Anomalous Data

1 What are they?

Anomalous data in science is scientific information that seems to contradict scientists ideas about a particular phenomenon. In the history of physics, the resolution of anomalous data has led to new paradigms. For example, Newtons Law of Universal Gravitation was unable to explain the precession of Mercurys orbit about the Sun. Einsteins General Theory of Relativity was able to explain this previously anomalous observation. In our approach to physics instruction anomalous data tasks involve experiments whose outcome is difficult [but not entirely impossible] to predict even if one knows physics sometimes due to the assumptions that we make or underestimations of the importance of some unknown variable. When students perform the anomalous data tasks they first read a description of the experimental set-up and then need to predict what will happen if the experiment is performed. The key here is that students use their previous knowledge (the concepts that they constructed and tested in class before) to make predictions and not nave ideas. Then students observe the experiment and see the contradiction between the prediction and the outcome. Now they have to revise the explanation to accommodate the experimental results. Then they assess themselves using a scoring rubric and a possible correct explanation suggested by their teacher.

Anomalous data tasks are a unique combination of formative and summative assessment. They represent formative assessment for two reasons: students receive feedback on their physics understanding when they observe the actual experiment and they receive feedback on their scientific abilities when they score themselves with a rubric. They represent summative assessment because they are given at the end of learning a particular concept. By analyzing their results a teacher can have a clear understanding of her/his students grasp of the material.

2 Why do you want to use them?

- *National Science Education Standards*
  Among the National Science Education Standards is Science as Inquiry, which specifies (among other things) that Students also need to learn how to analyze evidence and data. Anomalous data is listed as an example of the sort of data that should be analyzed.

- *Use of Feedback*
  The availability of feedback (in this case, by allowing students to directly observe the results of an anomalous experiment) provides an opportunity for both instruction and learning via deep processing (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991)

- *Explanation and the Nature of Science*
  The role of explanation is fundamental to the nature of science. Some philosophers of science have proposed that explanation is the very purpose of science itself (Kourany,1987; Nagel,1961)

- *Promote the Difference in Description vs Explanation*
  Students often confuse the process of description (what) of a phenomenon with the explanation (why) of a phenomenon (Horwood, 1988). Anomalous experiments as described above strengthen the distinction between the two.

- *Evaluation*
  Opportunities to observe, consider, and explain anomalous data enhance students ability to evaluate their reasoning.

3 How do you use them?

Anomalous data tasks are used at the stage of a learning cycle when students have constructed some scientific understanding of relevant phenomena. Students are asked to predict what will happen as a result of a particular experiment [anomalous data experiments are unusual situations that are not easily explained by a particular model]. Students need to write the prediction and a detailed explanation of the prediction. After making their prediction and writing an explanation, students observe the experiment directly. Most likely the outcome of the experiment will not match their prediction they will have anomalous data. Then the students have to revise their prediction by considering the possible causes that contribute to the anomalous data. In doing so, the students will need to either revise the model or revise their assumptions.

One can use them during instruction to build more sophisticated models of phenomena and at the end of learning a particular topic to assess students understanding of assumptions that they often make unconsciously.

4 What are some types?

As suggested above, the anomalous data experiments can be broadly divided into 2 categories: (1) tasks in which the model needs to be revised, and (2) tasks in which the student assumptions need to be revised. An example of each will be discussed below.

Revise the Model

An example of this type of anomalous task would be to connect a light bulb in a simple circuit with a voltmeter connected across the bulb, and an ammeter to read the circuit current. Have the students note the voltage to current ratio for the bulb. Next, connect the bulb in series to a resistor. The students are to predict the voltage to current ratio for the bulb. The standard model for Ohms Law would yield a prediction of the same value as originally noted. In fact, the voltage to current ratio changes. The model must be revised to take into account the temperature of the bulb, which causes its resistance (voltage to current ratio) to change.

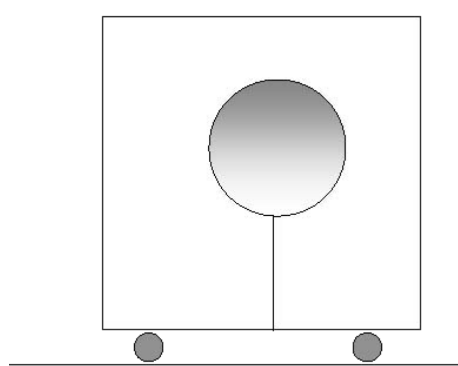
Revise the Assumptions

An example of this type of task is the Four Tracks experiment. In this experiment, the apparatus consists of four tracks, each of which has a different shape but the same vertical displacement. The task involves predicting where a ball, released from the top of each track, will land when the end of the track is positioned at the end of a table top (note: the end of each track is horizontal). A standard type of prediction would be that the ball will always land in the same spot. Since the ball will move through the same vertical displacement (assuming little or no friction), it will acquire the same horizontal speed at the end of any one of the tracks. Consequently, based on the projectile motion formulas, the ball should land in the same spot, regardless of the track. This is not what happens. It is observed that the ball that leaves the track of shortest length will go farther than the others. The student needs to consider that the ball is not being a point mass (a typical assumption), and its rolling motion will cause a loss of mechanical energy due to friction. Therefore, less mechanical energy is lost on the shortest track, meaning that the ball leaving the shortest track has the greatest amount of kinetic energy, and therefore the greatest horizontal velocity. It is this greatest horizontal velocity that enables the ball to go the farthest distance before hitting the floor.

5 How do you score them?

Example

Students watch a video of an experiment whose description is given below: (anomalous data type 2):



A helium balloon is attached to a string to the bottom of a cart on wheels. The sides of the cart are encased in clear plastic. The cart is on a level surface. A person will exert a horizontal force to the cart in such a way that it will first move faster and faster towards the left, and then move slower and slower towards the left.

The video is available at
http://paer.rutgers.edu/pt3/experiment.php?topicid=13&exptid=121

- **Predict** what the balloon will do during each time interval.
- **Explain** your prediction.
- **Observe** what happens
- Now that youve observed the actual behavior of the balloon, **revise** your prediction (if necessary), and provide **reasons** for your revision.
  (Note: If you correctly predicted what would happen, you can use this opportunity to further develop the explanation you offered above.)

A Complete Answer
The balloon will lean forward (toward the left) as the cart accelerates left. The balloon interacts with three objects: the Earth, the string and the air. The air exerts forces in two directions vertically and horizontally. When balloon is in equilibrium, the air pressure on the left and right of the balloon is the same, and the horizontal forces of the air on the balloon (left and right sides) are balanced. The vertical forces (on the top and bottom) are not balanced, creating an unbalanced upward force. The forces of the Earth and the string on the balloon balance this upward force of the air on the balloon. When the cart accelerates to the left, the air which is not attached to the cart, does not accelerate, and thus it piles up on the right of the balloon. The pressure to the right of the balloon (in the back of the cart) will be greater than to the left (the front). Therefore, there will be a net horizontal force on the balloon to the left that causes it to move (or lean) to the left. When the cart is suddenly slows down (decelerates), just the reverse is true, resulting in a net force exerted on the balloon by the air to the right that causes the balloon to move (or lean) to the right. Throughout this situation, the net vertical force on the balloon (the force of the Earth on the balloon, the vertical component of the force of the string on the balloon, and the buoyant force) remains essentially balanced.

A Sample Student Prediction
As the cart moves the balloon will move in the opposite direction because the object will want to remain at rest (Law of Inertia). As the cart slows down the balloon will move in the direction the cart is moving because the object will tend to want to remain in motion (Law of Inertia).

The Same Students Revision

I need to use the 2nd law. The applied force is greater than the air pressure and air resistance inside and thus the balloon will at first move forward with the cart because it is greater. But as the cart slows down the air pressure and force of air resistance is greater than the applied force, and so the balloon moves backward.

Example of Scoring Using Scientific Abilities Rubrics

Scientific Ability	0	1	2	3
Is able to make a reasonable prediction based on a relationship or explanation	No attempt to make a prediction is made. The experiment is not treated as at testing experiment.	A prediction is made but it doesnt follow from the relationship or explanation being tested, or it ignores or contradicts some of the assumptions inherent in the relationship or explanation.	A prediction is made that follows from the relationship or explanation and incorporates the assumptions, but it contains minor errors, inconsistencies, or omissions.	A correct prediction is made that follows from the relationship or explanation and incorporates the assumptions.

SCORE: 2

Scientific Ability	0	1	2	3
Is able to revise the explanation of a prediction, based on the results of an experiment.	No attempt is made to explain the outcome of the experiment, revise the previous explanation or assumptions. The difference between the prediction and the outcome of the experiment is not addressed.	An attempt is made to explain the outcome and revise the previous explanation or assumptions, but is mostly incomplete and/or based on incorrect reasoning.	The revision of the previous explanation or assumptions is partially complete and correct, yet still lacking in some relevant details.	The revision of the explanation or assumptions is explained completely and correctly.

SCORE: 2