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Plumbdads and Quarkles: Discussing Modeling Trends with Students Using Fictional Parameters

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Using the Lunar Phases Concept Inventory to Investigate College Students' Preinstructional Mental Models of Lunar Phases
Helping students develop an understanding of how to interpret experimental data trends is an important part of the introductory physics laboratory. Unfortunately, many of my colleagues have lamented that too many of their students do this poorly. This is a common refrain, and past research has already revealed student difficulties with measurement, uncertainty, and the overall meaning of data.\textsuperscript{1-3} Like many instructors, I prefer discovery-style labs and in many laboratory investigations students are asked to use curve-fitting tools to discover a relationship.\textsuperscript{4} But one day in lab, I began to wonder if students were looking at data and curve fitting in a way profoundly different than scientists. Research already indicates significant differences,\textsuperscript{5,6} but to get a clearer understanding of how students would treat general data, a hypothetical set of data using fictional parameters (plumbdads and quarkles) was given to first day students.

The plumbdad and quarkle exercise\textsuperscript{7} was developed as a precursor to physics laboratory investigations. Students are intentionally placed in a circumstance where they will have to analyze “data” and various curve fits using their logic and basic instincts. The use of nonsense words like plumbdads and quarkles was necessary because otherwise far too many students would immediately resort to using an Internet search instead of thoughtfully examining the experimental information. The developed exercise uses common language (except for the nonsense words) and avoids terms more commonly found in philosophy of science courses (Occam’s razor, induction, etc.). Its purpose is not to measure an aspect of a student’s scientific thinking, but rather as a prompt for a student-led classroom discussion. Therefore, it is usually given to students as a first homework assignment (graded on completeness of answers as opposed to how a scientist would answer), and then letting the students argue among themselves in a later classroom discussion guided by the instructor. If one has larger classes, one can use questionnaires and online surveys to display student opinions in class. For this work, this exercise was given to two distinct student groups of approximately 45 people. The first group was composed of students in a first semester calculus-based introductory physics course (47 people). The second group was composed of non-science majors in a physics general education course (43 people). The results from this small sampling are not meant to indicate expected results at other universities or schools, but rather to give readers a sense of student proportions and how two very different student sets reacted to the same exercise.

Specifically, the exercise features a difference in opinion between two fictional researchers named Abbey and Bernard. Abbey behaves much like a scientist and Bernard behaves like a person with a fixed and unshakable preconception. Students are asked what they think about Abbey and Bernard’s opinions as well as their own ideas concerning the data. The ultimate goal for this activity is to help students achieve a greater understanding as to how data are used to form and evaluate empirical relationships as well as to test proposed relationships. If we want students to “discover” relationships through their lab work, instructors need to promote this type of skill, and this exercise can help start the process. The full plumbdad and quarkle exercise is too long to fully cover in this brief note, but I will discuss some of the highlights.

The exercise begins by giving students a table (not shown) and graph of data (see Fig. 1) that was collected by Abbey

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**Fig. 1.** Graph given to students. Their task is to represent the data via a mathematical model.
a high success rate of ~ 90%. One of the main points to this task is to get students used to predicting the results of future measurements, which is something they will have to do in later lab activities. In the classroom discussion, I always find two people who came up with the same model but had no direct or indirect communication with each other. How could two independent people come up with the same exact model? While many students will say "It’s the obvious model" or "It’s the first one I came up with," it’s worthwhile to lead students toward "It’s the simplest model that represents the data."

The second task in the exercise examines what students are trying to accomplish with curve fits. It begins when Bernard adds a sinusoidal fit to the same data (see Fig. 2). A sinusoid was used because there is virtually no reason to apply this curve to this data (especially since too little is known about plumbdads/quarkles to form an evidence-based theoretical framework that would suggest using this model). Because the sinusoid uses more fitting parameters, it nearly perfectly passes through the center of each quarkle measurement range; it’s much closer to center than the simple linear fit and this is shown in a table in the full student exercise. Now students are asked which model is the better choice for research. For many of the students, the stated uncertainty in the exercise is only thought of as a shortcoming of the measurement apparatus and is rapidly forgotten when it’s time to examine the data. Thus, in that way of thinking, the sinusoid fit seems superior, as they are fitting to specific points as opposed to a blurry range of possible values. It does not occur to these students that there are an infinite number of mathematical functions that will also go through these same points. But to a trained experimental scientist, a fitted curve applied to data always suggests a specific relationship between the experimental measurements, and this means that following the data trend is preferred. Unfortunately, too many students do not recognize this entering a physics course nor do they see the full implications of that sinusoidal fit. Consider for a moment what it would mean if there actually is a sinusoidal relationship between plumbdads/quarkles. This would mean that the linear trend we observed in the data is due to aliasing (a false trend that is an artifact of the independent variable choices being too broadly spaced apart). Or more simply stated, the experimenters just happened to pick plumbdad/quarkle pairs that fall upon a line as well as the sinusoid. Given the limited data, this might have happened, but that would suggest either an improbable set of independent variables or experimenter collusion.

As the exercise proceeds, more measured values are found relating plumbdads to quarkles. As a result of the new data, Bernard changes his sinusoidal fit so that he again obtains a tight fit to the center of the uncertainty range. In so doing, his sinusoidal fit has greatly changed from its previous version (see Fig. 3). Abbey then declares that she doesn’t like Bernard’s new fit now shown). Approximately 70% of the calculus-based physics students prefer a linear model (on the written assignment). Unfortunately, only 50% of the general education students prefer the linear model. In my experience, this always leads to a valuable class discussion as some students will argue for the model that follows the data trend (a linear model) and others will argue for the model that has a tighter fit to the center of the data (the sinusoidal fit).

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**Fig. 2.** A sinusoidal fit is added to the same data shown in Fig. 1. Will students see value in this model given that no evidence-based theoretical framework is possible?

**Fig. 3.** One of the researchers changes his sinusoidal model to incorporate new data measurements. Another researcher changes her linear model (not shown in the graph) to incorporate the new data. Students are asked whether these model modifications are equally permissible.
liked Abbey’s new fit, and ~60% felt she went too far in her criticism). Among Bernard’s supporters, I have observed or heard general statements similar to, “Bernard must be smart to manage those fits so why not just go with his opinion?” or “If two models adequately represent all the known measurements, they must both be equally valued.” These issues are typically resolved in group discussions, but many students are surprised that their peers can initially see these issues so differently. One extreme of the student distribution argues that Bernard is clearly smart and is just looking at the data differently than Abbey, and the other extreme argues that there is little value in Bernard’s models.

In a later task in the exercise, the importance of a predictive model over a purely reactive model is examined. An abundance of new data confirms Abbey’s linear model, but Bernard is still able to find yet another sinusoid that adequately fits all of the data. Students are simply asked what they think of Bernard’s methods. In their written answers, ~85% of the calculus-based physics course students rejected Bernard’s latest actions. The results are more disappointing in the general education course (~50% rejected Bernard’s latest actions). During discussions I often find it useful to mention the words “scientific method” if they haven’t already been introduced by the students. Many students do not immediately see that a scientific method has actually occurred where the two experimenter’s models equate to hypotheses. Thus, the comparison at this stage is between an increasingly confirmed hypothesis and a person who produces a new hypothesis every time data are added.

There are other parts of the plumbdad/quarkle exercise that cover a range of related issues that can’t be fully described in this brief note. Abbey eventually wants people to fully accept her model over Bernard’s model, and so students are asked how many more measurements must she go through such that her fitted model is 100% certain (the answer, of course, is she can never reach 100% certainty because that would require an infinite number of perfectly accurate measurements). Finally, in the last question, students are told that Abbey is going to make more measurements where she will give them the plumbdad amount. They are asked which model would they use to predict the resulting quarkle amount and how confident would they be in that prediction.

At the end of the classroom discussions, whatever support Bernard had has eroded to the point that no one will openly support him or his methods. In fact it’s not uncommon for many students to be upset at Bernard and even question his intelligence. These two observations may be related. If one considers the written results, there is a distribution of student answers ranging from expert-like responses to responses where Bernard’s approach is seen as superior to Abbey’s. Unlike Bernard, there are no students who feel Abbey has been grossly inept. Thus, Bernard’s lack of open support in class may be due to a combination of students changing their minds (and moving toward the more expert end of the distribution) and students not wanting to be seen supporting him. However, this exercise has also demonstrated a more lasting impact for some students. I have observed students in following laboratory investigations rejecting other students proposed fit types because of the exercise. More testing is planned.

In conclusion, the plumbdad/quarkle exercise was developed to facilitate a classroom discussion. My colleagues and I have found that it helps prepare students for the upcoming laboratory exercises where students have the freedom to select fitted curves (linear, quadratic, etc.). It is the discussion that allows an instructor to stress guiding principles for using mathematical models, especially as they are applied to physical data. To ensure the success of this exercise for a greater audience, I would ask that those wishing to adapt all or part of it make up their own physical parameter names. That is, use nonsense words in the place of quarkles, plumbdads, mimfs, etc. Otherwise, before too long, a more proper analysis of plumbdads and quarkles will be available online.

References
7. The full exercise is available online at http://users.ipfw.edu/grovet/Plumbdads.html.

Timothy Grove is an associate professor of physics at Indiana University-Purdue University Fort Wayne. He received his BS in engineering physics from Lehigh University and his MS and PhD in physics from the University of Connecticut. He is currently interested in a variety of experimental atomic vapor and atomic beam experiments as well as advanced laboratory curriculum and pedagogy.

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