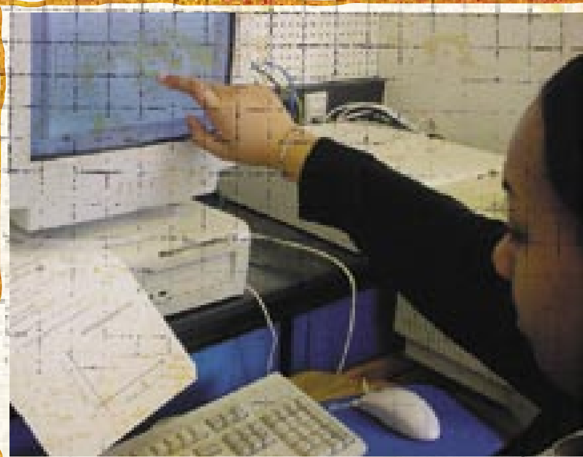
Graphing Predictions

Enhancing higher-order thinking skills in science and mathematics



Keely Flynn Connery

Have you ever designed what you considered a brilliant thought-provoking inquiry lab with the potential for students to develop clear connections between independent and dependent variables and collect and analyze great quantitative data? Have you ever read your students' lab reports after your "brilliant" inquiry lab and found you didn't provoke much thought at all and that too many of your students had no clue how to make sense of their data? Do any of your students struggle with the scientific and mathematical concepts underlying a lab investigation or to articulate conclusions based on their data?

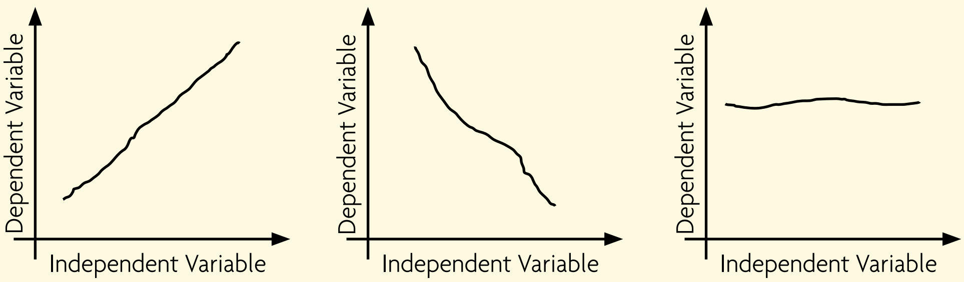
A few years ago, many of my physical science students were struggling with some or all of these issues, and I suspected it was a result of both ineffective prelab preparation and my failure to explicitly link science and math. I decided to try something different. Before students collected and graphed their actual data, I asked them to predict what they thought their data would look like and to *sketch* a graph of their prediction.

Every year, at least one student asks "How can I sketch a graph of something if I don't have any data?" For some students, especially those who tend to struggle in math, this is a challenging concept. In math, students have learned how to graph two points and connect them with a line. Many have never thought (or been asked) what the line actually represents. This goes to the heart of science and math literacy. My students are great data collectors, but when asked to construct meaning from a graph—what I call reading between and beyond the data—many students fall short. Asking students to graph their prediction before they begin a lab investigation helps them construct a theoretical context for the investigation.

FIGURE 1

What do you think your data will look like?

Do you think your data will look like this? **Like this?** **Or like this?**



Using graphing predictions

Graphing predictions is especially important in classes where relationships between variables need to be explored and derived. If students are determining the velocity of an object moving at constant speed, the density of a pure substance, a spring constant, the resistance of an ohmic device, or the acceleration of an object in free fall, they could predict a linear relationship. If students are studying human population growth over time, bacteria growth over time, or radioactive decay, they might predict an exponential association. If students are studying the electrostatic force between two charged particles, they might predict an inverse square relationship. If students are learning about "football physics" and studying parabolic trajectories, they may predict a quadratic relationship between the vertical height of an object and the horizontal distance (or time) traveled.

Graphing predictions may be started as early as eighth grade and may need to continue through twelfth grade for many students. Ultimately, as students begin to think quantitatively, they will mentally picture their predictions and naturally see the relationships between variables.

My students graph their predictions before any lab that has clear quantitative independent and dependent variables. Although I have my students create their graphs in Excel, it is *not* necessary to have access to computers or use Excel (or *Graphical Analysis*) to make graphing predictions a worthwhile experience. Hand-drawn graphs work just as well and perhaps even better because they force students to learn fundamental graphing skills.

FIGURE 2

Prelab handout.

Name________________________ Date____________
Period________________

(Name of Lab) Pre-Lab Home Assignment

1. Read the Lab handout.

2. Identify your variables:
   Independent variable ________________________
   Dependent variable ________________________

3. Write your prediction:
   If ______________________________________,
   then _____________________________________.

4. Sketch your prediction on the graph below (sketch your "educated guess" about how changing the independent variable will affect the dependent variable):

____

Title of Graph (*y* vs. *x*)
(Dependent Variable vs. Independent Variable)

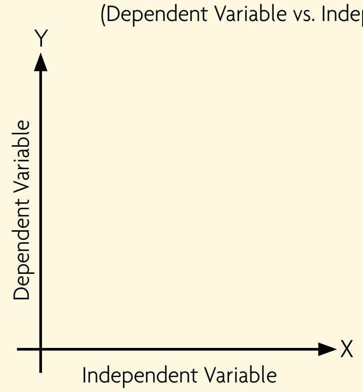
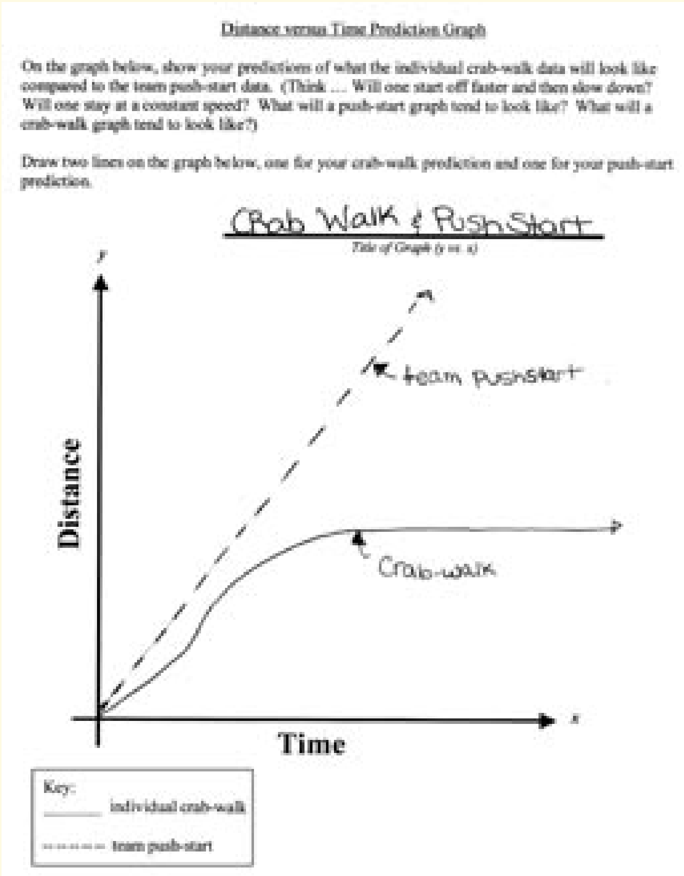


FIGURE 3

Prelab prediction.



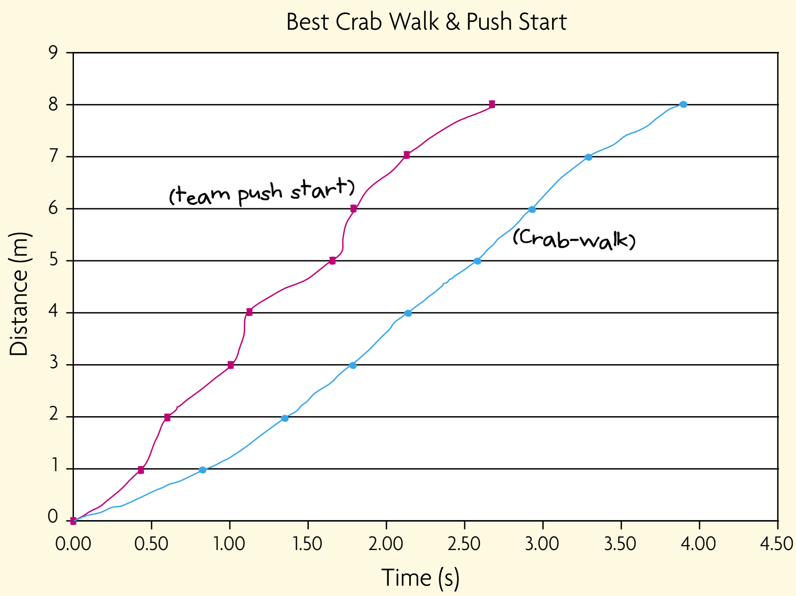
Distance versus Time Prediction Graph

On the graph below, show your predictions of what the individual crab-walk data will look like compared to the team push-start data. (Think … Will one start off faster and then slow down? Will one stay at a constant speed? What will a push-start graph tend to look like? What will a crab-walk graph tend to look like?)

Draw two lines on the graph below, one for your crab-walk prediction and one for your push-start prediction.

FIGURE 4

Graph of actual data.



Math connections

In math class, students learn to solve systems of equations: linear, quadratic, trigonometric, and exponential. Students learn about inverse relationships and direct relationships. Unfortunately, many students do not connect what they are learning in math class to what they are doing in science class. In a science class, there are often students of varying math ability. Some students only know how to plot data points and connect these points to demonstrate a linear relationship. Some are learning to graph linear equations and how to calculate slope. Others are learning to model quadratic inequalities both algebraically and graphically. Still others are learning about exponential and logarithmic functions, derivatives, sine waves, probability, etc. For most equations a student is learning in math class, there is a potential science application. Science teachers typically have access to labs and more hands-on equipment than math teachers and therefore have a better opportunity to facilitate a student's math-science connections.

Teaching students to graph predictions

The first time students graph their predictions, we work through it together as a class. After choosing their independent and dependent variables and writing their predictions, students try to depict their predictions graphically. Because most of my students have limited algebraic skills, the first time I ask them to graph their predictions, I draw three graphs on the board (Figure 1, p. 43) and explain "I just want you to tell me what you think your data will look like in general."

Then, I give students a prelab handout to fill in (Figure 2, p. 43). Students are instructed to keep this handout to help them write their lab reports. The first time students write a lab report, they write their conclusions in class. I instruct them to only take out their prelab prediction handout, data table, and graphs. I ask them: "What can you conclude? What does your data mean? Did you support or reject your prediction?" The following examples are from three different labs demonstrating how students used their prediction sketch to analyze their data and make conclusions.

Distance Versus Time Cart Race Lab

In this Distance Versus Time Cart Race Lab, students generated distance versus time data and graphs for two different motions. Students set up an 8 m straight racetrack with timers at every meter mark. The "crab-walk" race was an individual race where students sat on a scooter and pushed themselves to the finish line. The "push start" race was a team race where one student sat on the scooter with legs crossed and was pushed only once at the start by another student and "coasted" to the finish line. Before beginning data collection, students predict and sketch their time vs. distance graph for each race motion.

Resistance and Ohm's Law Lab

Toward the end of the school year, I ask students to design and conduct an experiment to study the resistance of a wire in relation to its diameter or length. Students sketch their predictions and collect, graph, and analyze their data independently.

Two students who chose length as their independent variable made the following conclusions. One student is a student with limited algebra skills; the other is an honors geometry student:

> "From the data points there isn't a clear reason for supporting or rejecting the prediction . . . But judging by the way the line on the graph is going, my prediction is rejected because the line on my hypothesis prediction sheet went the opposite way."

> "I predicted a linear increase in resistance as length increased. Even though the resistance did increase, my data showed that the increase of resistance grew exponentially as the wires got longer and longer. In the graph of voltage vs. current, I could see the slopes getting steeper as the lengths got longer, which is what I predicted."

Making Microcomputer Based Labs (MBL) even more effective

Another interesting application is to have students graph their prediction prior to gathering real-time data. Much has been published on the effectiveness of using MBLs to enhance student learning. If you are working with motion sensors and having students gather displacement-time data (or velocity-time data) for a particular motion, consider having students graph their predictions in advance. Perhaps adding this small step at the beginning will increase student understanding. As a minimum, it provides students and you an *immediate* opportunity to assess their understanding of both the mathematical and scientific concepts underlying an investigation.

What do students think?

After graphing predictions all year, I gave my students a survey to gauge their opinions on graphing predictions. Ninety percent of students "agreed" or "strongly agreed" with the following statements:

- "Graphing my prediction before a lab helps me understand how the independent and dependent variables are related";
- "Graphing my prediction before a lab helps me understand what I am doing in a lab";
- "It's easier to figure out if I supported or rejected my prediction if I have a graph of my predictions in front of me when I am writing conclusions for my lab report"; and
- "Graphing a prediction is helpful to me."

PHOTO COURTESY OF THE AUTHOR

A student compares a graph of her data (on screen) to a graph of her prediction (on paper).

FIGURE 5

Studying the resistance of a wire lab.

You and your partner(s) will design and conduct an experiment to study the resistance of a wire. You will investigate how resistance is affected by something you change about your wire (length, diameter (gauge), material, etc.). You may choose your own independent variable, however, be careful to change only one property of your wire (this is called "controlling your variables").

During this activity, you will work with your group. However, you must keep your own notes because, after you finish, you will work independently to perform the necessary calculations and write a formal lab report.

You will be provided with the following materials and equipment. It may not be necessary to use all the equipment that has been provided:

- Meterstick
- 5 D-cell batteries (1.5 v each)
- Wires of different materials and gauges
- Ammeter
- Voltmeter
- Wire cutters
- Micrometer

However, few students saw how graphing their predictions could help them spot sources of error in a lab. Perhaps this is best described by a comment one student included with his survey, "Comparing the predictions to the final graph to find error only works if you have a good idea what the results *should* look like."

Although this comment suggests the student does not understand the real nature of science by saying the "results *should* look like" something, this student raises a good point. I deliberately put the statement "Comparing a graph of my prediction to a graph of the data I collected in a lab helps me spot sources of error" in the survey because I think it addresses a tricky point about having students graph their predictions. Sometimes when entering an investigation, students will simply gather data to demonstrate or verify a particular law. Other times, they may be trying to derive a law (or a relationship between variables) through experimentation. Oftentimes, in real inquiry labs, students are predicting, gathering data, modifying predictions based on data, gathering more data, and so on.

The previous comment came from a student after completing a Resistance and Ohm's Law Lab. I had hoped this lab would reinforce Ohm's Law (which I had already taught) and introduce the concept of resistivity. I intended for students to find a direct relationship between resistance and length, and an inverse relationship between resistance and wire diameter through inquiry and experimentation.

Several students' predictions were indicative of what the data "*should*" have shown (a direct relationship between resistance and length, and an inverse relationship between resistance and diameter). Yet, after collecting and graphing their data, these same students had data and graphs that clearly rejected their predictions. Students had two "visuals" in front of them when making conclusions: a graph of their prediction and a graph of their data. Some students realized their prediction was indeed correct because they possessed a more natural grasp of the concepts guiding the investigation (or they looked it up in the book). Other students simply looked at the graph of their prediction, looked at the graph of their data, assumed their data was correct, and therefore rejected their prediction. As with *any* inquiry lab, teachers need to be aware of reinforcing (or creating) misconceptions.

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Addressing the Math Standards

NCTM Algebra Standard Grades 9–12 (NCTM 2000)

Students shall:

- Use mathematical models to represent and understand quantitative relationships.
- Draw reasonable conclusions about a situation being modeled.

Addressing the Science Standards

Content Standard A (Science as Inquiry) (NRC 1996)

Students shall:

- Identify questions and concepts that guide a scientific investigation.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Communicate and defend a scientific argument.

A stronger grasp of the nature of science

Prior to collecting data, graphing a prediction helps students evaluate the relationship between their variables and establishes the foundation for the scientific concepts and mathematic principles underlying the investigation. Beginning level students could be asked to predict a *general* trend in the data, upper-level students could be asked to predict in more detail (Will it be a linear relationship? An exponential relationship?). After collecting and graphing data, it is easier for students to determine if they supported or rejected their prediction if they have a graph of their prediction in front of them.

Perhaps most importantly, graphing their predictions forces students to analyze their thinking process prior to gathering data. It also provides a theoretical context for both the mathematic principles and scientific concepts underlying their investigation. This process leads students to a better understanding of both the nature of science and the nature of mathematics. Science and math are not simply two separate subjects that students learn at school. Not only do both play a central role in modern culture, as science and math teachers we know the power of teaching one through the other.

By getting our students to "think graphically" in science class, perhaps they will be more inclined to look critically at a graph in a newspaper instead of avoiding it. Perhaps, the next time they are learning a new equation in math class, they will instinctively link it to an everyday application. ■

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References

National Council of Teachers of Mathematics (NCTM). 2000. *Principals and standards for science mathematics.* Reston, VA: NCTM.

National Research Council (NRC). 1996. *National science education standards.* Washington, DC: National Academy Press.