Bringing New Life to "Open World" Intro-Physics Labs

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Introduction

The current focus on remote teaching suggests that a class of "open world" intro-physics labs, first discussed in *The Physics Teacher* almost a half century ago[1][2][3], might be ripe for a closer look in context of new technology now widely available to the general public as well as to schools. To this end, let's define "open world labs" as assigned experiments which involve real world (i.e. not simulator) experiments outside the classroom with a well-defined objective, toward which students play an active role in choice of experimental focus as well as in experimental design.

By way of example, in an earlier incarnation of the "real world acceleration" experiment described below, groups of 4 or 5 students were assigned the two-week task of measuring the maximum acceleration of anything they like. One group took an old jalopy out on a dirt road with a bunch of sandbags in the backseat. While one student floored the accelerator after starting from rest, other students took turns throwing sandbags out the windows at 1 second intervals. With a tape measure after the fact, they were then able to infer the acceleration of the vehicle second after second, as shown in the figure at right. No faculty member could have imagined, let alone been able to assign, such an experiment to a group of students at that time, so the pride of vision and accomplishment in that experiment belonged to the students alone.

In this paper, we offer updated versions of the two earlier-referenced open world experiments, and then discuss prospects for expanding these to a wider range of topics. We also discuss some of the challenges to giving students a more active role in experimental design, and scientific reporting.

Acceleration in the Real World

"Acceleration in the real world" below is adapted from a McGill takehome experiment reported by Landry et al.[1]

Object: The aim of this experiment is to have you yourselves work through some of the real problems involved in planning and making a measurement.

Context: Cars, buses, trains, skiers, skaters, toboggans, bobsled, elevators, snowmobiles, bicycles and tractors all undergo proper acceleration and deceleration. Gravity and inertial forces cause geometric accelerations which are invisible to on-board accelerometers[4], but might be measured by external means (including the proper reaction force needed to prevent them from acting).

In this experiment you are to measure the *maximum* acceleration of any accelerating body of interest to you. You must devise a method of measuring acceleration that does not depend on laboratory equipment but on measuring devices normally available. These might include a homemade pendulum, a postal scale, a stopwatch and a ruler or speedometer, a digital video camera, or even your cell phone's accelerometer which can even graph 3-axis data in real time using apps like Google's Science Journal, phyphox, or Physics Toolbox by Vieyra Software.

A problem of interest might be to compare the deceleration of a vehicle or train when stopping, with its acceleration when it starts up again. Another possibility might be the vector acceleration of a fly ball by analyzing the frames of a video, the acceleration of an elevator starting and stopping with help from a sensitive scale, or the centripetal acceleration experienced by a cellphone on a turntable of one sort or another.

For safety reasons, do not study the acceleration of a vehicle that you control (e.g. a car that you are driving). If you think that your measurements may cause any inconvenience to the public, you should request permission from the appropriate authorities and also check with your lab teaching assistant (TA).

Organization: It is planned to have this experiment cover two laboratory periods, instead of just one. In the first lab meeting, discuss possibilitie and strategies with your TA. Students interested in studying the same accelerating system might at that time form a small group. Whether singly or in group, decide what you will try to do (and who will do it), and discuss your plans with the TA. The second lab meeting will be held for students to bring in questions but will be optional if students would rather use that time to gather and analyze data.

Report: Give a full description of the acceleration studied, the method used to calculate the maximum acceleration and any assumptions made, along with graphs, results, conclusions. If the report is part of a group experiment, describe the contribution of each group member in the acknowledgements.

Everyday Poisson Statistics

"Everyday Poisson statistics" below is adapted from a McGill takehome experiment described by Lafleur et al.[2]

Object: The aim of this experiment is to investigate the ubiquity of physical phenomena obeying Poisson statistics, by analyzing a single example of your own choosing.

Context: There are many phenomena which have the appearance of randomness. Try to think of some such phenomena, which could be tests against the Poisson model to be described here. To get you started, we suggest the following possibilities:

- The number of people, cars, clouds, or stones with some specific characteristic found in a certain interval of time or space.
- The distribution of: (a) baseball runs per team per 3-inning interval, (b) hockey goals per team per period, or (c) basketball fouls per player per game.
- The number of: (a) visible meteors in a constellation, (b) fights in a pub, (c) burglaries in a city, or (d) two-alarm fires in an area, per night.

- The number of births per day, or listings in a phonebook page, of people whose first name begins with a specific letter in the alphabet.

Theory: In the physical world we observe a number of phenomena in which events occur more or less at random. Events which occur perfectly at random are ones which are not affected by the occurrence of another i.e. they are not correlated. As an example, consider the sipping of soda by an audience watching a movie. At first glance it appears to be quite random with people taking a sip at each individual whim. Yet is it really at random? Does some person decide to take a sip because she or he notice another doing the same? Will a dry desert scene cause more than one to take a sip? If such factors are present, then the events have some correlation and will not occur perfectly at random.

A way to test for randomness is to set up a model for events distributed randomly in time, and from it calculate the theoretical distribution of events given data on the average number of occurrences in each of a series of equal time intervals. We then observe if a chosen phenomenon obeys the theoretical distribution when observed over a large number of time intervals.

Step 1: Organization: It is planned to have this experiment cover two laboratory periods, instead of just one. In the first lab meeting, discuss possibilities and strategies with your TA. Students interested in studying the same system might at that time form a small group. Whether singly or in group, decide what you'll try to do (and who will do it), and discuss your plans with the TA. Before leaving the first lab session, it is imperative that you communicate with your TA the following: (i) just what measurements you plan to make, (ii) when and where the measurements will be made, and (iii) if part of a group what each member of your group expects to have in hand by the time of the 2nd lab period one week hence. The second lab meeting will be held for students to bring in questions, but will be optional if students would rather use that time to gather and analyze data.

Step 2: The Actual Experiment: An important consideration, after you have chosen a phenomenon to work on, is to decide what is a reasonable time (or space) interval to use. In order to get an interesting curve, you should pick an interval in which the average number of events per interval is between 1.5 and 3.0. Also, in order to smooth out statistical fluctuations, you may need to record at least 200 to 300 intervals.

Step 3: Analysis and Report: First construct a table (e.g. Table 1) which lists: (a) in Column 1 the number of events per interval beginning with 0 and going to the maximum number of events i per interval observed, (b) in Column 2 the number n_i of intervals observed to contain i events, (c) in Column 3 the value of n_i from column 2 divided by the total number of intervals observed, thus giving an observed probability that a given interval will contain i events. Lastly (d) in Column 4, using the observed average number of events per interval, list the theoretical probability for each value of i from the Poisson equation.

To see how the amount of data taken affects your results, also construct a version of the foregoing table (you might call this partial list Table 2) which incorporates only the first third of the data that you took. Next display the comparative results from Table 1 graphically by plotting the probability expected in Column 4 versus the number I of events per interval in Column 1.

Join the points with a smooth curve. Then plot with different symbols on this same chart the experimentally observed probabilities (Column 3) to see how close your experimental distribution comes to the theoretical one. Construct a second such comparison graph using only the first third of the data, from Table 2.

Are the experiments in each case consistent with a Poisson model for the phenomenon that you've chosen? If your experimental and theoretical curves don't fit, can you think of any mechanism responsible for correlation between events which might be the cause?

Discussion

In addition to the **acceleration**[1] and **everyday statistics**[2] experiments mentioned above, as well as the **g-determination**, **velocity of sound in air**, and **mass of an object** experiments described later by the McGill group[3], some basic **oscillator experiments** at home might be done with a pendulum made from a washer and a piece of string (a really special toy for kids in 12th century England), or a computer mouse dangling from the end of its wire. Perhaps even the Starfleet survival manual tells you how to use these things to determine "g", if you are not sure what planet you are on.

Should students find a way to measure light intensity, they could explore **$1/r^2$ intensity variations**, and if they can find a way to record RGB ratios in a color image they can do **pyrometry of glowing objects**, and also explore a variety of **color-related interference and transmissivity effects**. Both of these things can e.g. be done with most smart phones, or a digital camera. Similarly, for **sound intensity and pitch**, a wide range of experiments can be done with a sound recorder and software to analyse the recordings. Many cell phones have magnetometers, which can be used e.g. to look at the rate of **fall-off of magnetic field from a current carrying wire, or a permanent magnet**. Thermometers (both cooking and "point and click") can be used to examine **cooling rates** e.g. of a turkey just out of the oven, or temperatures as ice warms up on a hot day. Diffraction gratings or even feathers might let students **use scattering to measure spatial period**, which in turn might be checked with a magnifying glass or a cell phone magnifier app.

If a series of **open world experiments** like this were to be developed for use with intro-physics courses at your school, an initial lab on experiment design and documentation might itself be a good idea first to help bring out each students' "inner scientist". One might alternatively decide what such a course should include, and then introduce the same content incrementally within successive experiments, designed so as to shift more and more of that burden to the students as the course unfolds. Lab-report rubrics to assess the various components, which might include e.g. calibration steps, source citing..., might be organized around five "C's", e.g. clarity, correctness, completeness, connectedness (to the literature and everyday life), and creativity.

Open world physics experiments can help students develop a deeper understanding of physics by giving them the ability to create, explore, and analyze a fundamental physics concept on their own. This gives them the power to create an experiment in a manner which is relevant to them.

One of Art Hobson's five principles of relevant science teaching is to "Make It Modern". Very few students find themselves wondering how long it would take an object to fall under Earth's gravity while neglecting air resistance. Instead, a more relevant question might be: Using the kinematic equations, estimate how long you have to try and catch your cell phone if you drop it from chest height. A question like this might even inspire a series of free fall experiments.

Giving students control over their own experiment can lead to a more fulfilling and inclusive experience with physics. Getty et al. (2020) found in their development of inclusive teaching methods that students responded well to a Design Your Own Problem (DYOP) assignment. In the DYOP students were asked to not only create a problem and solve it, but also to create an incorrect solution to the problem. By creating an incorrect solution, students are able to reflect on how the overall concept works. An open world experiment should be analogous to this type of assignment, except students are prompted with a general problem and asked to design a method which will allow them to prove a physics concept to the best of their ability.

1. P. C. Landry, F. M. Gurr, P. F. Hinrichsen, and R. B. Moore (1971) "The Acceleration of a Metro Train", *The Physics Teacher* **9**, 441-446 link.

2. Miriam S. Lafleur, P. F. Hinrichsen, P. C. Landry, and R. B. Moore (1972) "The Poisson Distribution", *The Physics Teacher* **10**, 314-321 link.

3. Mimi Lafleur and Fiona Gurr (1974) "Note: Physics Really does Work", *The Physics Teacher* **12**, 235-237 link.

4. Peter F. Hinrichsen (1974) "The Poisson and interval distributions", *American Journal of Physics* **42**, 231-238.

5. Hobson, Art. "Teaching relevant science for scientific literacy." *Journal of College Science Teaching* 30.4 (2001): 238-243.

6. Getty, Stephen, et al. "Supporting Inclusive Teaching in Introductory College Physics." *The Physics Teacher* 58.5 (2020): 312-315.