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Improving Students' Graph Literacy: Report of an Experiment in Maine

by

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Executive Summary

As part of the Piloting Graph Literacy Activities in Maine ("Graph Literacy") project (funded by NSF grant # DRL-125649), the Concord Consortium created six software activities designed to teach graph literacy to middle school science students. During the winter of the 2013-2014 school year the project staff conducted a randomized experimental trial of these activities in Maine. The primary research question is whether use of the software activities would increase experimental students' understanding of graphs, compared to the control group that did not use the software. (Project website: http://concord.org/projects/graph-literacy.)

Nine teachers in Maine were recruited to participate in the study. All of them taught science or math in grades 6-9. Five teachers were randomly selected for the experimental group and four for the control group. Data were collected from all teachers about the experiences of three sections of students. In total, more than 500 students in 27 classes participated in the research.

With assistance from an expert item writer, the project developed a 20-item multiple-choice assessment of students' understanding of graphs. The same assessment, which was delivered online, was used as a pre-test in November 2013 and as a post-test in February 2014. In all, 378 students completed both the pre-test and post-test. Each item was matched to one of seven learning objectives that were established for this project, based on a review of research about how people learn to "read" and understand graphs. (An example of a learning objective is, "*The student will understand how zooming, panning, stretching, and shrinking do not change the data within a graph.*") Statistical tests established that the assessment is reliable.

The other instrument used for the study is a weekly log. Teachers were asked to describe instructional activities each week in which students used graphs. Experimental teachers also answered questions about their use of the six software activities. All the teachers submitted weekly logs for three sections of students. More than 300 logs were submitted.

Pre-test scores for the students in the experimental and control groups were not statistically different. However, the mean gain from pre to post for the 214 experimental students was 1.23 (median = 1.5, mode = 2, sd = 3.09), which was statistically significant. The gain from pre to post for the 164 control students was 0.17 (median = 0, mode = 0, sd = 2.99), which was not statistically significant. The effect size of the difference in gain scores is 0.35, which is considered a small to medium size effect, and this result is statistically significant ($t = -3.347$, $df = 376$, $p = .001$). We conclude that the experimental treatment—use of the six software activities—had a statistically significant positive impact on students' understanding of graphs, as assessed using the pre/post test.

The secondary research question for this study is whether, after using the activities, the experimental teachers believe they are valuable to students, easy to use, and worth the time and effort to include in the STEM curriculum. Teachers reported that it took students an average of 20 minutes to complete an activity. In 75% of the instances when teachers used an activity with a class they reported they would use the activity again "as is" or "with minor changes." In 75% of the trials teachers agreed or strongly agree that the content was accessible to their students, and 80% of the time they agreed or strongly agreed that the software activities helped their students achieve the learning objectives for that activity.

The overall conclusion of this study is that the approach used to teach graph literacy is promising.

Graph Literacy: Report of an Experiment in Maine

The Piloting Graph Literacy Activities in Maine project (shortened to Graph Literacy below) is funded by an EAGER grant from the National Science Foundation (grant # DRL-125649). For this project the Concord Consortium created six software activities designed to teach graph literacy to middle school science students. During the winter of the 2013-2014 school year the project staff conducted a randomized experimental trial of these activities in Maine.

This report begins by describing the graph literacy learning objectives (section 1), the study participants, the research questions, and the instruments. Next, results are presented comparing learning gains by students in the experimental and control groups (section 5). The report then explores the experiences and opinions of the experimental teachers regarding the software activities (section 6) and the other graph-related activities used by teachers (section 7).

1. Graph Literacy Learning Objectives

Based on a review of the literature, which was described in the grant proposal, the project established a set of learning objectives for students. Briefly, our reading of the research literature suggests that people learn to "read" and understand graphs in three steps. First, someone looking at a graph must identify and encode superficial graph features; next, link these superficial features to quantitative facts, trends, or other relationships; and finally, integrate the features and relationships with the context of the graph.

Given these three steps, we established seven learning goals and a dozen objectives associated with the goals, as shown in Appendix A. However, due to time and budget constraints, and because most students have mastered Objective 1.1, reading (x, y) coordinates, by the time they reach sixth grade (the lowest grade level included in the research), we chose to focus especially on the seven learning objectives identified, by activity, in Exhibit 1.

Exhibit 1: Graph Literacy Learning Goals and Objectives

Objective #	Objective	Software Activity Title
1.2	*The student will understand how zooming, panning, stretching, and shrinking do not change the data within a graph.*	Equivalent Graphs
1.3	*The student will be able to interpolate between points on a graph.*	Interpolation
1.4	*The student will be able to determine the dependent and independent variables.*	Dependent and Independent Variables
2.1	*Identify the overall shape and direction of a line graph, and connect the shape with the real-world meaning.*	Graphs Tell a Story
2.2	*Identify the maxima and minima of a graph and interpret their meaning.*	Hurricane Katrina
2.3	*Estimate the slope of a line and describe its real-world meaning.*	Growing Up
6.1	*The student will be able to connect sections of a piecewise linear graph with sections of a story.*	(various of the above)

During the first fourteen months of the project we developed the six activities identified in Exhibit 1, pilot tested them with teachers and students, using paper and pencil, and then converted the paper activities to software. The runtime software and activity authoring system that we used to develop the graph literacy activities was developed in a separate but related project called SmartGraphs (NSF grant # DRL-0918522). Multi-page SmartGraphs activities (http://smartgraphs.org), which run in a Web browser, scaffold students who need help as the students answer questions about, and interact with, graphs (see http://concord.org/gl).

2. Participants

Nine teachers in Maine were recruited to participate in research using the software activities. None were involved in the pilot testing. Five teachers were randomly selected for the experimental group and four for the control group. Teachers did not know which group they would be part of until they came to a half-day training (separate morning and afternoon events held on the same day, one for the experimental group and the other for the control group).

Seven of the nine teachers were teaching science to seventh and eighth graders. One of the five experimental teachers was teaching ecology and earth systems to ninth graders, and one experimental teacher taught earth science to sixth graders.

For teachers in both groups, data were collected about the experiences of three sections of students. In all, there were more than 500 participating students in 27 classes.

3. Research Questions

1. The primary research question in the Graph Literacy study is whether students using the Graph Literacy activities increased their understanding of graphs, compared to students who did not use those activities. That question will be answered based on pre/post test data from students in the experimental and control classes.
2. The secondary research question is: Do teachers believe the activities are valuable to students, easy to use, and worth the time and effort to include in the STEM curriculum? That question is answered based on the teacher log data.
3. A tertiary research question is: What other types of instructional activities, besides the six software activities, were offered to students to help them learn graph literacy skills?

4. Instruments Used in the Study

Two instruments developed by this project provide data to answer the research questions: 20-item pre/post tests (assessments) for students, and weekly logs for the teachers.

Pre/Post Tests

To create the student assessments an expert item writer, hired as a consultant, first developed four items for each of nine graph literacy related learning goals. For some, she found and adapted items from existing assessments (such as NAEP or MCAS), but most items were written for this project. All the items were multiple-choice. Items were revised in consultation with the research director for the project, and then shared with teachers in Maine who examined them for alignment to the graph literacy learning goals and for grade appropriateness. The two teachers who responded were a sixth grade science teacher and a middle school math teacher, and their opinions may not provide equal validity for students in 7th and 8th grade science classes. None of the items were eliminated based on the responses from the two teachers.

After an artist created graphics for all items, suitable to be delivered online using Survey Monkey, the items were divided into three forms of 20 items each. Some items were included on all three forms. Two teachers administered the three forms of the online assessment to their classes, having students count off (A, B, C) to determine which form they would take. A third teacher (middle school science) administered the assessments on paper because she no longer had access to computers for the school year, and these results were entered into a spreadsheet by hand to be included in the analysis. The assessment pilot took place in May and June 2013.

Analysis of the pilots looked at descriptive statistics to determine if items would be too difficult or too easy. Reliability analysis identified items that lowered reliability when deleted. Rasch analysis identified items with high outfit, meaning they did not fit with the scale, indicating they may have been measuring a different construct than the other items. During analysis, two items were found to be faulty. One had no correct answer, so the item was eliminated from analysis. The second had an ambiguous answer so for these analyses both possible answers were counted as correct, and a separate analysis was completed with the item deleted.

For the study, learning objectives were narrowed to seven (see Exhibit 1), and an assessment with 20 items selected to match those seven objectives was developed. The final items were selected based on results of the pilot test analysis. The same 20-item assessment was used as both the pre-test and post-test. Each correct answer was worth one point, so the maximum score was 20. Two sample items are shown in Appendix B.

Eventually only six activities, aimed at six objectives, were used by the experimental groups. Thus learning objective 6.1 ("the student will be able to connect specific sections of a piecewise linear graph with specific sections of a story") is included in the assessment, but teaching students this objective was not the sole or primary objective of any of the six activities.

Teacher Logs

Both experimental and control teachers completed weekly online logs for each section starting in late November 2013 when they administered a pre-test to students and ending in mid-February 2014 when they administered a post-test. The logs completed by the experimental teachers included questions about their experiences using the software activities with students. For all teachers, the logs also included questions about other instructional activities related to graphs. Altogether, the nine teachers completed more than 300 weekly logs.

5. Learning Gains: Experimental Findings

There were 509 students who took the pre-test, the post-test or both. We defined completion as answering ten or more questions. On the pre-test, 482 students took the test and 462 completed it (96%). On the post-test, 438 students took the test and 412 completed it (94%). Across all 509 students, 378 students (74%) completed both the pre and the post-test.

On the pre-test there was not a significant difference in performance between the experimental and control groups ($t = -.070$, $df = 460$, $p = .944$)—see Table 1—which provides confidence that the two groups are similar. However, on the post-test there was a significant difference in performance between the experimental and control groups ($t = -2.056$, $df = 410$, $p = .040$); see Table 2.

Table 1: Pre-Test Descriptive Statistics

	Number completing	Mean	Median	Mode	Standard deviation
Experimental	248	9.54	9.00	6	4.013
Control	214	9.51	10.00	10	4.191
Total	462	9.52	9.00	6	4.092

Table 2: Post-Test Descriptive Statistics

	Number completing	Mean	Median	Mode	Standard deviation
Experimental	234	10.77	11.00	15	4.404
Control	178	9.90	10.00	12	3.987
Total	412	10.40	10.00	12	4.246

The remaining analyses only apply to students who completed both the pre and the post-test (378 students). For these groups there was statistically significant improvement from pre to post for the experimental students, but not for the control students. See Table 3.

Table 3: Comparing Pre and Post-Tests

	N	Pre-Test Mean (sd)	Post-Test Mean (sd)	Statistical Significance?	Effect Size
Experimental	214	9.58 (4.04)	10.81 (4.40)	t = -5.821, df = 213, p < .0005	.40
Control	164	9.88 (4.07)	10.05 (3.96)	t = -.731, df = 163, p = .466	.06
Total	378	9.71 (4.05)	10.48 (4.23)	t = -4.848, df = 377, p < .0005	.25

The mean gain from pre to post for the 214 experimental students was 1.23 (median = 1.5, mode = 2, sd = 3.09). The gain from pre to post for the 164 control students was 0.17 (median = 0, mode = 0, sd = 2.99). The effect size of the difference in gain scores is 0.35, which is considered a small to medium effect. This result is statistically significant (t = -3.347, df = 376, p = .001).

An analysis of students' pre/post test scores was also conducted by teacher. For the four teachers in the control group, none showed statistically significant gains from pre to post. For the five teachers in the experimental group, three showed statistically significant gains for their students. Students of two teachers, AH and RL, did not have statistically significant gains. In the next section we will see that those same two teachers' reported experiences with and opinions about the software differed from the other teachers in the experimental group.

We conclude that the experimental treatment, use of the six software activities, had a statistically significant positive impact on students' understanding of graphs, as assessed using the pre/post test.

6. Use of and Opinions about the Graph Literacy Software Activities

The five experimental teachers used each activity with three sections of students, producing log data that included information from five teachers about 15 uses of each activity. There were six activities, so logs provided data about 90 uses of the activities in all.

Teachers reported that each activity took about 20 minutes for students to complete; this is the median value for each activity. (See Table 4.) There were some variations by activity. The maximum median time was only 30 minutes, which was in line with our intentions.

Teachers spent about an equal amount of time preparing to use each activity as in using it with a class. (See Table 5.) Preparation included trying the activity, and perhaps reading the lesson plan and paper-and-pencil student assessment ("check-in") provided to teachers for each activity.

Use of the lesson plan and the student assessment was optional. About half of the time teachers used an activity with students they used the lesson plan; however, they used the student assessment with classes only 20% of the time. (See Table 6.)

Table 4: About how long did it take most of your students to complete this activity?

	Median (minutes)
Equivalent Graphs	30
Interpolation	20
Dependent & Independent Variables	15
Graphs Tell A Story	20
Hurricane Katrina	20
Growing Up	30
ALL ACTIVITIES	**20**

Table 5: How long did it take you to prepare to teach this activity?

	Median (minutes)
Equivalent Graphs	15
Interpolation	20
Dependent & Independent Variables	10
Graphs Tell A Story	15
Hurricane Katrina	15
Growing Up	30
ALL ACTIVITIES	**20**

Table 6: Use of the lesson plan and student assessment

	Yes	No	Total
Did you use the lesson plan for this activity?	46%	54%	100%
Did you use the assessment ("check-in") for this activity?	20%	80%	100%

Teachers were asked to answer opinion questions about each use of a software activity. Perhaps the most informative summary question regarding the efficacy of the activities was, "Please comment on the overall usefulness of the activity. Would you use this activity in your classroom again?" On 75% of the 90 logs teachers answered "yes" or "yes with minor changes," while on 24% they answered "no." (The total is not quite 100% due to rounding. See Table 7.)

There were substantial variations by activity in teachers' opinions whether they would use the activity again. (See Table 7.) Interpolation stands out as the activity with the largest percentage of "no" responses while Hurricane Katrina had by far the largest percentage of "yes" responses, in part because students found the topic of hurricanes especially engaging, according to the teachers. (One teacher wrote, "*Students love hurricanes! Well, learning about them anyway.*")

Table 7: Would you use this activity in your classroom again?

	Would you use this activity in your classroom again?			
	Yes	Yes with minor changes	No	Total
Equivalent Graphs	40%	60%	0%	100%
Interpolation	7%	40%	53%	100%
Dependent & Independent Variables	33%	33%	33%	100%
Graphs Tell A Story	47%	13%	40%	100%
Hurricane Katrina	73%	27%	0%	100%
Growing Up	47%	33%	20%	100%
ALL ACTIVITIES	41%	34%	24%	100%

What factors might explain teachers' lack of enthusiasm for the Interpolation activity? Responses to several other questions help answer that question. On 60% of the logs about the Interpolation activity teachers indicated that they do not usually teach interpolation. (See Table 8.) Moreover, teachers more often reported that the content of the Interpolation activity was *not* accessible to their students than for any other activity, and that the activity did *not* help their students meet the learning goal. (See Tables 9 and 10.)

Table 8: I usually teach the content of this activity in this course

	I usually teach the content of this activity in this course					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total
Equivalent Graphs	13%	40%	7%	40%	0%	100%
Interpolation	20%	20%	0%	60%	0%	100%
Dependent & Independent Variables	47%	13%	0%	20%	20%	100%
Graphs Tell A Story	33%	47%	0%	20%	0%	100%
Hurricane Katrina	0%	53%	27%	20%	0%	100%
Growing Up	0%	53%	27%	20%	0%	100%
ALL ACTIVITIES	19%	38%	10%	30%	3%	100%

Table 9: The content of the activity was accessible to most students in my class

	The content of the activity was accessible to most students in my class					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total
Equivalent Graphs	33%	47%	13%	7%	0%	100%
Interpolation	0%	27%	33%	40%	0%	100%
Dependent & Independent Variables	7%	67%	7%	0%	20%	100%
Graphs Tell A Story	20%	73%	7%	0%	0%	100%
Hurricane Katrina	0%	100%	0%	0%	0%	100%
Growing Up	27%	53%	0%	0%	20%	100%
ALL ACTIVITIES	14%	61%	10%	8%	7%	100%

Table 10: The activity helped my students meet the stated learning goals

	The activity helped my students meet the stated learning goals					
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Total
Equivalent Graphs	14%	71%	14%	0%	0%	100%
Interpolation	0%	40%	20%	40%	0%	100%
Dependent & Independent Variables	7%	73%	0%	0%	20%	100%
Graphs Tell A Story	20%	73%	7%	0%	0%	100%
Hurricane Katrina	7%	93%	0%	0%	0%	100%
Growing Up	0%	80%	0%	20%	0%	100%
ALL ACTIVITIES	8%	72%	7%	10%	3%	100%

Experimental teachers were asked to explain their answers about whether or not they would use an activity with their students again. Among responses for the Interpolation activity, the teachers' comments included:

> *I think that this would be more beneficial with a math teacher as my current curriculum was very different and did not 'lend' itself to this.*

I would probably have fewer points [on the graph] and try to relate the data in the graph to a topic that we were covering.

I think it is a bit too advanced for my 6th graders at present.

More practice with easier interpolation questions would be useful.

Not unless [page] #6 is edited to be more user-friendly with iPads.

Analysis by Teacher

The logs were also analyzed by teacher. (See Tables 11 and 12.) There were two outliers in those analyses. The sixth grade teacher, RL, was by far the *least* likely to answer "yes," she would use the activities again. An eighth grade teacher, AH, was by far the most likely to *disagree* that she usually taught the content of the activities.

Table 11: Would you use this activity in your classroom again (by teacher, all activities)

	Would you use this activity in your classroom again?			
Teacher	**Yes**	**Yes with minor changes**	**No**	**Total**
AH	39%	22%	39%	100%
DY (grade 9)	44%	22%	33%	100%
JN	56%	44%	0%	100%
RK	50%	33%	17%	100%
RL (grade 6)	17%	50%	33%	100%
ALL TEACHERS	41%	34%	24%	100%

Table 12: I usually teach the content of this activity in this course (by teacher, all activities)

	I usually teach the content of this activity in this course					
Teacher	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Total**
AH	0%	6%	0%	94%	0%	100%
DY (grade 9)	33%	67%	0%	0%	0%	100%
JN	33%	39%	11%	17%	0%	100%
RK	28%	50%	0%	22%	0%	100%
RL (grade 6)	0%	28%	39%	17%	17%	100%
ALL TEACHERS	19%	38%	10%	30%	3%	100%

7. Other Graph-related Instructional Activities

Both the experimental and control teachers were asked to answer questions on their logs about uses of graphs *not* related to the Graph Literacy software activities. The purpose of these questions is to learn more about teachers' ordinary or typical instruction using graphs.

There were a total of 170 logs completed by the experimental teachers, 73 of which were for a week that included use of a Graph Literacy activity and 97 of which were logs when they did not use one of the software activities. The control teachers completed 117 logs, with the four control teachers completing an average of 29.25 logs per teacher while the five experimental teachers completed an average of 34 logs per teacher, numbers that are roughly comparable, although experimental teachers completed somewhat more logs, on average across the teachers.

In response to the following question about *non-Graph Literacy* activities, "On how many days [this week] did this class see or use graphs," the experimental teachers reported 1.1 days per week, on average. That average was virtually identical for logs submitted on weeks the teachers used a Graph Literacy activity with the section, or weeks they did not. In comparison, the control teachers reported only 0.53 graph-related activities per week, or about half the number reported by the experimental teachers. In other words, the experimental teachers reported using more graph-related activities, even activities that were not part of the experimental treatment.

Table 13 shows the frequency of different types of graph-related activities used with students, as reported by the teachers, expressed as a percent of all the days on which students used graphs. Because one graph-related activity can be used in multiple ways (such as creating a graph and then interpreting information about the graph), the totals do not add to 100%.

Table 13: Frequency of types of graph-related activity, as a percent of all graph-related activities

	Experimental Teachers	**Control Teachers**
Creating graphs by hand	13.9%	27.0%
Creating graphs with software	4.8%	9.5%
Reading information from graph	41.7%	63.5%
Interpreting information on graphs	37.4%	58.7%
Relating graphs to real-world phenomenon	28.3%	41.3%
Any of the above (sum)	126%	200%

When graph-related activities were used, the control teachers used them to accomplish multiple goals more often than the experimental teachers. However, as previously noted, the randomly-selected experimental teachers used graph-related activities more often than the control teachers. In both groups the most frequent uses of graphs were to read information from a graph and interpret information on a graph. Graphs were used for a wide variety of topics that included genetics, weather, density, and space science.

The data suggest two reasons that students in the control group did not show significant gains from pre to post on the 20-item assessment. For one thing, they were exposed to instructional activities using graphs only about once every two weeks, which is not frequent exposure. In addition, the topics of the graphs, and the purposes for which they were used, varied widely so that there may not have been consistent instructional messages received by students to help them read other graphs besides one in front of them. In other words, there is no reason to believe that the control teachers had any specific set of learning objectives in mind when they used graphs. One control teacher commented that students' use of graphs that week would have been "*by* *chance as students researched life on the International Space Station*." Another teacher said students "*used graphing to help visualize information from their data tables*," which is an important skill but one that most students would have learned in grades K-5 and that probably required a scatter plot rather than a line graph.

8. Additional Information from Teachers and Students

Additional information comes primarily from the teacher logs and the post-test for the experimental students. For those students, we included four items at the end of the post-test asking about their experience using the six activities. We also conducted one teacher interview after the classroom trials were completed.

Students' Opinions about the Activities

Many students reported that the software activities helped them to learn about graphs. Among 227 students who responded to the question, only 12 percent "disagreed" or "strongly disagreed" that "I learned a lot about graphs when using Graph Literacy activities," while 42 percent agreed or strongly agreed. The remaining 46 percent responded "neutral."

At the same time, students did not especially enjoy using the activities. Only 17 percent agreed or strongly agreed, "I would like to use Graph Literacy activities for more topics or in other classes," while 35 percent disagreed or strongly disagreed. The remaining 48% responded "neutral."

Software Features

Before the activities were used in classrooms we used software to check the reading level (difficulty) of each one and made some adjustments. Nonetheless, there are challenges creating software activities that will be used by a wide variety of students. One teacher reported, "*in this class there are 7 students with IEPs, who have various problems with learning*," whereas a classroom down the hall, or during another time period, may consist mostly of advanced students. Another teacher, who works with sixth-graders said, "*They had to have [this activity] read to them*," and, for a different activity, reported that her students did not understand some words, such as "unit," "automatic," and "analogy," whereas other teachers did not report any problem with unfamiliar words in that same activity.

Fortunately, teachers can often find a way to adapt activities to a particular class. The teacher of sixth-graders reported for one activity that "*we did the activity together as a class*" and nonetheless "*students really liked the activity and generally gave positive feedback*."

The research literature suggests that many students who are faced with a computer screen quickly look for something to do, rather than something to read. Some teachers encountered this issue, noting "*students tended to skip over [pages] that did not have activities on them without reading them (despite teacher direction); when later questions asked to build on that content, students were not able to click back without restarting the entire activity.*" (For better or for worse, we intentionally disabled the Back button in the activities.) Teacher guides for each activity provided guiding questions to teachers for each activity.

Related to disabling the Back button as a design feature, it is always possible to think of other software features that would be desirable in one instance or another. A few comments from teachers mentioned including a software calculator at certain places, or creating the capability for SmartGraphs to read text aloud to students.

Graphs in Science and in Math

In an earlier study of the use of SmartGraphs activities to teach about the motion of objects in 8th/9th grade Physical Science classes,[1] we discussed some of the challenges teachers experience coordinating instruction across math and science departments. For example, many of the three-dozen Pennsylvania teachers who participated in that study expressed concern about the differences in vocabulary used in math and science classes. They said that math teachers often do not use units, and that students who learn about rise over run in math classes too often do not connect slope to speed or to other slope-related science concepts.

Some of the Maine teachers participating in the current study also raised concerns about coordinating the teaching of graphs across math and science departments. In a follow-up interview with AH, the teacher who most often *disagreed* that she usually taught specific graph literacy topics in science (Table 12), she said, "*I don't teach graphs. [The curriculum] is more pure science than teaching about graphs, like scales. So maybe I wish that were taught in math. But it is not in the curriculum. It may change as we adopt the Next Generation Science Standards. Right now, we teach formulas. You read the text, we will discuss it and test. There is a lot of vocabulary; the curriculum is very language oriented. We do not have students graph results in science class as often as we might.*" AH noted that her school's science scores on the state test are very high (87% of students "pass"), whereas the math scores "*are really low*." The math and science departments have not assigned specific responsibilities for teaching students about graphs. "*We need better coordination*," she admitted.

Table 12 shows that in some respects AH was an outlier among the teachers in the experimental group. Nonetheless, we continue to wonder whether teachers in *any* department—English and language arts, science, or mathematics—believe they have responsibility, let alone primary responsibility, to teach what we call "graph literacy."

[1] Zucker, Kay, & Staudt. (2014). Helping students make sense of graphs: an experimental trial of SmartGraphs Software. *Journal of Science Education and Technology*, 23:3, 441-457.

Appendix A

The following information describes the steps, goals, and objectives for learning to read and understand graphs, as identified by this project. Science and mathematics education standards are included with which many of the learning goals are aligned (where NGSS refers to the Next Generation Science Standards and CCSS-M refers to the Common Core State Standards for Mathematics).

I. Identify and encode superficial graph features. This "bottom-up" process focuses on features such as the graph title, the axes and their titles, the shapes of the graph(s), and any other visual cues, such as color or grouping.

GOAL 1. Identify and Use Scales. The first step in graph comprehension involves focusing on the scales and noticing and correctly interpreting the quantity graphed, units (if any), and numerical range.

Objective 1.1: *The student will correctly name the coordinate values of any point on any single line graph or scatter-plot, including units, if any.*
Objective 1.2: *The student will understand how zooming, panning, stretching, and shrinking do not change the data within a graph.*
Objective 1.3: *The student will be able to interpolate between points on a graph.*
Objective 1.4: *The student will be able to determine the dependent and independent variables.*

Alignment of Goal 1 with Standards:

NGSS: MS-PS3-1. *Practices* - Construct and interpret graphical displays of data to identify linear and nonlinear relationships.
NGSS: MS-LS4-3. *Practices* - Analyze displays of data to identify linear and nonlinear relationships.
NGSS: MS-PS4-1, MS-LS4-3 *Cross-Cutting Concepts* - Graphs, charts, and images can be used to identify patterns in data.
CCSS-M: 5.G.2 Graph points on the coordinate plane to solve real-world and mathematical problems. (Geometry)
CCSS-M: 6.NS.8 Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate. (The Number System)
CCSS-M: 6.EE.C.9 Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. For example, in a problem involving motion at constant speed, list and graph ordered pairs of distances and times, and write the equation $d = 65t$ to represent the relationship between distance and time. (Equations and Expressions)
CCSS-M: A.CED.2 Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. (Algebra)

GOAL 2. Identify General Graph Features. The other part of the first step in graph comprehension involves visual processing of the overall graph shape. This also includes relating graph shapes and meanings. We expect that instruction that focuses on specific kinds of features will help students acquire this skill.

Objective 2.1: *Identify the overall shape and direction of a line graph, and connect the shape with the real-world meaning.*
Objective 2.2 *Identify the maxima and minima of a graph and interpret their meaning.*
Objective 2.3: *Estimate the slope of a line and describe its real-world meaning.*

Alignment of Goal 2 with Standards:

NGSS: MS-PS3-1. *Practices* - Construct and interpret graphical displays of data to identify linear and nonlinear relationships.

NGSS: MS-LS4-3. *Practices* - Analyze displays of data to identify linear and nonlinear relationships.
NGSS: MS-PS4-1, MS-LS4-3 *Cross-Cutting Concepts* - Graphs, charts, and images can be used to identify patterns in data.
CCSS-M: 6.EE.C.9 Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. For example, in a problem involving motion at constant speed, list and graph ordered pairs of distances and times, and write the equation d = 65t to represent the relationship between distance and time. (Equations and Expressions)
CCSS-M: 6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems. (Ratios and Proportionalities)
CCSS-M: 8.F.A.3 Interpret the equation $y = mx + b$ as defining a linear function, whose graph is a straight line; give examples of functions that are not linear. (Functions)

II. Link superficial graph features to quantitative facts, trends, or other relationships. The second step involves associating visual features with information that might apply to *any* graph with similar features. For instance, for a rising, straight-line distance-time graph, the viewer might associate "rising" with an increase of the y-value over time, and "straightness" with constant, steady change.

GOAL 3. Recognize Basic Functions and their Significance. This goal focuses on mathematical functions that often match (or "model") the data. One advantage of modeling data in this way is that the function provides a way to extrapolate beyond the data.

Objective 3.1: *The student will be able to identify a graph or scatter plot of data that can be approximated by sections of linear functions.*
Objective 3.2: *The student will be able to identify a graph or scatter plot of data that can be approximated by sections of quadratic functions.*
Objective 3.3: *The student will be able to extrapolate a linear function beyond available data and describe the behavior of the extrapolated function.*

Alignment of Goal 3 with Standards:

NGSS: MS-PS3-1. *Practices* - Construct and interpret graphical displays of data to identify linear and nonlinear relationships.
NGSS: MS-LS4-3. *Practices* - Analyze displays of data to identify linear and nonlinear relationships.
NGSS: MS-PS4-1, MS-LS4-3 *Cross-Cutting Concepts* - Graphs, charts, and images can be used to identify patterns in data.
CCSS-M: 5.G.2 Graph points on the coordinate plane to solve real-world and mathematical problems. (Geometry)
CCSS-M: 6.NS.8 Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate. (The Number System)
CCSS-M: MP.2 Reason abstractly and quantitatively. (Math Practices)

GOAL 4. Recognize the Significance of Breakpoints.

GOAL 5. Identify Trends in Noise.

III. Integrate the features and relationships with the context of the graph. When under-standing does not come with steps I and II, it requires a more complex process of inference. The general, context-free associations made about the graph in the first two steps must be linked to the specific contextual clues provided by the labels, axes, graph shapes, captions, and any information or knowledge about the context in long-term memory. For example, this step might result in the viewer seeing a graph as a story about Sally walking at a constant speed from home to the bus stop.

GOAL 6. Link Stories and Graphs—Piecewise Linear. This goal focuses on mathematical functions that often match (or "model") the data. One advantage of modeling data in this way is that the function provides a way to extrapolate beyond the data.

Objective 6.1: *The student will be able to connect specific sections of a graph with specific portions of a story.*

Objective 6.2: *The student will be able to connect multiple representations — including the graph, table, function, and animation — to specific portions of a story.*

GOAL 7. Link Stories and Graphs—Any Common Function.

Alignment of Goal 7 with Standards:

NGSS: MS-PS3-1. *Practices* - Construct and interpret graphical displays of data to identify linear and nonlinear relationships.

NGSS: MS-LS4-3. *Practices* - Analyze displays of data to identify linear and nonlinear relationships.

NGSS: MS-PS4-1, MS-LS4-3 *Cross-Cutting Concepts* - Graphs, charts, and images can be used to identify patterns in data.

CCSS-M: 5.G.2 Graph points on the coordinate plane to solve real-world and mathematical problems. (Geometry)

CCSS-M: 6.NS.8 Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate. (The Number System)

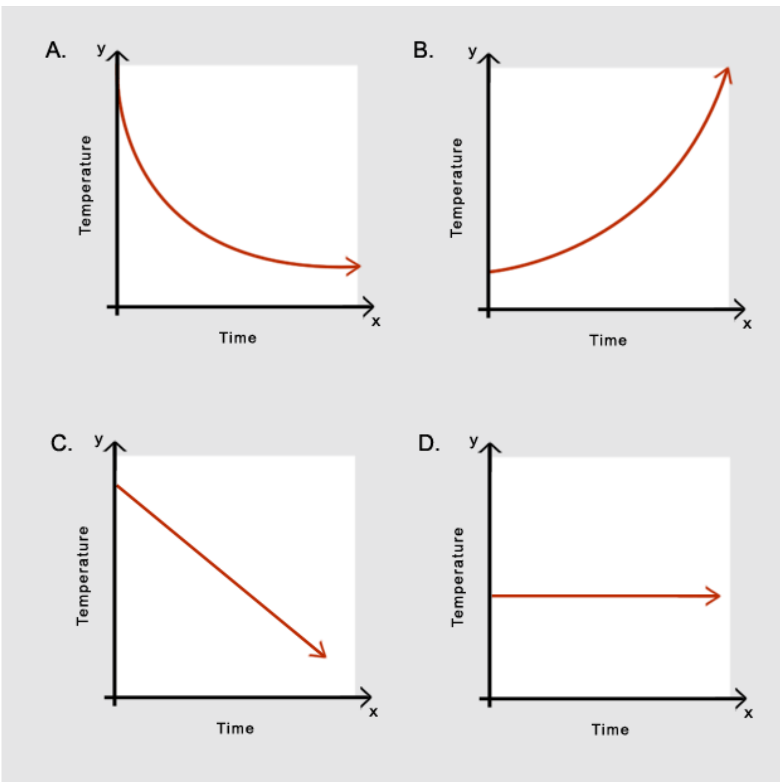
CCSS-M: MP.2 Reason abstractly and quantitatively. (Math Practices)

Appendix B

Two sample items from the 20-item graph literacy assessment are shown below. For both of these items students in the experimental group had statistically significant gains from pre to post, while students in the control group did not.

Question 10

(Note: This item addresses learning objective 2.1, "*Identify the overall shape and direction of a line graph, and connect the shape with the real-world meaning.*")



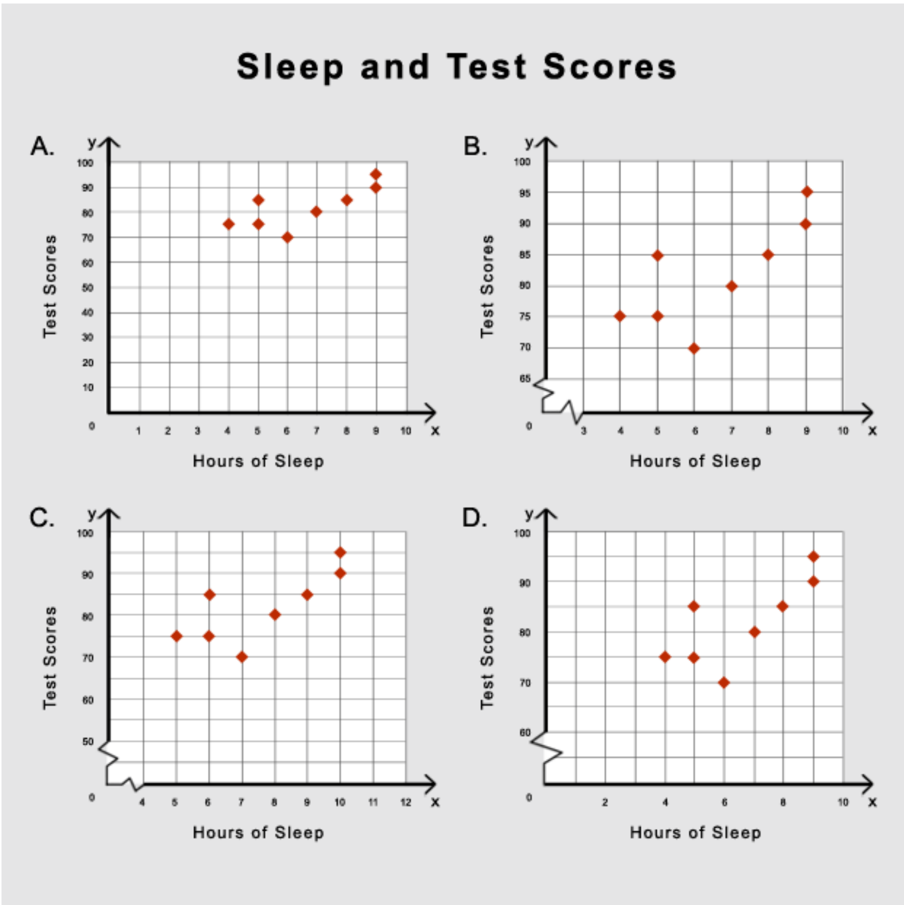
Miguel makes a cup of hot cocoa and leaves it to cool on the counter. He measured the temperature every minute and notices it is not cooling at a constant rate.

Which graph above could show how the cocoa's temperature changes over time?

O Graph A
O Graph B
O Graph C
O Graph D

Question 14

(Note: This item addresses learning objective 1.2, *"the student will understand how zooming, panning, stretching, and shrinking do not change the data within a graph."*)



Each scatter plot above shows the number of hours eight students slept the night before a test and their test scores. Three scatter plots show the same data. Which shows different data?

- O Graph A
- O Graph B
- O Graph C
- O Graph D