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## Problem-based Learning Across the Curriculum: Exploring the Efficacy of a Cross-curricular Application of Preparation for Future Learning

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## **Abstract**

The research reported in this paper explores the applicability and efficacy of a variant of problem-based learning, the Preparation for Future Learning (PFL) approach, to teaching and learning within the context of a cross-curricular, middle school data literacy unit called *Thinking with Data* (TWD). A quasi-experimental design was used to compare pre-to-post-test data literacy gains of seventh grade students participating in the TWD unit with other seventh graders in two middle schools in northeast Ohio. Results show statistically significant differences between the two groups. Taken together with participant comments, the findings suggest that the PFL approach can be effectively implemented across subject areas to support the development of data literacy.

Keywords: problem-based learning, PFL, data literacy, middle school

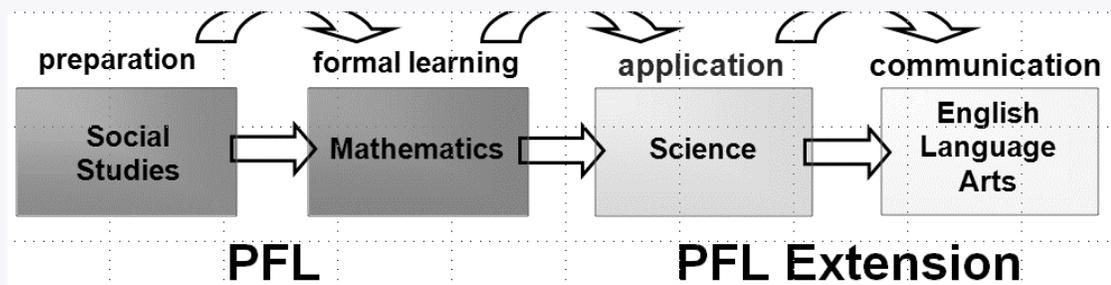
## Background

### *Preparation for Future Learning (PFL)*

The purpose of the research reported in this paper was to explore the applicability and efficacy of the Preparation for Future Learning (PFL) approach to the teaching and learning of problem solving (Bransford & Schwartz, 1999) within the context of a cross-curricular, middle school data literacy unit. The PFL approach argues that certain kinds of conceptual learning are more likely to occur when students are prepared to learn before formal instruction takes place. According to the PFL model, students prepare to learn a particular concept by exploring the domain space and working on sets of problems before they receive formal instruction on how to solve them. Through exploration, learners internalize key dimensions of these problems. Instead of creating complete solutions, students come to understand the structure of the concept and internalize key dimensions of the situation. This prepares them for the formal learning that follows, during which they are introduced to a standard, generalized solution for the type of problem they have been working on. This provides students the opportunity to reflect on both the context-bound solutions and the abstracted knowledge that makes such solutions possible. The PFL approach has been found to enhance the learning of statistical concepts in both high school and undergraduate populations (Bransford & Schwartz, 1999; Schwartz & Martin, 2004).

The PFL approach is arguably a variant of problem-based learning (Hmelo-Silver, & Barrows, 2006). Problem-based learning (PBL) is commonly characterized as driven by challenging, open-ended questions, collaborative learning, and constructivist pedagogies (Savery, & Duffey, 2001), qualities which are also an important part of PFL approaches. In addition, PFL exhibits at least five of the six attributes Barrows (1996) identified as key characteristics of problem based learning—learning is student-centered, learning occurs in small groups, teachers act as facilitators, problems form the organized focus and stimulus for learning, and problems stimulate the development and use of problem solving skills. PFL, however, reverses the typical PBL modeling, scaffolding, and fading sequence as well as the traditional lecture-and-apply process (Klahr & Nigam, 2004), by allowing students to first flounder before solutions are formally introduced and modeled (Schwartz, Bransford, & Sears, 2005). The approach, however, 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, 2003; Strike & Posner, 1992).

While PFL has been shown to support learning within a single subject area (Schwartz & Martin, 2004), we sought to use the PFL framework across an interdisciplinary data literacy curriculum consisting of interrelated modules in social studies, mathematics, science, and English language arts. In the PFL framework, students are first prepared for formal learn-

**Figure 1.** Thinking with Data PFL+ sequence.

ing by attempting to solve problems for which the concepts to be learned would provide the solutions, before being given formal instruction on these concepts. In the *Thinking with Data* (TWD) curriculum, such preparation comes in the social studies module, while formal instruction is provided in the mathematics module. Moreover, more conventional approaches to the transfer of learning are found in the subsequent science and English language arts modules, which focus on the application of data literacy skills and the communication of data-based arguments. We thus have come to think of our approach as PFL+ (Figure 1). It is important to note that the PFL+ sequence that drives the TWD curriculum across the subject area modules is also used to drive problem solving within them. The purpose of the research reported in this paper was to test the effectiveness of the PFL+ approach for developing seventh grade students' data literacy skills.

### *Data Literacy*

Data literacy is the ability to ask and answer meaningful questions by collecting, analyzing, and making sense of data encountered in our everyday lives (Rubin, 2005). Data literacy centers on the use of data to solve problems. In our increasingly data-driven society, data literacy is 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 acquiring skills in inquiry, critical reasoning, argumentation, and communication.

Data literacy requires that students investigate authentic problems; use data as part of evidence-based thinking; use appropriate data, tools, and representations to support this thinking; develop and evaluate data-based inferences and explanations; and communicate solutions (e.g., Briggs, 2002; Cobb & Moore, 1997; Madison, 2002; Rubin, 2005; Scheaffer, 2001; Steen, 2001). The data literacy objectives of the TWD unit focus on asking and answering data-based questions; using appropriate data, data manipulation tools, and data representations to solve problems; and developing and evaluating data-based arguments, inferences, and explanations. These objectives are addressed, in one form or another, in national standards for middle school social studies, mathematics, science, and English language arts (Figure 2).

The mathematics underlying data literacy in the TWD unit focuses on a central middle school concept: proportional reasoning, and in particular, on the calculation and use of

**Figure 2.** Data literacy standards across the middle school curriculum

| Data Literacy Requirement  | Middle School SS Standards (NCSS)  | Middle School Math Standards (NCTM)   | Middle School Sci. Standards (NSES)  | Middle School ELA Standards (NCTE)  |
|--|--|---|--|---|
| Formulate and answer data-based questions                          | Formulate historical questions, obtain data, question and identify gaps in data, and construct sound historical interpretations.                                 | Formulate questions, design studies, and 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 and refocus broad and ill-defined questions.                    | Conduct research on issues and interests by generating ideas and questions, and by posing problems.   |
| Use appropriate data, tools, and representations to solve problems | Use appropriate geographic tools such as atlases, data bases, systems, charts, graphs, and maps to generate, manipulate, and interpret information.              | Select, create, and use appropriate graphical representations of data; discuss and understand the correspondence between data sets and their representations. | Use appropriate tools and techniques to gather, analyze, and interpret data, including mathematics, guided by the question asked and the investigations students design. | Gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate discoveries to suit their purpose and audience. |
| Develop and evaluate data-based inferences and explanations        | Encourage increasingly abstract thought as learners use data and apply skills in analyzing human behavior in relation to its physical and cultural environments. | Use observations about differences between two or more samples to make conjectures about populations and formulate new questions and studies to answer them.  | Formulate questions, design and execute investigations, interpret data, use evidence to generate and critique explanations, and propose alternative explanations         | Use spoken, written, and visual language for learning, enjoyment, persuasion, and the exchange of information.  |

compound measures to solve problems. Whereas the phrase *data literacy* often connotes images of students at the middle school level comparing populations using measures of spread and central tendency, we have found that proportional reasoning can help students make sense of data encountered in both school and “real life.” From this perspective, the creation of common measures, particularly compound measures which are fundamental for comparison, prediction, problem solving, and argumentation, are at the center of data literacy (Vahey et al, 2012). A particularly productive form of common measure creation is the proportional 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, such as a per capita measure (Adjage & Pluvinae, 2007; Thompson & Thompson, 1992).

The section which follows explains how PFL+ is enacted across and within the modules of the TWD unit to support the development of data literacy and content area learning.

### *The Thinking with Data (TWD) Unit*

The TWD unit is spread across four two-week modules in social studies, mathematics, science, and English language arts. The modules are designed to be used consecutively and in the sequence given above. The need for proportional reasoning is evoked through problems introduced in in the social studies module. The mathematics module provides formal instruction in proportional reasoning, specifically the development of compound measures, and their application to solve the problems introduced in social studies. Opportunities for applying proportional reasoning in problem solving contexts and communicating proportional solutions are presented in the science and English language arts units respectively. Moreover, a PFL approach is taken within most lessons in each of the modules. The complete TWD unit materials can be found at: <http://www.rcet.org/twd/index.html>

**Social Studies.** The context for the entire TWD unit is world water issues. Water issues are introduced in the social studies module and situated in the Tigris/Euphrates watershed. Students are asked to make sense of a variety of real-world data about water availability and use in Turkey, Syria, and Iraq, using spreadsheets and graphical representations to manipulate, organize, and explain the data. Students are introduced to a resolution passed by the United Nations (1997) which states in part that “Watercourse States shall in their respective territories utilize an international watercourse in an *equitable and reasonable manner*,” and asked to determine whether the current allocation of water in the Tigris/Euphrates watershed is “fair,” and if it is not (and it clearly isn’t), what a fair solution might be.

Students who have not yet been introduced to the proportional reasoning tools they need to solve this problem struggle with it. While most realize the allocation is unfair, they do not know how to make it fair. A typical (more advanced) solution is to give 1/6 of the water to Syria, 1/3 of the water to Iraq, and 1/2 of the water to Turkey. Social studies thus represents the preparation phase in PFL+.

**Mathematics.** Formal learning comes in mathematics classes. Before revisiting the water sharing problem, students are given a series of related PFL-based lessons on proportional reasoning that build from simpler to more complex problems. For example, in the third mathematics lesson (Figure 3) they are asked to decide if the water availability among three counties who share water is distributed fairly. The problem, which of course resembles the problem of fair allocation in the Tigris/Euphrates basin, is simplified through the use of symbolic representations and by using more manageable numbers. It is only after students have worked in groups to answer this question, that they are introduced to the scale the symbols represent and shown how to calculate the proportion of water to people in each county to answer the question.

In the fourth lesson of the mathematics module, students investigate the original issue of fair allocation in the Tigris/Euphrates watershed. Again they are asked to work on it before being introduced to the formal solution, which requires calculating a per capita allocation for the entire region and then allocating water based on the populations of the three countries. In the mathematics module, students are also introduced to the notion of argumentation and the use of data to support arguments that are factual and whose conclusions follow from relevant data (for a more complete description of the mathematics module, see Vahey et al., 2012).

**Science.** In the science module, TWD moves into PFL+. Science represents the application phase of the PFL+ sequence. In the first part of the science module, students

**Figure 3.** First activity in Mathematics Lesson Three.

**Who Has the Most Water?**

**Activity 1: Water Availability**

Three counties have to share all their water. People in each county think that residents of the other counties are getting more than their fair share of the water. It is your job to determine who is getting less or more than their fair share.

The following charts show how much water and how many people each county has.

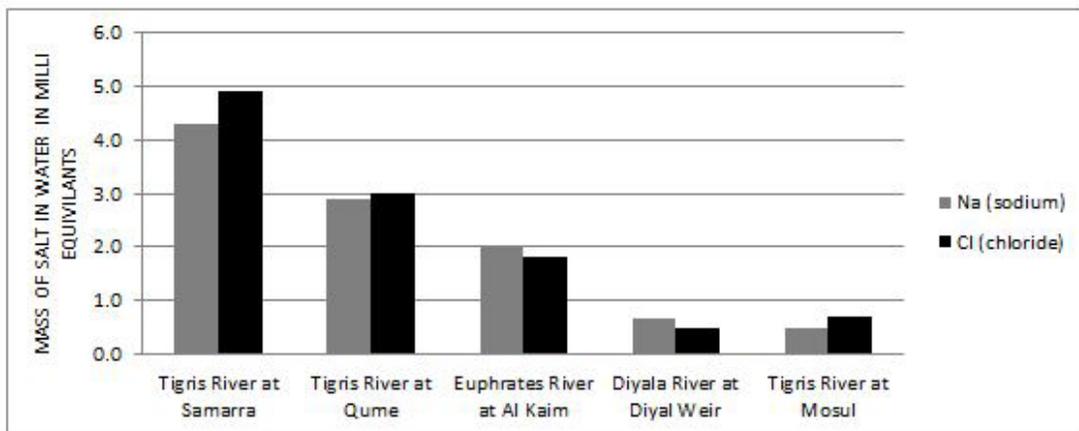
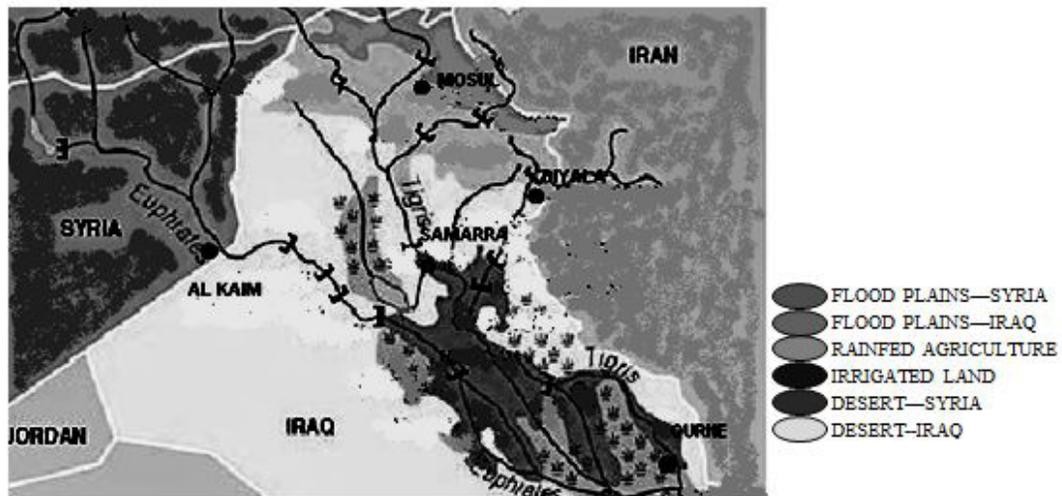
**Jefferson County**

**Clay County**

**Douglass County**

**Figure 4.** Data representations in Science Lesson Three

|        | agricultural land (km <sup>2</sup> ) | irrigated land (km <sup>2</sup> ) | irrigated land w/ salty soil (km <sup>2</sup> ) | severely salty irrigated land (km <sup>2</sup> ) |
|--------|--------------------------------------|-----------------------------------|---|--|
| 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  |



are asked to solve a series of problems involving the water cycle in the Tigris/Euphrates watershed, ditch irrigation, soil salinity, and the effects of salty soil on plant growth. Each of these activities follows a PFL sequence in which groups of students craft arguments and/or explanations for real-world phenomena and support their conclusions with data-based evidence before they are introduced to formal explanations. For example, the third science lesson presents students with three sets of data in differing representations (Figure 4) from which they are asked to decide whether or not there is evidence to support claims that ditch irrigation is causing salinity problems in the Tigris/Euphrates watershed.

In the science module, students also begin scaffolded research on problems in US watersheds.

**English Language Arts.** Students use the research on US watersheds from science class to develop persuasive essays and oral presentations in English language arts that focus on solutions to the problems they have uncovered. English language arts, then, is the communication phase of the PFL+ sequence. This phase builds on skills and understanding acquired across the modules—the knowledge of world water issues developed in social studies, the concepts of proportional reasoning and argumentation developed in mathematics, and the knowledge of the science underlying water issues and solutions gained in science. By applying the knowledge and skills gained in the social studies, mathematics and science modules together to develop data-based arguments to support the solutions to US watershed problems, students reinforce what they have learned.

## Methods

The research question addressed in this paper is:

Can a cross-curricular PFL+ approach enhance the data literacy skills of seventh grade middle school students?

The PFL+ approach utilized in the TWD unit was investigated using a quasi-experimental design within a field study involving seventh graders in two northeast Ohio middle schools. Both schools were organized into grade level teams and in each school one team (consisting of a social studies, a mathematics, a science, and an English language arts teacher and their students) completed the TWD module, while the other seventh grade teams served as a control group. In both schools, teachers and administrators characterized the students in the experimental (TWD) team as generally slightly lower than average achievers. A total of 576 students (373 in School 1 and 203 in School 2) participated in the research by completing pre/post data-literacy tests. One hundred and fourteen of these students (85 in School 1 and 29 in School 2) were taught using the TWD materials. The research took place during the 2008/2009 school year, with TWD implementation completed before winter break.

### *Data Sources and Analyses*

Data sources for the TWD research consisted of:

1. Pre/post data literacy assessment (Appendix A). The pre/post assessment was a problem-based test consisting of five questions concerned with a common issue and context, and designed to explore students' ability to ask and answer data-based questions; to use appropriate data, data representations, and data manipulation tools (proportional reasoning in particular); and to develop and evaluate data-based inferences, arguments, and explanations. It was administered to all seventh grade students in both schools at the beginning of the school year and again just before winter break, and pre-to-post-test gain scores were calculated for all students. The research design used was quasi-

experimental. Differences in average gain scores between students in the TWD team and all other seventh grade students in each school (control group) were compared using factorial analysis of variance (ANOVA). Differences on individual test questions were explored using multivariate analysis of variance (MANOVA).

2. Student reflections on the TWD unit as a whole. Students at School 1 were also asked by their English language arts teacher to create a written reflection on the TWD unit as a whole. Specifically, students were asked to elaborate on what they liked about the unit, what they disliked about it, and what they learned from it. Students' written reflections were reviewed, and emerging themes explored using constant comparison analysis.
3. Teacher interviews. An outside evaluator conducted interviews with all participating teachers immediately after they finished teaching their modules

In this paper, we report primarily on the comparison of data literacy gains between the experimental and control groups at the two schools in which the TWD unit was tested, using some of the data collected from student reflections and teacher interviews to support our interpretation of the quantitative findings.

## Results

### *Analysis of Pre-Post Test Gains*

An analysis comparing pre-to-post-test gains on the data literacy assessment across schools between students who participated in the *Thinking with Data* (TWD) unit ( $n = 114$ ) and those who did not ( $n = 462$ ) was performed using a 2x2 factorial ANOVA (Tables 1 and 2). Total possible score on the data literacy assessment was 15, and student scores ranged from 1 to 14. The range of pre- to post-test gain scores were, at School 1: -1 to 11 for the experimental group and -6 to 8 for the control group, and at School 2: -3 to 8 for the experimental group and -7 to 7 for the control group.

While the results indicate that there was no interaction between the variables "School" and "TWD Unit" with regards to differences in pre- to post-test gains, separate main effects were found for each. For the variable "TWD Unit", pairwise comparison resulted in  $MD = 2.703$ ,  $SE = 0.282$ ,  $p < .01$ , with TWD students outperforming the non-TWD students. For the variable "School", pairwise comparison yielded  $MD = 1,227$ ,  $SE = 0.282$ ,  $p < .01$ , with School 1 outperforming School 2. The findings indicate that while School 1 students' data literacy skills were greater than those of students at School 2 (both before and after the intervention), TWD students at each school developed greater data literacy skills than students in the control groups. They thus provide evidence that the PFL approach supported the development of data literacy skills in middle school students who participated in the TWD intervention.

| School | TWD Unit | <i>n</i> | Pre-Test <i>M</i> ( <i>SD</i> ) | Post-Test <i>M</i> ( <i>SD</i> ) | Pre-Post Test Difference <i>M</i> ( <i>SD</i> ) |
|--------|----------|----------|---------------------------------|----------------------------------|---|
| 1      | Yes      | 85       | 2.26 (1.79)                     | 5.95 (3.04)                      | 3.69 (2.76)                                     |
| 1      | No       | 288      | 2.60 (2.50)                     | 3.16 (2.82)                      | 0.56 (2.39)                                     |
| 2      | Yes      | 29       | 1.45 (1.86)                     | 3.48 (2.31)                      | 2.03 (2.37)                                     |
| 2      | No       | 174      | 2.74 (2.63)                     | 2.50 (2.58)                      | -0.24 (2.21)                                    |

**Table 1.** Data sample descriptives (N=576).

| Source            | Type III Sum of Squares | <i>df</i> | Mean Square | <i>F</i> | <i>p</i> | Partial Eta Squared |
|-------------------|-------------------------|-----------|-------------|----------|----------|---------------------|
| School            | 108.598                 | 1         | 108.598     | 18.896   | .000     | .032                |
| TWD Unit          | 526.734                 | 1         | 526.734     | 91.652   | .000     | .138                |
| School * TWD Unit | 13.489                  | 1         | 13.489      | 2.347    | .126     | .004                |

**Table 2.** Factorial analysis of gain scores differences on the Data Literacy Assessment.

| Question | Type III Sum of Squares | <i>df</i> | Mean Square | <i>F</i> | <i>p</i> | Partial Eta Squared |
|----------|-------------------------|-----------|-------------|----------|----------|---------------------|
| 1        | 22.662                  | 1         | 22.662      | 23.249   | .000     | .039                |
| 2        | 41.462                  | 1         | 41.462      | 60.470   | .000     | .095                |
| 3        | 25.121                  | 1         | 25.121      | 17.727   | .000     | .030                |
| 4        | 87.787                  | 1         | 87.787      | 96.681   | .000     | .144                |
| 5        | 10.383                  | 1         | 10.383      | 29.866   | .000     | .049                |

**Table 3.** Between-subjects effects for gain scores by question.

#### *Analysis of Pre-Post Test Gains by Question*

MANOVA was used to determine gain scores and effect sizes for each question separately for the students in the TWD groups only. Again, results were calculated for the overall sample as well as by school. For the overall MANOVA, the Box *M* test of equality of covariance matrices yielded an *F*-statistic of 6.172,  $p < .000$  (i.e. equality of variance was violated). Hence, the MANOVA result reported here is for the corrected model. The overall multivariate test yielded  $F(5, 570) = 32.92$ ,  $p < .000$ , with a partial eta-squared = .308, meaning that approximately 31% of the difference in total gain scores between the TWD and control groups can be explained by the TWD intervention.

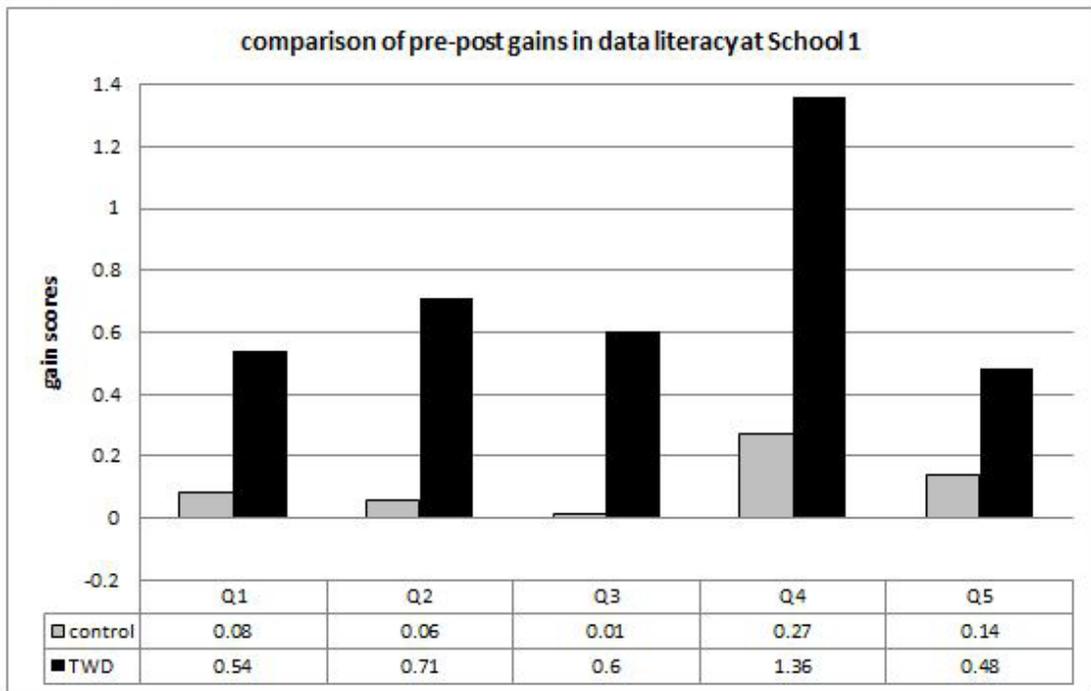
Homogeneity of variance for each question considered separately was similarly violated. Results for the corrected model are given in Table 3. Note that the *F*-statistic for each of the tests is statistically significant at  $p < .000$ , and the partial eta square statistics indicate that the variability in gain scores between the TWD and control groups explained by each question individually is 3.9% (Q1), 9.5% (Q2), 3.0% (Q3), 14.4% (Q4), and 4.9% (Q5) respectively.

Thus, when considering test questions individually, TWD student scores improved the most on those items that required data interpretation and synthesis across multiple tables and data manipulation involving proportional reasoning and calculation (questions 2 and 4; see Table 3). Similar patterns emerged when gain scores by question were analyzed by school. Figures 5 and 6 compare these gain scores on each question between the TWD and control groups at School 1 and School 2, respectively. The patterns are slightly different for each school.

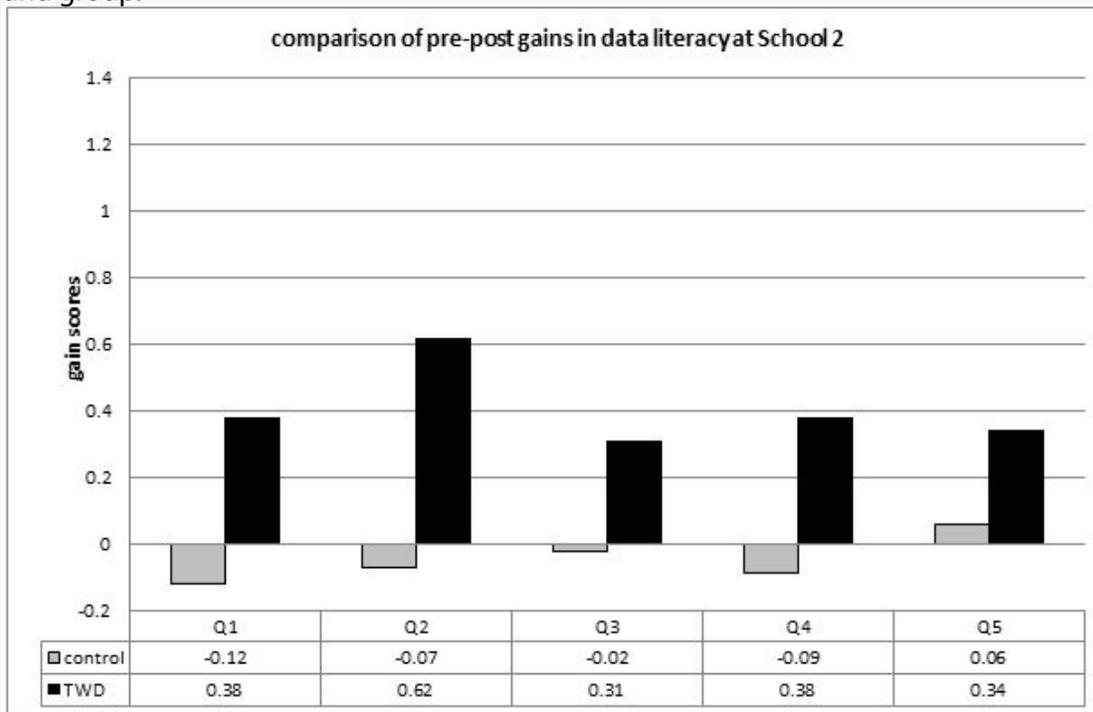
At School 1, the greatest gains realized by the TWD group were on Question 4, which asked students to complete a table by computing proportions and interpreting the results, followed by Question 2, which asked students to synthesize and interpret data across two tables. They improved a good deal more than the control group on these questions, as well as on question 3, which assessed students' ability to discern arguments presented in a narrative form. It is important to consider data literacy gains in this context to eliminate possible gains attributable to maturation or to the common seventh grade curriculum. For example, note that the greatest gains made by the control group involved the calculation of proportions, a skill focused on in the seventh grade mathematics curriculum.

At School 2, the greatest gains in the TWD group were found on Question 2, followed by Questions 1 and 4. Question 1 asked students to use data from a single table to evaluate competing arguments. It is interesting to note that at this school, the scores of students in the control group actually decreased on four out of the five questions.

**Figure 5.** School 1 comparison of Data Literacy Assessment pre/post gains by question and group.



**Figure 6.** School 2 comparison of Data Literacy Assessment pre/post gains by question and group.



## Discussion

Comparisons of gains in data literacy skills of students who participated in the TWD unit with those of similar seventh graders who did not participate in the TWD unit revealed significant differences between the two groups both across and within the two schools who participated in the field test. Although the gains were greater at School 1, overall differences between the two schools indicate that at School 2 students in both the control and experimental groups had lower scores on average on both the pre and post-tests of data literacy than similar groups at School 1. Moreover, no significant interaction between School and TWD Group was found, indicating that the TWD intervention was similarly effective for both populations. These findings indicate that the TWD materials did indeed support the development of data literacy among a seventh grade population and therefore provide evidence supporting the efficacy of the PFL+ approach embodied in them.

This conclusion is supported by student and teacher reflections on the unit. For example, when asked what they liked best about the TWD experience, many students commented on its cross-curricular nature in general, and the PFL+ sequence in particular:

The best part is that every subject was involved. In every subject it got easier and easier because we would know more and more.

After social studies we traveled to math and I thought it made me understand more of the stuff we were being taught in social studies.

I liked how we did social studies and science before language arts. Because of the knowledge you need to know, it was better to have the other subjects before language arts.

When you first started you didn't really understand it. But after switching social studies, math, science, language arts, you do things different ways. Every class has some way different to understand.

Teachers interviewed agreed that the PFL+ approached seemed to help their students learning. One of the English language arts teachers told us,

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.

She explained that the essays were particularly good because of how well the students understood the content and the way they used data as evidence to support their arguments. She thought this was because of the way students had learned data literacy skills across the four modules.

## Conclusions

Our findings indicate that preparing students for data literacy learning can occur in one curricular context (social studies) with formal learning occurring in another (mathematics), strengthening the plausibility of claims that PFL uncovers a general mechanism of transfer (Bransford & Schwartz, 1999). We also found that subsequent application (science) and communication (English language arts) of understandings may amplify learning that happens when using PFL strategies, extending the framework to a PFL+ sequence which involves more conventional, problem-based learning transfer activities. Our findings thus lend support to the efficacy of problem-based approaches in general.

Furthermore, this study provides a theoretically and empirically grounded basis for using problem-based learning in general, and the PFL framework specifically, as the basis for developing instructional materials that use real-world data to develop middle grades students' data literacy across the curriculum. Based on the results from this study, future work will include additional inquiry into the PFL+ cycle and its impact on student learning, particularly how teachers use cross-disciplinary links across modules and how student-made links between the various disciplinary modules can be made more explicitly visible. Increased understanding in these areas will then enable us to adjust the curricular and related pro-

professional development materials to stress the importance of the PFL+ cycles and their role in educating middle school students about data literacy in relevant and meaningful ways.

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**Tina Stanford** is an educational researcher at SRI in the Center for Learning and Technology. She is currently working on projects in implementing visualizing tools in the chemistry classroom (Chem-Sense and ChemViz) and the development of an instrument to assess students ICT skills to be used internationally (SITES M3). Her background is as a veteran high school science teacher. She has also served as a consultant for UC Berkeley on the SEPUP middle school science project. She served on the design team for the Golden State Exam in Science as well as conducted teacher training on assessment throughout the state of California. She represented the state of California on a national team (CCSSO-SCASS) of science assessment developers.

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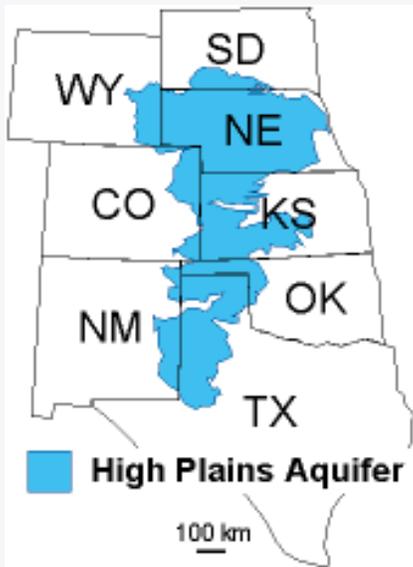
**Louise Yarnall** is a senior research social scientist at the Center for Technology in Learning. She specializes in assessment design, evaluation design, community college education research, and journalism education research. Her assessment design work is grounded in evidence-centered design and employs SRI's Principled Assessments for Design in Inquiry (PADI) assessment design system. This work involves integrating insights from cognitive science into the design of classroom testing. Her evaluation designwork examines how teachers adapt to new pedagogies and technologies for instruction. This work has focused on how community college educators use problem-based learning in technical education courses and how K-12 educators have used handheld devices to support science inquiry and collaborative learning. Her journalism education research explores how to use new technology to improve investigative and analytical reporting. This work has involved co-designing instructional materials for a graduate journalism program and conducting an international survey into how journalism professors teach journalistic analytical techniques.

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**Dale Cook** was the founder of the ATT Classroom and the Research Center for Education Technology (RCET) at Kent State University. During his tenure at Kent State, he served as the Summit Professor for Learning Technology, Professor of Educational Administration, and Director of the RCET. Dr. Cook retired from Kent State in 2012 and founded *MuveED*, Multi-User Virtual Environments for Education, of which he is the president. He has over 35 years of experience in interagency collaborative projects, political aspects of educational leadership, and community engagement. For the past fifteen years, Dr. Cook's research interests have focused on digital game-based learning and learning in virtual environments.

Appendix

Pre-/Post-Test on Data Literacy



The High Plains (or Ogallala) Aquifer is an underground reservoir of water. It contains about as much water as Lake Huron. Most of the aquifer’s water was deposited during the Ice Ages. The High Plains Aquifer lies under 174,000 square miles of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The depth of the aquifer ranges from 0 feet at its boundaries to more than 1,000 feet in west-central Nebraska.

The High Plains Aquifer is the most important source of water in the High Plains region. It provides nearly all the water for residential, industrial, and agricultural use. Irrigated agriculture forms the base of the regional economy. It accounts for 94% of the use of

water drawn from the aquifer. It also supports nearly one-fifth of the wheat, corn, cotton, and cattle produced in the United States.

|                     | 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                              | +0.08                         |

**Table 1.** Changes in Water Levels in the High Plains Aquifer, 1950-1997

|                     | 1980-1995<br>avg yearly pre-<br>cipitation in<br>inches | 1980-1995 de-<br>parture from<br>30-year avg in<br>inches | 1996 pre-<br>cipitation in<br>inches | 1996 depar-<br>ture from<br>30-year avg in<br>inches |
|---------------------|---|---|--------------------------------------|--|
| Colorado            | 17.5  | +1.3  | 19.0                                 | +2.0   |
| Kansas              | 22.6  | +1.3  | 26.7                                 | +5.4   |
| Nebraska            | 23.3  | +1.5  | 24.1                                 | +2.3   |
| New Mexico          | 17.6  | +1.3  | 15.4                                 | -1.0   |
| Oklahoma            | 21.3  | +1.3  | 25.3                                 | +5.3   |
| South Dakota        | 20.3  | +2.0  | 22.4                                 | +4.0   |
| Texas               | 20.1  | +1.2  | 18.6                                 | -0.3   |
| Wyoming             | 15.6  | +1.1  | 13.6                                 | -0.9   |
| High Plains Aquifer | 21.2  | +1.4  | 22.0                                 | +2.2   |

**Table 2.** Precipitation and Changes in Precipitation in the High Plains Aquifer, 1980-1997

In the 1940s, farmers began pumping large amounts of water for irrigation from the High Plains Aquifer. Farmers were taking more water from the aquifer than was naturally replaced by water seeping into it from the surface. By 1980, water levels had dropped by over 100 feet in parts of Texas, Oklahoma, and Kansas.

People decided something had to be done. Government programs encouraged **better irrigation and more efficient agricultural practices**. The leaders of this movement believe it has been successful. They say that the decline in water levels has slowed since 1980 when changes were made.

Others argue that **above average rain** from 1980 to 1996 is what slowed the decline in water levels.

1. The Agricultural Association of the High Plains (AAHP) argues that **changed irrigation practices and smarter use of land** have slowed the decline in water levels in the High Plains Aquifer. Use data from the tables above to support AAHP's argument. Give as many arguments in support of their position as you can.
2. The High Plains Water for All Organization (HPWA) argues that **increased precipitation** has slowed the decline in water levels in the High Plains Aquifer. Use data from the tables above to support the HPWA's argument. Give as many arguments in support of their position as you can.
3. Read "**Plains Farmers Learn from Past as Aquifer Depletes**" (attached). The two farmers quoted in the article have different points of view on using the water from the High Plains (Ogallala) Aquifer. Summarize their arguments in the space that follows. Which argument do you think is fairer and why?

| State        | 1950-1980<br>water level<br>change in feet | 1980-1995<br>water level<br>change in feet | 1950-1980<br>Change PER<br>YEAR in water<br>level in feet | 1980-1995<br>Change PER<br>YEAR in water<br>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                                       |   |   |

**Table 3.** Changes in Water Levels in the High Plains Aquifer, 1950-1995

4. Complete the following table and answer the question that follows. What **new information** do the data that you just calculated (per year changes) give you?
5. What other information or data would you need to explore the issue of irrigation versus above average rainfall further? Explain why you would need this information.

### Plains Farmers Learn from Past as Aquifer Depletes

by Debbie Elliott

**NPR, *All Things Considered*, August 11, 2007**

About a quarter of a million people left the Great Plains during the Dust Bowl of the 1930s, but for the families who stayed, hope lay in a massive aquifer of clean, fresh water right beneath their feet.

The Ogallala Aquifer, which lies under parts of eight states, was like lifeblood for Great Plains farmers who today pump billions of gallons of water from the underground supply to their crops annually. But widespread use of the Ogallala for irrigation is depleting the aquifer in some areas, leaving farmers with yearly decisions about how to use the water and how to conserve it for future generations.

#### *An Enormous Resource*

The Ogallala, a vast formation of sand and gravel, is part of a larger aquifer that once held more than 3 billion acre-feet of water, roughly the equivalent of 3 billion acres of land covered in a foot of water. The aquifer’s depth varies by state. In parts of Nebraska, there are still 1,000 feet of water saturating its sand and gravel. But in parts of Texas,

Oklahoma and Kansas—states that had less water to begin with—the water table has dropped steeply.

Just outside of Colby, Kan., farmer Lon Frahm uses 38 sprinklers to pump water over 5,000 acres of farmland. His center-pivot irrigation system sprinkles 600 gallons per minute on his corn, making up for where Mother Nature leaves off in a semi-arid zone that gets less than 20 inches of rain a year.

Frahm estimates that he pumps around 2 billion gallons of water from the Ogallala annually. In recent years, his wells have dropped about 6 inches, though in years when there is more rain, he uses less water. As a member of the Kansas water board, Frahm regularly wrestles with the question of what to do as the water table drops.

“We’ve got some people that use the analogy of oil. What’s the difference between taking oil from the ground, and taking water from the ground? It’s a resource not doing any good down there,” Frahm says, citing a view he often hears from other farmers.

Kansas has created local groundwater management districts to manage water use in the state. But some believe that only a wholesale shift in the economy can reduce the demand on the Ogallala.

### *Improving on the Past*

Some farmers are returning to dryland farming—raising crops without irrigation—rather than depending on the Ogallala for hydration. Bill Mai, a farmer in Sharon Springs, Kan., was born in the middle of the Dust Bowl. During the worst of the Dust Bowl, his parents considered moving away, but they mustered the will to stay, and discovered they could tap the Ogallala for their crops.

But Mai realized years ago that there wouldn’t always be enough water for him to irrigate, so he modified pre-Dust Bowl farming methods to cultivate his wheat and corn crop. In the early 20th century, farmers plowed millions of acres of the Great Plains to plant wheat. Their plows freed soil from the roots of native grass that had evolved over millions of years to hold the earth in place. Once the wheat withered away, the loose soil blew black blizzards across the Plains. At its peak, the Dust Bowl covered 100 million acres.

Rather than repeat the mistakes of the past, Mai now protects his soil by leaving stubble from previous harvests intact. Rain falls on the ground cover, creating a spray that drains down into the soil. He says that dryland farming will help conserve the Ogallala for his grandchildren.

“The water here is probably the most valuable natural resource that we have for every purpose that there is,” he says. “If you’re looking at economic development and we don’t have water, you’re dead in the water. Literally.”