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Tackling Experimental Design Concepts with Rubber Bands

Boriana Marintcheva

Bridgewater State University, Department of Biological Sciences, Connant Sciences Building, Room 309, 131 Summer St. Bridgewater MA 02325 USA
(**Boriana.Marintcheva@bridgew.edu**)

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 exercise described here introduces key concepts of experimental design using rubber bands and can be easily executed on any level of instruction.

Keywords: scientific method, experimental design

Link to Original Poster: http://www.ableweb.org/volumes/vol-34/poster?art=58

Introduction

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 sessions taking place during the first two weeks of the laboratory of BIOL 200/Cell Biology course. BIOL200 is a core course required for all Biology majors in our curriculum, as well as Chemistry majors with Biochemistry concentration. Traditionally, the course is taken by a diverse student population including many transfer students and returning students who often have completed the course prerequisites (General Biology I and Chemical Principles I) several years before taking BIOL200/Cell Biology and need a refresher. The exercise follows a sequence on making and communicating experimental observations and extends to graphing, data interpretation, and figure generation. The described exercise could be executed in a lab setting as a quick refresher of basic principles of experimental design or in a context of a lecture as a complementary hands-on activity to formal instruction on the scientific method. In the interest of space, the “fill in” areas of the student handouts below have been reduced to two lines and the number of rows in the data recording table reduced to only four.

Student Outline

By its nature, Biology is a continuous process of applying the scientific method to study living systems in order to describe and understand how they work. The scientific method is the sum of logical steps by which scientists experiment and reach conclusions about the surrounding world. It can be viewed as a circular process (Fig. 1) of making observations, asking questions, formulating hypotheses, 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, and timed. Collectively, the scientific investigation results in an organized body of knowledge that allows better understanding of the underlying principles of life and drives further investigation.

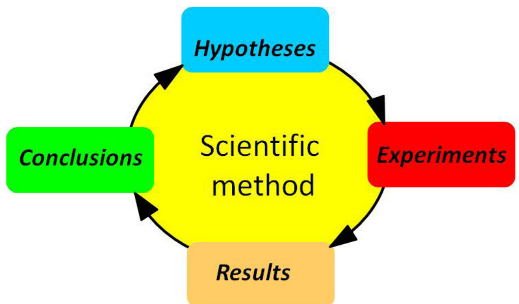

Figure 1. Flow diagram of the major steps of the scientific method.

Materials and Equipment

- Thin rubber bands
- Thick rubber bands
- Scissors
- Timer

Practicing the scientific method (a self-guided exercise)

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!

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 "X" takes place,** 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.

State your prediction:

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Step 4: Design experiment(s) to test your hypothesis and draw conclusions.

Lucky for us, all three 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. On your tables you have 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 sheets and on the classroom board.

Your results:

- time for cutting 10 thin bands in seconds: ....
- time for cutting 10 thick bands in seconds:..................................

What is your conclusion?

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Table 1. Class results

	Time for cutting 10 thin bands (seconds)	*Time for cutting 10 thick bands (seconds)*
1.		
2.		
3.		
4.		

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 refresh 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 in the figure legends of tables, graphs, diagrams.

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 changing in your "individual" experiment? List it/them:

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   What "thing(s)" were 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 the subject of investigation will look if the process/ action being performed 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 of subjects before it is declared safe and effective and distributed to the world population.

   How many times did you repeat your experiment?

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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 three principles of good experimental design?

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Notes for the instructor

Exercise materials

- Staples rubber bands #16/ Catalog # 808576
- Staples rubber bands #64/ Catalog # 808659
- Set of identical scissors for all students. Small size scissors work better since they create difficulties to cut a group of 10 thick rubber bands in one shot, thus creating larger variability in the experimental results and triggering more effective discussion.
- Timer/stop watch/ phone chronometer with capabilities to measure seconds

Comments

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 (for example some students cut the bands one by one, others hold them as a bunch and cut them together in one shot) the class data is controversial and does not support the intuitive expectation that it takes less time to cut the 10 thinner bands than the 10 thicker bands. If the same person meaningfully repeats the experiment several times it becomes apparent that on average it takes the same time to cut both types of bands. The difference in thickness between both types of bands is not large enough to result in measurable differences on the time scale of seconds that can be recorded. That problem situation sparks meaningful discussion of:
   - The importance of precise experiment recording and communication of specifics of the procedure
   - The role of experiment repetition
   - The role and importance of equipment in scientific experimentation
   - Experiment resolution
   - Experiment design refining
   - Importance of technology for science advancement

2. The simplicity of the system lets students build a visual model of concepts of positive control and negative control that is straightforward to remember and apply to future experiments. In the course of the BIOL200 laboratory I use the rubber bands to demonstrate restriction enzyme digest, as well as to visualize different levels of DNA supercoiling of plasmids and their relationship to plasmid mobility in an agarose gel.

About the Author

Boriana Marintcheva received her Ph.D. at the University of Connecticut - Health Center, Farmington, studying Herpes virus replication. As a postdoc at Harvard Medical School she worked on the role of bacteriophage T7 ssDNA-binding protein at the replication fork. She is currently an Assistant Professor at Bridgewater State University in Bridgewater, Massachusetts, where she teaches Cell Biology, Molecular Biology and Virology.

Mission, Review Process & Disclaimer

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