Predictions and Pedagogy

The most productive student predictions fall somewhere between the extremes of guesswork and pure logic.

By Dougal MacDonald

"THE PEOPLE WHO DON'T seem to be able to predict anything may also not understand anything." The superconductivity pioneer Bernd Matthias made this comment in reference to the criteria for accepting scientific theories, but his words also hold great significance for the elementary teacher (Schechter 1989, 132).

In teaching science, we often ask students to predict. Such requests are made within different contexts that convey, whether implicitly or explicitly, various notions of what we mean by the phrase "scientific prediction."

One way of schematically representing these various notions is along a continuum. At one end, the emphasis is on uncertainty. At this extreme, we call a prediction a guess. On the opposite end, the emphasis is on certainty, and a prediction at this extreme is known as a logical deduction. Between these extremes lies a middle ground where a prediction is more than a guess but less than a logical deduction.

Of course, the distinction between these two types of predictions is not perfectly precise. On the contrary, the categories tend to overlap. But the distinction can help us to clarify how we present the idea of prediction in science teaching.

Guesswork

Let's apply our continuum to several sample science lessons. Consider the following exchange between teacher and student.

> *Teacher:* As you can see, I have set up this long, thin copper strip so that three candles can be placed directly beneath it at different points. When I light the candles and heat the strip, what will happen?
>
> *Student:* The strip will melt.

Because we know that, in fact, the strip will expand, the student's response seems poorly conceived. But let's outline the context of the teacher's question.

He does the copper-strip demonstration as the interest-provoking, opening salvo in his effort to teach children about the properties of matter. In that light, the student's response is more understandable. The properties of matter have not yet been discussed, so the student has no basis on which to make the hoped-for prediction.

The teacher is attempting to illustrate the fact that most materials expand when heated, but the student has no way of knowing this. In this case, the student's prediction has no basis in previous teaching, so it would fall on the uncertainty-end of our continuum. This prediction is a guess.

Logical Deductions

Now, let's consider a second example.

> *Teacher:* You've seen that the red solution floats on top of the blue solution, and that the blue solution floats on top of the green solution. What will happen when we mix the red solution with the green solution?
>
> *Student:* The red solution will float on top of the green solution.

This time the student already knows something about the comparative densities of the three solutions, and she draws upon this knowledge as the basis for her prediction. She has recognized a logical relationship among the densities, such that if red is less dense than blue, and blue is less dense than green, then red must be less dense than green. Following these logical steps has led her to the correct prediction. In fact, whether she predicts correctly depends more on her ability to reason logically than on her grasp of the scientific concept of density. Because the outcome of the event can be calculated with certainty using logic, this prediction falls on to the certainty-end of our continuum. In this case, the student's prediction is a logical deduction.

Generalizations

In our first example (heating the copper strip), the student had no preexisting knowledge on the topic. Let's reconsider that demonstration in a different context, the context of preliminary teaching.

Prior to displaying the copper strip, the teacher had students do an activity using two glass tumblers, one stuck inside the other. By pouring hot water on the outside tumbler while filling the inside tumbler with cold water, students could slide the two tumblers apart quite easily. As a result of this activity and follow-up discussion, students were able to state that almost all materials expand when heated (and contract when cooled). If one of these students were asked about the copper strip, he would give a different response.

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Teacher: As you can see, I have set up this long, thin copper strip so that the three candles can be placed directly beneath it at different points. When I light the candles and heat the strip what will happen?

Student: The strip will expand.

This student makes an informed prediction rather than a guess. But perhaps he is too informed! Once he has accepted the principle that most materials expand when heated, can he do otherwise than predict that the copper strip, too, will expand when heated? His prediction, although based on grasping a scientific principle rather than a logical relationship, can be deduced directly from the principle of expansion.

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Pedagogy and Authenticity

It could be argued that the third scenario is an improvement over the previous two. The student's prediction that the copper strip will expand is obviously informed by his knowledge of a scientific principle.

Can we do even better? Can we use prediction in a manner that retains the exploratory element of learning—the "guesswork" that makes student science truly thought-provoking—and at the same time conveys an authentic notion of prediction within science—not just a flight of fancy, but a judgment made on the basis of some degree of previous understanding? In terms of our continuum, can we strike an appropriate balance between uncertainty and certainty?

Prediction and Explanation

For assistance in this endeavor, let's turn to science itself. Science can be looked at as being "done" by scientists who develop generalizations about patterned regularities in nature, then try to explain why these regularities exist. A proposed explanation is usually tested by prediction: observable consequences are deduced from the explanation, then testing is done to see if these consequences occur. The process follows along the lines of, "If this explanation is appropriate, then I should observe x when y." Confirmation of the prediction is taken as support for the explanation.

For example, geologist Patrick Hurley became a supporter of the theory of continental drift only after he had confirmed his 1967 prediction that if Africa and South America had once been joined, then the boundary between certain ancient rock formations found near Accra, Ghana, should enter South America near Sao Luis, Brazil. Einstein's theory of general relativity, which proposed to explain the nature of space, time, and gravitation, became generally accepted by scientists only after its experimental success in predicting the bending of starlight by the sun's gravitational pull during a solar eclipse.

Until tested by prediction, many scientists consider a scientific explanation to be mere philosophical speculation.

Testing Teachers

Consider another example from science teaching. During a unit on changes in energy and matter, a student has already dripped water into a cup "full" of water and observed that additional water can be heaped above the top of the cup. She has also watched a film showing how a column of water streams downward and then breaks into droplets. Finally, she has observed a teacher demonstration showing that the length of the water stream from a squirt bottle containing soapy water is shorter than the stream from a bottle containing plain water.

Teacher: Based on what you have done and observed up until now, predict what will happen when you try to heap soapy water in a cup. Will soapy water heap higher or lower than plain water?

Student: It will heap lower.

Teacher: Why do you think so?

Student: Because the soap will make the water slippery and it won't stick to itself so well.

Here, we will argue that, like Goldilocks and the baby bear, the students' prediction is "just right." First, it is based on previous teaching and learning, but not directly. In fact, this question, when asked of either elementary students or student teachers, often elicits predictions of both lower and higher heaping, and both groups back up their predictions with reasonable explanations.

Second, the use of prediction is pedagogically powerful. Enough uncertainty exists to make a prediction's success or failure genuinely significant to students as a means of choosing between competing explanations. Also, the use of prediction in the final heaping test neatly wraps up the lesson and emphasizes the key point of all the activities mentioned; that is, that molecules of the same substance, in this case, water, have an attraction for each other (cohesion).

Testing Students

Just as prediction can test a teacher's explanation, it can also test a student's explanation, as in the example that follows.

For a lesson from a unit on electricity, a student worked with a selection of batteries, bulbs, and wires to create a simple electrical circuit that lighted a bulb. When the teacher asked why the bulb lighted, the student explained that when electricity traveled to the bulb, some of it was consumed by the bulb.

> *Teacher:* Let's test your explanation. I have two ammeters, which are instruments that measure the amount of current flowing through an electrical circuit. We can connect one ammeter into the circuit before the bulb and connect the other ammeter into the circuit after the bulb. If your explanation is correct and some of the current is consumed by the bulb, what do you predict about the two ammeter readings?
>
> *Student:* The ammeter that is connected after the bulb should show a lower reading.

This prediction is both authentic and pedagogically powerful. It is significant as a test of the student's proposed explanation, and its disconfirmation emphatically makes the point that, contrary to what the student believes, the electrical current is not consumed. In fact, comparing the ammeter readings shows the student that the current is actually the same in all parts of the circuit (Osborne and Freyberg, 1988).

Another example of testing a student-generated explanation involves a demonstration often used when studying the properties of air. A candle is set in a bowl, the bowl is filled ¾ full of water, the candle is lit, and a jar is inverted over the candle. Eventually the candle goes out, and observers can see that the water has risen in the jar. The student explains the rising water as a result of water rushing in to fill the space vacated by the oxygen consumed when the candle burned.

> *Teacher:* Let's test your explanation. As you know, air is about one-fifth oxygen. If we burn two or three candles in the jar, how far should the water level rise compared to when we used just one candle?
>
> *Student:* It should rise the same amount, because the percentage of oxygen in the air is a fixed amount and so the same proportion of the air will be used up in the jar no matter how many candles we burn.

Again, this prediction is both authentic and pedagogically powerful. When the student observes that the water level rises higher when two candles are burned, and higher still when three candles are burned, she realizes that oxygen consumption cannot be the main factor. She also becomes aware that the significant variable is the number of candles, and hence, the amount of heat. This puts her on the track of the relationship between the amount of heat and the degree of expansion of the air in the jar, leading her to accept an explanation which has primarily to do with the lowering of the pressure in the jar rather than with the consumption of oxygen.

Teaching and Prediction

We ask students to make predictions in science class because we hope that in so doing we will advance students' science learning. When using prediction as a pedagogical strategy in science, we must keep in mind both effective pedagogy and scientific authenticity. Certainly, it is pedagogically desirable and scientifically authentic to have students use logical reasoning to make deductions and to apply their knowledge of important generalizations in science to specific phenomena. But often, student interest escalates when predictions involve some genuine uncertainty.

At the same time, of course, an authentic notion of prediction in science does involve some degree of certainty, because students predict from an informed rather than uninformed basis. Using predictions to test explanations allows teachers to be both pedagogically effective and to convey an authentic notion of science in their teaching. And while it is true that devising appropriate ways of using prediction to test explanations, especially those generated by students during classroom teaching, can often tax the knowledge and ingenuity of even the most experienced science teacher, in so doing both students and teacher will increase their understanding of both the subject matter of science and of what the scientific endeavor is all about. They will be emphatically reminded that the power of science comes from precisely the fact that our scientific explanations for events we encounter in our explorations can be tested in the real world through experiment and prediction.

Resources

Alberti, D., Davitt, R., Ferguson, T., and Repass, S. (1974). *Teacher's guide for kitchen physics.* Elementary Science Study. New York: McGraw-Hill.

Hacking, I. (1983). *Representing and intervening.* Cambridge, England: Cambridge University.

Kiefer, I. (1978). *Global jigsaw puzzle.* New York: Atheneum.

Osborne, R., and Freyberg, P. (1986). *Learning in science.* Auckland, New Zealand: Heinemann.

Roberts, D., and Chastko, A. (1990). Absorption, reflection: An exploration of beginning science teacher thinking. *Science Education, 74*(2), 197–224.

Schechter, B. (1989). *The path of no resistance.* New York: Simon and Schuster.

Will, G. (1986). *Was Einstein right?* New York: Basic Books.

Yager, R., and Hofstein, A. (1984). Enlarging the boundaries of school science. *Curriculum Review, 24*(1), 85–90.

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