Converting Cookbook Labs into Inquiry Labs

by Carl J. Wenning, Ed.D.
Physics Teacher Education Program
Illinois State University

Too often physics teachers will employ the traditional verification lab instead of allowing students to use lab activities to work like scientists to discover actual physical relationships. For instance, when dealing with transverse wave propagating on a string (fundamental frequency, first harmonic only), the traditional form of lab has students collect data to verify the theoretically derived relationship

$$\nu = \frac{1}{2d}\sqrt{\frac{T}{\mu}}$$

where ν equals the frequency of the standing wave, d the length of the string (equivalent to $\lambda/2$), T the tension on the string, and μ the linear density of the string. The traditional confirmatory lab will generally consist of varying T for fixed values of d and μ. Lost in such approaches is the opportunity to experience using intellectual scientific process skills: thinking hypothetically, creating an experiment, controlling variables, constructing knowledge, overcoming preconceptions, etc. It is imperative, then, that teachers concerned with teaching physics through inquiry know how to transform traditional cookbook labs into authentic inquiry exercises.

An inquiry-based approach would be much different from the rather mindless step-by-step directions provided in the traditional approach. An inquiry approach dealing with the above law would begin with an examination of the characteristics of a stretched string that might affect the fundamental frequency of the first harmonic standing wave. This can be done with a guitar string for instance. Moving fingers up and down the frets will show that frequency is influenced by the length of the string – shorter spans result in higher frequencies. Adjusting the tension on a string also will affect the frequency – the greater the tension the higher the frequency. When reducing the tension of the thin strings designed to provide the highest pitch, such strings soon begin to "rattle" rather than to produce lower notes. Lower notes only seem to be possible with wound strings that have higher linear density. With these three factors shown to affect the frequency of the fundamental frequency of oscillation, it is possible to state the relationship in the form of a mathematical equation.

$$\nu = f(d, T, \mu)$$

That is, frequency is a function of d, T, and μ. Dimensional analysis of this equation will then allow for the creation of a hypothetical form of the relationship. Rewriting the above functional relationship in the form of a proportionality so that we can avoid having to work with dimensionless proportionality constants we have

$$\nu^1 \propto d^a T^b \mu^c$$

Replacing the variables with units (e.g., ν is expressed in s^{-1}, d is expressed in meters, m) gives

$$s^{-1} \propto m^a \left(\frac{kg \cdot m}{s^2}\right)^b \left(\frac{kg}{m}\right)^c$$

that simplifies to

$$s^{-1} \propto m^{(a+b-c)} kg^{(b+c)} s^{-2b}$$

Equating exponents on both the left and right sides of this equation (assuming the presence of m^0=kg^0=1 present on the left side), results in three simultaneous equations with three unknowns that are readily soluble.

$$0 = a + b - c$$

$$0 = b + c$$
$$-1 = -2b$$

Solving these equations for their unknowns results in the following

$$a = -1$$
$$b = 1/2$$
$$c = -1/2$$

With this information, we can rewrite the hypothetical form of the relationship as

$$\nu \propto d^{-1} T^{1/2} \mu^{c-1/2}$$

or, by including a proportionality constant, *k,* we can rewrite this as an equality

$$\nu = \frac{k}{d}\sqrt{\frac{T}{\mu}}$$

This is nearly identical with the traditionally posited form of the relationship. An experimental analysis will show the value of *k* to be 1/2 in the situation where we are dealing with the fundamental mode of oscillation of a string. Now, to verify this experimental form of the relationship, a step-by-step analysis of the physical situation can be conducted. Students working independently in three groups will check the following independent relationships controlling extraneous variables appropriately.

$$\nu \propto \frac{1}{d}$$
$$\nu \propto \sqrt{T}$$
$$\nu \propto \frac{1}{\sqrt{\mu}}$$

This can most readily by done with the use of a relatively simple physical set up. Acquire a standard set of six guitar strings from a local music shop. Then set the strings up individually supported with triangular blocks and tensioned with weights. Once these materials available, let the students devise their own means to see if these hypothetical relationships are real.

For instance, the first group will vary *d* and, with the aid of MBL equipment such as a microphone, a computer interface, and a Fast Fourier Transform computer package, be able to find that indeed the inverse relationship holds through the use of graphical analysis. When this has been done in the three cases, there is experimental evidence to support the hypothetical form of the relationship

$$\nu \propto \frac{1}{d}\sqrt{\frac{T}{\mu}}$$

which transforms to the equality

$$\nu = \frac{k}{d}\sqrt{\frac{T}{\mu}}$$

The proportionality constant, *k*, can then be derived experimentally. By plotting

$$\nu \text{ versus } \frac{1}{d}\sqrt{\frac{T}{\mu}}$$

for a combination of *d, T,* and μ values, one obtains a slope that has the value of *k* which is 1/2 for the first harmonic. That is,

$$v = \frac{1}{2d}\sqrt{\frac{T}{\mu}}$$

By working with a wider range of standing waves and more sophisticated physical lab set ups, students can find the even more general relationship

$$v = \frac{n}{2d}\sqrt{\frac{T}{\mu}}$$

where n = 1, 2, 3…, the number of half wavelengths present on the standing wave interval, d.

Practical Pointers for Writing Inquiry Labs

- One must not attempt to write an inquiry lab without meticulously thinking through the intellectual processes required to conduct the lab.
- One must have a lab that is logically organized. First things must come first.
- Inquiry labs should build on the conceptual, and only then move to the mathematical.
- Lab guidelines should be read for clarity and with understanding.
- Lab guidelines should not be used with students until they have been piloted with a group of volunteers who do not constitute the writer(s).
- Lab guidelines should contain a set of objectives, with "tasks" associated with each objective.
- Lab guidelines should contain a pre-lab that focuses on the knowledge and processes required to complete the actual lab.
- The pre-lab should be separable from the lab guidelines; lab guidelines should not reference a pre-lab that has already been handed in.
- The lab and its various activities must be "doable." For instance, don't expect students to determine using dimensional analysis the relationship for range, R, of a horizontal projectile with initial speed, v, located a height, h, above a floor, in a gravitational field, g. R = $f(v, g, h)$. This won't work. Do the activities yourself successfully before you ask your students to do them.
- Make certain that the topic is meaningful, worthy, and appropriate.
- The subject of the lab activity should be appropriate for the course being taught.
- Note and follow the format of the model inquiry lab guidelines given you in this course.
- If you insert equations, use *Equation Editor* or some similar such program.
- Make certain your diagrams are computer generated and have a professional appearance.
- Before starting to convert a cookbook lab into an inquiry lab, be absolutely certain you understand the differences. Also see the *Inquiry Lab Scoring Rubric*.