Tackling experimental design concepts with rubber bands

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Abstract

Understanding the principles of experimental design is pivotal for studying and doing science. Teaching undergraduates how to design experiments is a challenging task especially in freshmen and sophomore courses. Often students are taught how to do so at the crossroads of new biological content, new hands-on skills and introduction to scientific equipment. As a result their efforts typically focus on the technical aspects of the experiments rather than on the process of scientific inquiry itself. The designed laboratory introduces key concepts of experimental design using rubber bands as manipulatives. Students are challenged to explore alternative hypotheses to formulate research questions and perform self-designed experiments to answer them. The exercises emphasize the following key elements of experimental design: one experiment/one variable; positive control, negative control, experiment precision, reproducibility and validity. The laboratory is appropriate for introductory courses for majors and nonmajors and could be easily executed in large classrooms.

The idea of the lab exercise

The scientific method is a sum of logical steps by which scientists experiment and reach conclusions about the surrounding world. It can be viewed as a circular process of making observations, asking questions, formulating hypothesizes and experimentally testing them to reach conclusions. One can enter the process at any step and pursue investigation through multiple cycles performing specific experiments that could be objectively interpreted, i.e. something is reliably described, measured, scored, timed. Collectively, the scientific investigation results in an organized body of knowledge that allows better understanding of the underlying principles of life and propelling further investigation.

The presented self-guided lab exercise aims to stimulate students to review the basic principles of experimental design and apply them to a simple and straightforward situation simulating experimental design. Currently, the exercise is being taught as a part of basic lab skills boot camp sessions taking place during the first two weeks of the laboratory of BIOL 200/Cell Biology course. The exercise follows a sequence on making and communicating experimental observations and extends to graphing, data interpretation and figure generation tasks. In the interest of space fill in areas of the student handouts have been reduced to two lines.

Student self-guided exercise

Practicing the scientific method

Step 1: State the problem/ ask a question.
You cannot solve a problem unless you know exactly what it is. Our test drive problem is very simple. Imagine that you are "very interested" to know how easy it is to cut thin vs. thick rubber bands. Not very exciting problem to investigate but very fast and easy to perform and model experimental design with. You look around and see that on your lab bench there are thin and thick rubber bands and scissors.

Formulate a scientific question/problem you can pursue to satisfy your curiosity.
Tip: What is measurable? Easy or fast?
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Step 2: Research the problem. Construct a hypothesis.

What will it take to solve my problem? What do I know, and need to know, about my problem?
What are the possibilities? Consider how likely each possibility is.

For our simple test drive problem one can think of 3 possibilities:

It takes longer to cut the thicker rubber band, than to cut the thinner rubber band.
It takes longer to cut the thinner rubber band, than to cut the thicker rubber band.
It takes the same time to cut the thinner and the thicker rubber band.

Think about all 3 possibilities and write down which one you consider the most likely and why?
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You just formulated your hypothesis. You can think about your hypothesis as an educated guess stated in a manner that allows straightforward testing.

Step 3: Make a prediction.
Predictions reflect your expectations for the outcome of the experiment and generally can be described in the following format:

"If ***I do "X"***, then *"Y"* will happen."

In our case, the prediction can be formulated along the following lines:

•If **I cut the same number of thin and thick rubber bands**, then I will see that it takes longer to cut thicker rubber bands than thinner ones. ***or***

•If **I cut the same number of thin and thick rubber bands**, then I will see that it takes longer to cut thinner rubber bands than ticker ones. ***or***

•If **I cut the same number of thin and thick rubber bands**, then I will see that it takes the same time to do both.

Step 4: Design experiment(s) to test your hypothesis and draw conclusions.
Lucky for us, all 3 possible predictions can be tested with the same experiment. If each student cuts 10 thin and 10 thick rubber bands using the same pair of scissors and the time needed to do so is measured, one should be able to reach a conclusion.
Is that a fair experiment? Why or why not?
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Let's perform the experiment. Each student will be given 10 thin rubber bands and 10 thick rubber bands. Work as a pair with your partner and time each other how long it takes to cut each bundle of rubber bands. Record your results in your lab manual and on the board.

Your results (All data should be entered in the table on the white board to generate a class data table :
time for cutting 10 thin bands in seconds: ……………………………
time for cutting 10 thick bands in seconds:……………………………
What is your conclusion?……………………………………………………………………
……………………………………………………………………………………………

Class conclusion*: Is your conclusion and the class conclusion the same or different? Explain possible reasons?*
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Let's analyze what we did and review some terminology that will be used repeatedly during BIOL 200 lab and all biology courses. In general, the design of each experiment can be correctly described by identifying all variables. A variable is a parameter that changes. There are 3 types of variables:

•**independent variable** – the variable, that is being consciously changed to address the question to be resolved, in our case that is the thickness of the rubber band.

•**dependent variable** – the variable/ "result" that we will be measuring, in our case time measured by stop watch.

•**controllable variable** – variables that are strictly controlled (usually kept the same) during the experiment to ensure fairness of the experiment.

In our case we will be using the same pair of scissors to cut both: the thin and the thick rubber bands, also both types of band will be from the same material and the same manufacturer.
The independent and dependent variables can be found in tables, graphs, diagrams, i.e. within any means presenting the results of the experiment. Controllable variables can be usually found in the description of the experiment, the materials section and/or tables, graphs, diagrams figure legends.

How to design a good experiment? What makes an experiment fair and precise?

1. Each experiment should have no more than one variable, i.e. only one condition of the experiment should change. If more than one variable is changing, there is no certainty about which variable caused the effect you were examining.
What "thing(s)" were you changing in your "individual" experiment? List it/them:
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What "thing(s)" were you changing in your "class" experiment? List it/them:
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2. Controls or standards are needed to reliably appreciate the results of any experiment. Each experiment should have a negative control, which is usually the place or the condition you have started before any changes took place. Each experiment also should have a positive control, i.e. standard how things will look if the process is working. In our experiment the controls are intuitive:

• **Negative control** is an uncut rubber band, i.e. the status of the subject of the experiment **before** the action took place.
• **Positive control** is a cut rubber band, i.e. the status of the subject of the experiment **after** the action took place

Please, be aware that positive and negative controls are not always easy and straightforward to set up.

3. Each experimental result has to be reproducible by you and other people.
No experimental result can be a source of valuable information if it is performed only once and no one can reproduce it. Replicates also assist in determining whether variation detected is experimental error or true biological variability. The number of replicates depends on how reliable the data need to be and it is field specific. For instance, if you are testing the safety of a drug it is critical the testing to be done on a large enough group before it is declared safe and effective and distributed to the world population.

How many times did you repeat your experiment?………….
Can the 16 runs of the same experiment in the lab count as 16 repetitions? Why or why not?
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How would you change the design of the rubber bands experiments, so that it fits the described 3 principles of good experimental design?……………………………………………………………

Outcomes and conclusions

1. **The presented exercise challenges students to discover by themselves that practicing the scientific method is not a trivial process. Since students approach differently the cutting of the rubber bands the class data is controversial and does not support the intuitive expectation that it takes less time to cut the ten thinner bands than the ten thicker bands. That problem situation sparks meaningful discussion of:**

- **The importance of precise experiment recording and communication**
- **The role of experiment repetition**
- **The role and importance of equipment in scientific experimentation**

2. **The simplicity of the system allows students to build a visual model of the concepts of positive control and negative control, that is straightforward to remember and apply to future experiments.**

3. The exercise is easy to execute and requires minimal resources, thus making it a wonderful tool for reviewing principles of experimental design in laboratory settings, as well as a manageable hands on supplement for lecture instruction on the scientific method.

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