The Use of Writing in Investigative Biology Laboratories

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Ralph Preszler was introduced to the study of biology and developed an interest in botany and plant ecology at Southern Oregon State College (now Southern Oregon University) in Ashland Oregon where he earned his B.S. in biology. He then moved to Northern Arizona University, where he earned his M.S. and Ph.D. studying interactions between plants and herbivores and where he was given the opportunity to discover the fascinating and challenging nature of teaching.

Reprinted From: Preszler, R. W. 2000. The use of writing in investigative biology laboratories. Pages 492-496 *in* Tested studies for laboratory teaching, Volume 21 (S. J. Karcher, Editor). Proceedings of the 21st Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 509 pages.

Many schools across the country have recently changed from primarily observational laboratory exercises to more investigative, hypothesis-testing experiments. This shift in the nature of laboratory activities has dramatically altered the purpose of laboratory reports. What once were fairly descriptive reports which could be successfully written outside of class have become writing exercises that help the students synthesize and interpret their experiments. It is no longer realistic to expect that students can successfully complete this challenging component of the experimental process without considerable guidance. We have been developing activities in the laboratory that help students learn the synthetic and creative reasoning skills that they will need to complete their scientific investigation successfully as they write their reports.

After in-class activities that help students distinguish hypotheses from predicted results, and after learning to recognize and describe the relevant patterns (or lack of patterns) in their observed results, most students are able to form a conclusion regarding a hypothesis. This initial conclusion is the starting point of our students' discussion sections. This conclusion should be consistent with and supported by the comparison between their predicted and observed results. It is the subsequent components of the discussion — critical evaluation of experimental assumptions and discussion of implications — that our students find the most challenging. This paper provides a detailed description of a laboratory experiment that we have developed (Preszler and Haas 1999) that helps students learn to identify and evaluate the consequences of assumptions that are imbedded within their experimental design. I close with a brief description of assignments that have helped our students explore the implications of their work.

This experiment, derived from the work of Reinking et al. (1994), uses enzymes found in two dietary supplements to evaluate the lock and key model of enzyme specificity. The first dietary supplement, Lactaid® contains beta-galactosidase which breaks the beta-linkage in lactose to produce glucose and galactose; in contrast, Beano® contains alpha-galactosidase which breaks the alpha-linkage in melibiose which also produces glucose and galactose (Figure 1, Step One). Yeast is also included in each solution to produce a bioassay that generates carbon dioxide from glucose if the first reaction has occurred (Figure 1, Step Two). The four treatments shown in Table One provide a test of the specificity of the two galacotsidases.

Before they have conducted the experiment, I ask each group of students to identify an assumption in the experimental design. To help them discover underlying assumptions, I discuss the following categories of assumptions that are present in nearly all experiments:

- We are able to measure the dependent variable accurately. In this experiment we hope to measure the rate of the initial reaction, but we are actually measuring the production of a gas during the bioassay.
- We are able to manipulate the independent variable in the intended fashion. Are we really controlling combinations of enzymes and sugars?
- There are no additional variables that may bias our results.

I then ask each group to contribute to the class list of assumptions. After we have identified the assumptions associated with the design of the experiment, students design their control variables. Table One illustrates the initial four treatments that test the specificity of the enzymes followed by control variables that can be used to evaluate the validity of the following assumptions. (After each assumption I've listed in parentheses the number of the corresponding control variable):

- Yeast cannot metabolize lactose (5);
- Yeast cannot metabolize melibiose (6);
- The dietary supplements do not contain any ingredients that can be metabolized by yeast (7&8);
- Yeast can metabolize glucose (9).

The results of this experiment generally support the hypothesis that the enzymes are specific to their respective sugars, but there is an interesting exception to this correspondence between the predicted and observed results. As indicated in Table One, Beano and lactose produce a small amount of carbon dioxide. However, if students understand the purpose of their control variables, they can use them to identify the assumption that was not met and that accounts for the CO_2 that is produced by this treatment. Notice Control #8 indicates that Beano contains substrates which can be reduced by yeast. These ingredients within the dietary supplement help account for the unexpected CO_2 produced by the combination of Beano and lactose.

Table One. Enzyme specificity treatments and controls. Cells initially left blank to be filled in by students have been filled in with italicized answers. Sample results, when materials are incubated at 37° C for 25 minutes, are included in the last column.

TREATMENT	SUGAR (2.5%) OR CONTROL (4 ml)	ENZYME (25 pills / 100 ml of water) OR CONTROL (2 ml)	YEAST (7%) (10 ml)	PREDICTION CO_2 production or No CO_2.	Results (ml.)
Treatments that Test the Hypothesis					
One	Lactose	Lactaid	Yeast	*Yes*	13
Two	Melibiose	Lactaid	Yeast	*No*	0
Three	Lactose	Beano	Yeast	*Yes*	1.5
Four	Melibiose	Beano	Yeast	*No*	9
Controls: Treatments that Test Assumptions					
Five	*Lactose*	*Water*	*Yeast*	*No*	0
Six	*Melibiose*	*Water*	*Yeast*	*No*	0
Seven	*Water*	*Lactaid*	*Yeast*	*No*	0
Eight	*Water*	*Beano*	*Yeast*	*No*	1.3
Nine	*Glucose*	*Water*	*Yeast*	*Yes*	18

The value of this experiment is not only that it provides students with an interesting test of enzyme specificity, but that it also helps them begin to look more critically at experimental conclusions. As they begin to work on the implications of this experiment, I introduce another layer of assumptions that are imbedded in scientific argument. I ask my students how realistically does the fermentation tube represent the human body? This leads to discussions of the need for series of experiments from *in vitro* work to clinical studies.

After students have evaluated the hypothesis and considered the effects of assumptions in the design of their experiment, I ask them to discuss the implications or applications of their conclusions. Encouraging our students to take this most challenging step in the scientific process is essential if we hope to train students who are able to apply scientific information to societal issues. I have used non-traditional laboratory reports and structured in-class discussions to help students develop the ability to discuss the implications and potential applications of their work. An example of this first approach is asking them to write a report comparing their experimental system to an analogous system. After they have conducted a yeast complementation experiment (originally developed by the GENE project) with prototrophic and auxotrophic yeast, I ask them to read material describing phenylketonuria and alkaptonuria. Rather than writing a traditional laboratory report, they write an essay discussing and explaining the analogy between the yeast and human conditions. Many of the students are surprised by the striking similarities of these two superficially very different systems. Exploring this analogy has improved their understanding of the use of model systems in biology and has improved their discussions of the implications of their experiments in subsequent reports.

As the structure of activities in teaching laboratories moves toward investigative exercises, it is important that the use of writing assignments to facilitate the development biological literacy also evolves toward assignments that encourage the production of scientific argument that elucidates connections between topics within biology and is tied to larger societal issues.

References

Reinking, L.N., J.L. Reinking, and K.G. Miller. 1994. Fermentation, respiration and enzyme specificity: a simple device and key experiments with yeast. American Biology Teacher, 56: 164-168.

Preszler, R.W., and L.L. Haas. 1999. Student investigations of cellular and organismal biology. EMC / Paradigm Press, St. Paul, MN. ISBN 1-58175-068-4

Figure One. A bioassay of galactosidase activity.