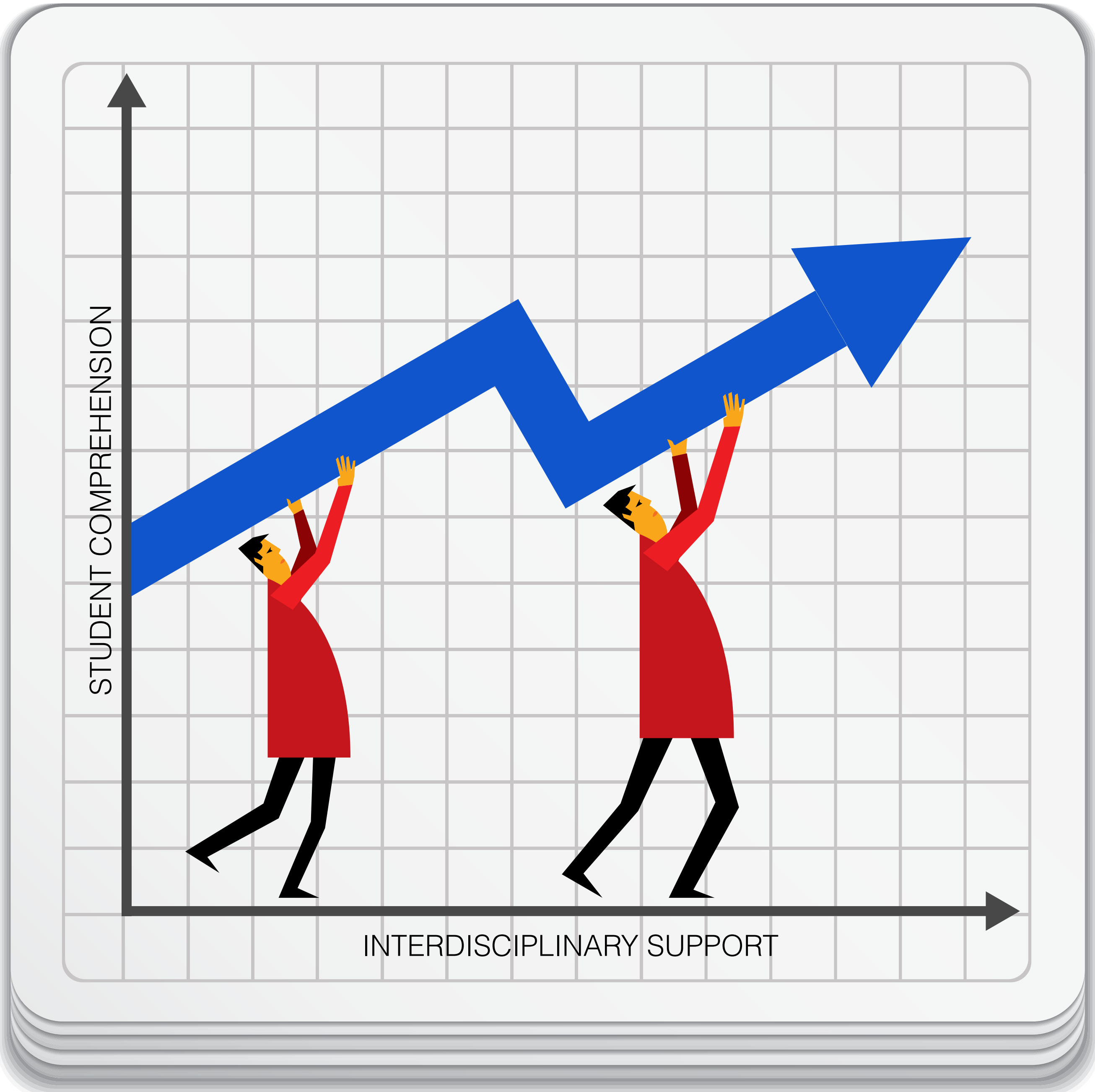
by Andrew Zucker, Carolyn Staudt, and Robert Tinker

Teaching Graph Literacy Across the Curriculum



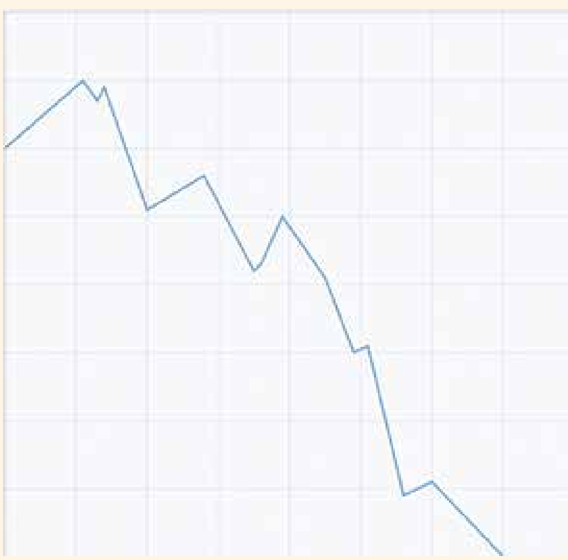
According to the *Common Core State Standards* (*CCSS ELA*), English and language arts teachers share the responsibility with other educators for teaching students to understand "informational text," including science material found in books, magazines, and newspapers, and on the web (NGAC and CCSSO 2010). What is less well known, let alone practiced, is that the same standards require that ELA educators teach students how graphs and tables communicate meaning in conjunction with text.

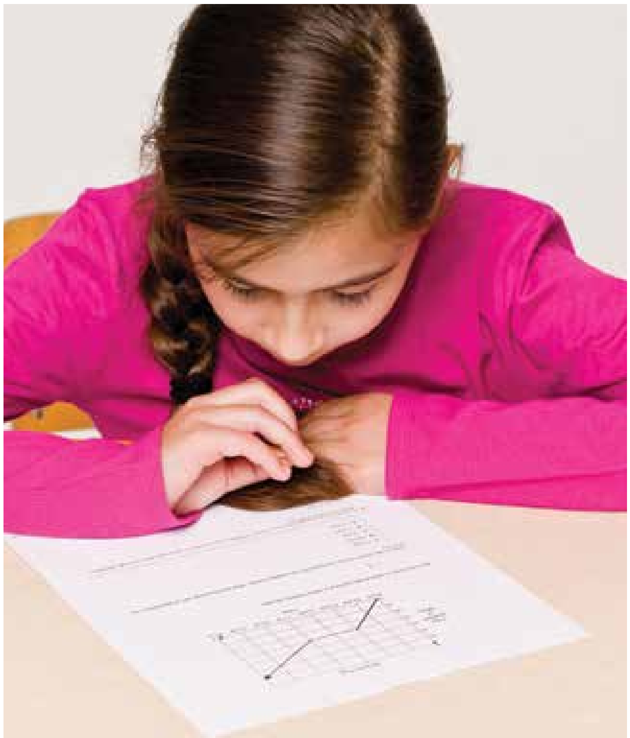
This is a significant addition to earlier ELA standards because although graphs are ubiquitous, they are not nearly as easy to read as a picture, as most science teachers know from their classroom experiences. Some ninth-grade teachers bemoan the fact that their students still do not understand that one point on a graph has two coordinates, *x* and *y*.

Like a picture, a graph can be worth a thousand words. However, almost all students need teachers' help, over a period of years, to read graphs well. In that sense, graph literacy is like learning to read text; each requires repeated practice and a focus on greater complexity as students develop their skills.

Of course, the *Next Generation Science Standards* and the *Common Core State Standards, Mathematics* also focus teachers' attention on the importance of teaching graphs (see sidebar, Standards About Graphs and Graphing, on p. 24). More than ever, then, teaching students to read and understand graphs is a

FIGURE 1 A mystery graph





responsibility shared across multiple subjects and departments, including at a minimum teachers of ELA, science, and mathematics. Classroom instruction about graphs is designed (1) to help students learn and practice a skill set that is independent of content, and (2) to help students learn a particular standards-based topic (e.g., kinetic energy). Most teachers believe that both approaches are useful to students, although ultimately the purpose of using graphs in science classes is to concisely convey large amounts of information about important topics.

A simple graph

A cartoon published in *The New Yorker* magazine in 2009 showed a collie holding a graph in its mouth and approaching a woman with a worried look on her face, who is saying, "What is it, Lassie—is Timmy in trouble?" The graph the dog holds is similar to the one shown in Figure 1.

Perhaps your students would see the cartoon and have no idea who Lassie is—a popular, intelligent female canine featured for decades in books and movies and on TV. A more significant issue for teachers than students' being able to identify Lassie, or Timmy for that matter, is for them to be able to make sense of the graph in Figure 1, or any other graph they might encounter. It is true that there are no axis labels on the graph the dog is carrying, and we are always supposed to label our axes, as the cartoon in Figure 2 reminds us. And yet for someone who is graph literate, the downward trend of the line in Figure 1 means something. It means that a quantity shown on the vertical axis is getting smaller, perhaps as time goes by on the horizontal axis. Falling prices over time, sales revenue approaching zero, a person's heart rate that is crashing—these are some guesses of the trouble that may be represented on the graph. Whatever that trouble may be, the idea that anyone would see a dog holding a graph in its teeth as a call for help is unexpected and humorous.

Graphs are widely used for learning about many topics, such as weather, history, economics, psychology, physics, genetics, and astronomy. Yet national and international assessments show that although most students can identify values on a graph (e.g., the temperature at noon was 59 degrees), many have trouble identifying what trends are shown on this graph, the key points where some phenomenon changed dramatically, the rate of change indicated by the points, and other less obvious information.

Significant policy issues—such as climate change or the federal debt and deficit—are presented in graphs. So are personal concerns, such as the declining principal owed over time on a mortgage or other loan. Students who cannot read graphs are at a disadvantage in school and out; simply reading graphs in the newspaper will be a challenge.

How to understand a graph

Teacher guides for most textbooks do not include clear explanations of the steps people go through to understand a graph. In contrast to reading text—where pedagogical approaches such as decoding and phonics are familiar to teachers—there is little information presented to teachers about how we understand a graph, or how to teach students about graphs. Sometimes there seems to be a tacit assumption that making graphs from time to time is all that students need to learn to understand graphs, which is like saying that to teach reading, all teachers need to do is provide occasional writing assignments.

Over the past two years, we have reviewed dozens of research studies on teaching and learning graphs (e.g., Friel, Curcio, and Bright 2001; Leinhardt, Zaslavsky, and Stein 1990; Roth and McGinn 1997; Shah and Hoeffner 2002), spoken with experts in graph comprehension, developed a new teaching framework, and tested it in middle schools with promising results. The framework is easy to understand and use, in part because it has clear and direct parallels with teaching students to read text.

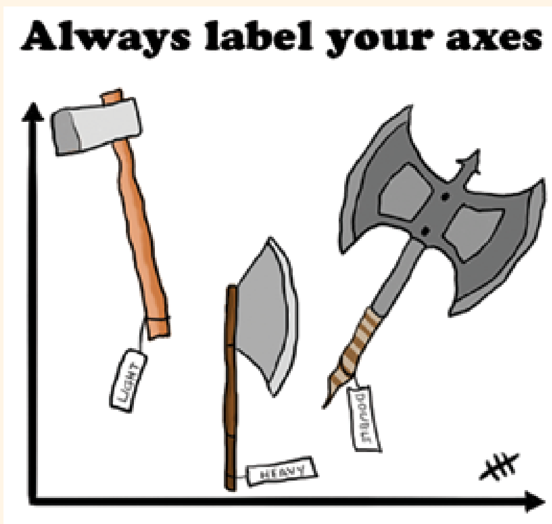
Our framework is based on research indicating that everyone goes through three steps to understand a graph, as follows.

Step 1: Identify and encode prominent visual graph features. Features such as the graph title, the axes and their titles or labels, the shape of the graph, and other visual cues such as color or grouping need to be noticed and understood by someone reading the graph. Students often need to slow down to seek out and examine supposedly obvious graph features.

Step 2: Link visual 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 graph, the viewer might associate rising with an increase of the *y*-value (over time, if the *x*-axis shows time) and straightness with constant, steady change. These associations need to be taught; most students do not understand these meanings without instruction.

Step 3: Integrate the features and relationships with the context of the graph. When comprehension does not come quickly based on steps 1 and 2, a more complex process of inference is needed. The general, context-free associations made about the graph in the first two steps must be linked to the contextual clues provided by the labels, axes, graph shapes, captions, and any information or knowledge about the context that the viewer has. For example, this step might result in the viewer seeing a particular graph not as just any graph about distance and time but as a specific story about Sally walking at a constant speed from home to the bus stop. In the same way we know that reading text often requires students

FIGURE 2 An important rule about graphing



REPRODUCED WITH PERMISSION (HTTP://FLUFFWARE.TUMBLR.COM/POST/4580822773/AXES) to use their background knowledge, not to simply decode words, so too does reading a graph require inference, not simply a literal interpretation of its features.

We set out to create a suite of free software activities to help students better understand graphs, based on this step-by-step framework. However, because the three steps are giant ones for many students, they need to be broken into smaller chunks. We created a set of more detailed goals and objectives linked to the steps in the framework (Figure 3).

For one example, students need to learn that zooming in or out may change which numbers show up on

FIGURE 3 A framework of graph literacy goals and objectives

I. Identify and encode prominent visual graph features.

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, the units (if any), and the numerical range.

Objective 1.1: The student will correctly name the coordinate values of any point on any single line graph or scatterplot, 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.

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.

II. Link superficial graph features to quantitative facts, trends, or other relationships.

Goal 3. Recognize basic functions and their significance. This goal focuses on the single mathematical function that often matches (or "models") the data well. 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 scatterplot of data that can be approximated by linear functions.

Objective 3.2: The student will be able to identify a graph or scatterplot of data that can be approximated by 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.

Goal 4. Recognize the significance of breakpoints. Points where the graph changes from one shape to another indicate where something significant happened in the system being graphed.

Goal 5. Identify trends in noise. Two important graph skills in science are perceiving the trend of the data by ignoring the fluctuations and then estimating the extent of the noise.

III. Integrate the features and relationships with the context of the graph.

Goal 6. Link stories and graphs—piecewise linear. This goal focuses on more complex data and the piecewise linear 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 functions. Students describe the story conveyed by graphs consisting of sections made from any common functions.

the vertical and horizontal scales, and the appearance of the graph, but does not change the underlying data or the meaning of the graph (Objective 1.2). We believe that this single objective (learning about zooming, panning, etc.), as well as each of the other objectives shown in Figure 3, deserves focused attention by teachers. We created six free online software activities, each linked to one of the objectives (see Resources). Six activities aimed at six objectives, we reasoned, are sufficient to test whether the framework works in classrooms.

We then conducted a randomized experimental trial. Reflecting work with 27 different middle school classes, and based on random assignment of nine teachers to experimental and control groups, the results showed statistically significant gains in understanding graphs for students taught by the five teachers who used the software, whereas students in the classes taught by the four teachers in the control group, who did not use the activities, did not demonstrate any statistically significant gains in understanding graphs over the three-month period between the pretest and posttest (see Resources for details about our study).

In other words, not only does the research literature show that people understand graphs by using these three steps, our preliminary research suggests that by breaking those steps into pieces, and providing instruction focusing students' attention on the learning objectives, one by one, teachers can increase students' understanding of graphs.

The software activities

The six graph-literacy software activities we tested, which are freely available online, are identified in Figure 4, which also includes the learning objective for each one. Teachers in the experimental group used all six of these activities for the research study. Teacher guides are available online for the activities, as well as *check-ins*, which are brief, paper-based student assessments. (Experimental-group teachers in the study could use the lesson plans and check-ins if they wanted to, but their use was not required.)

As an example, the purpose of the Hurricane Katrina activity is to help students understand the meaning of maxima and minima on a graph. Students observe a series of line graphs showing wind speed, distance of the hurricane from New Orleans, and barometric pressure over time. They use the graphs to tell the story about this historic and destructive storm's progress through New Orleans.

The free graph-literacy activities, teacher guides, and check-ins can be found online (see Resources). These activities are appropriate for students in grades 6–9.

Ideally, each student should have a computer or tablet device to work on an activity. On average, it takes 20 minutes for students to complete an activity.

One advantage of using our software compared with similar paper activities is that it is designed to provide help and hints to students who need them.

Sharing responsibility for teaching

Science, mathematics, and ELA teachers share responsibility for students' "graph literacy." Whether teachers decide to use the free activities we developed or create their own paper-and-pencil activities is less important than paying attention to the framework in Figure 3 and consciously working together as a team.

FIGURE 4 Graph literacy activities and objectives

Activity title	Objective number	Objective
Equivalent graphs	1.2	Understand how zooming, panning, stretching, and shrinking do not change the data within a graph.
Interpolation	1.3	Interpolate between points on a graph.
Dependent and independent variables	1.4	Determine the dependent and independent variables.
Graphs tell a story	2.1	Identify the overall shape and direction of a line graph, and connect the shape with the real-world meaning.
Hurricane Katrina	2.2	Identify the maxima and minima of a graph and interpret their meaning.
Growing up	2.3	Estimate the slope of a line and describe its real-world meaning.

The web has created new options for presenting information dynamically in graphs. For example, Gapminder (*www.gapminder.org*) presents an animated graph representing nations' per capita income versus life expectancy, showing how these variables evolved year by year from 1800 to 2000, and the *New York Times* is using complex interactive graphs more and more often. Making sense of these dynamic and interactive graphs is challenging, but rewarding. Yet students must learn to walk before they run, and therefore it is more important than ever that science, mathematics, and ELA teachers help students develop graph literacy, beginning with the basics laid out in Figure 3. We hope you'll find these online resources useful in building your students' graph literacy. ■

Acknowledgments

The work reported here was supported by a grant from the National Science Foundation (Grant No. DRL-1256490). Any opinions, findings, or conclusions expressed in these materials are those of the authors and do not necessarily reflect the views of the National Science Foundation. We are grateful to the members of the project's advisory panel for their expert counsel.

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Resources

Free online software activities—*http://concord.org/projects/graph-literacy#curriculum*

Graph-literacy research—*http://concord.org/projects/graph-literacy#research*

Standards about graphs and graphing

Science, mathematics, and English language arts standards each emphasize the importance of teaching about graphs, which makes teaching students about graphs a shared responsibility. Sample graph-related standards in these three disciplines are shown below.

The *Next Generation Science Standards* (*NGSS*) include practices that require the use of graphs, such as Analyzing and Interpreting Data and Obtaining, Evaluating, and Communicating Information. The *NGSS* also asks teachers to emphasize crosscutting concepts (e.g., Scale, Proportion, and Quantity) that use graphs, as well as performance expectations (PEs), which explicitly require students to understand and use graphs, such as:

Standard MS-PS3: Energy

MS-PS3-1. Construct and interpret graphical displays of data that describe the relationship of kinetic energy to the mass of an object and to the speed of an object.

The *Common Core State Standards, ELA,* include graphs. For example:

Reading Standards for Literacy in Science and Technical Subjects 6–12

Grades 6–8

Integration of Knowledge and Ideas

7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

The *Common Core State Standards, Mathematics,* like the *NGSS*, include practices, such as "model with mathematics," that require attention to graphs and graphing. In addition, many grade-level mathematics standards focus on graphs, such as:

Standard 8.F (Grade 8)

5. Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.

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