The science module builds on the context of the Middle East water crises developed within social studies, and the ideas and skills developed in mathematics class. Students use their recently-developed understandings in these areas to then generate scientifically accurate comparisons of physical entities using number measurements (e.g. water distribution and salinity among several topics). These comparisons are foundational to developing scientifically accurate understandings of the core scientific ideas of precipitation and the water cycle, the impact of technology on man and nature (e.g. through different forms of irrigation), and the impact of salinity and pollution on agriculture and other forms of water use. Students then reinforce and expand these understandings as they study water concerns in the United States.

The science unit begins by having students use GIS data (representing rainfall and temperature per year) to determine information about climate conditions in the Middle Eastern countries of Turkey, Syria, and Iraq. Through this activity students compared water available between the three countries to obtain an understanding of the water that is available from the natural process of water cycle changes. Students then explored data from three sources: a data table, a bar graph, and a map, to find links between irrigation and soil salinity. Their findings were compared with data from a hands-on experiment investigating the growth of plants in various concentrations of salinity in water. These activities led to the creation of a report of their findings that drew conclusions about the effect of salinity of plant growth.

In the last section of the science lessons, students conducted research on a set of United States watersheds. They investigated problems in those areas, which included water scarcity, water pollution, and invasive species. Through comparisons with what they learned about the Middle East, they built and understanding of associated causes and developed arguments for possible solutions. These initial scientific arguments formed the basis for the final arguments developed in English language arts.

English Language Arts

In English language arts, argumentation is a means to uncovering the "horizon of possibilities" (Langer, 2000) inherent in texts; that is, in developing defensible interpretations of literary work or being able to synthesize defensible themes across works of non-fiction. "Texts" here includes not only printed texts but also a variety of media formats such as film, video, audio recordings, and Internet sites. The emphasis is not on absolute truth but rather on developing understanding and an appreciation of multiple perspectives (Applebee, Langer, Nystrand & Gamaron, 2003). Whereas reasoning in science and mathematics usually converges on a single best explanation or proof, reasoning in the English language arts is typically divergent and involves discovering multiple plausible explanations.

In the Thinking with Data unit, the English language arts module brings together the varying aspects of argumentation explored in the preceding modules. It focuses on persuasive argument, on developing effective arguments concerning water problems in US watersheds and reasonable solutions to them. To develop an effective argument, students must be able to synthesize, analyze and evaluate data to create a fair, complete, and logical argument. Students must be able to ground their argument in context and support their argument with real world data. They must also represent and communicate their findings, conclusions and recommendations accurately and effectively. The primary focus, however, is formal and rhetorical.

In the TWD unit, a central challenge is also the understanding and use of data from a variety of media sources and across multiple literacies. Middle school ELA standards call for students to be able to "gather, evaluate, and synthesize data from a variety of sources and to communicate their discoveries in ways that suit their purpose and audience. Students must be able to think critically about concepts, claims and arguments as well as be able to read, interpret and evaluate information (AASL, 1998). Further, the standards now extend beyond skills for reading, writing, speaking and listening to an emphasis on multiple literacies, including visual literacy and information literacy. Operating from this premise, the ELA module encompasses skills for data literacy, information literacy, and visual literacy. Students' creation of data-based arguments surrounding water-related issues and solutions serves as the context for addressing these literacies. Similarly, it also served as a context for transferring students' understanding and use of data as evidence while also engaging students in the use of accurate, appropriate, and meaningful representations as evidence to support an argument.

Data literacy and argumentation across the disciplines

Each disciplinary module had two argumentation goals: to provide opportunities for students to engage in disciplinary-relevant argumentation, while also helping students to appreciate the multidisciplinary form of argumentation required by true data literacy. Our attempt to meet these two, possibly competing, goals was to have each module focus on the core argumentation required by the discipline, with explicit links to the types of arguments that require a broader, cross-disciplinary perspective. For instance, in mathematics class, students generate "fair" measures of water distribution using per capita calculations. The class engages in an explicit discussion around what "fairness" really means in this case: Turkey may claim that such a measure of water distribution is not "fair" at all, as the water that falls in Turkey *should* belong to Turkey.

Such activities provide students a window into the meta-understanding that there are different analyses that come from different perspectives, and it is not necessarily the case that one perspective is more valid than the other. This does not mean, however, that "anything goes" in terms of argumentation: all arguments, no matter what their perspective, must use data appropriately. This meta-understanding applies beyond this particular project, and is relevant to making sense of media reports, position papers, advertising, political claims, and the many other instances in which people use data in an attempt to persuade.

Conclusions

The TWD project is using authentic data and real world problems to promote the cross-curricular teaching and learning of data literacy in middle school setting**s**, a critical skill in our data- and technology-rich society. The efficacy of our approach is demonstrated by the significant differences in data literacy skills between seventh grade students who participated in the TWD unit and their peers who did not. Indeed, the notion that we cannot separate literacy in English language arts from comprehension in science is becoming commonplace, and interdisciplinary teaching and learning is widely promoted. However, our work has uncovered challenging differences in data-based argumentation across the disciplines which, we believe, reflect fundamental differences in approaches to meaning-making that are often obscured in both the media and in schools because of the ways school curricula and cultures are organized.

It is our belief that such differing approaches to meaning-making both challenge and enrich cross-disciplinary approaches. They challenge cross-disciplinary approaches in that they require disciplinary experts to step back and seriously interrogate the perspectives often taken for granted within a discipline so that these can be fore-grounded and explained. A further challenge is to integrate multiple perspectives into a meaningful approach, to move beyond the blind men to reveal the elephant. On the other hand, we believe that the real strength of cross-curricular approaches lies precisely in the foregrounding of epistemological differences among the disciplines because, if done well, it helps prepare students for thinking and decision-making in the real world where such differences are often obscured.

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