Introducing the Better (and possibly illuminating) student thinking about experimental design and the role of controls

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Introduction

A major learning goal for MCDB students is the ability to evaluate experimental design. Experimental controls are central to valid experimental design. Positive controls ensure that a given procedure results in an expected effect, while negative controls ensure that experimental outcomes can be attributed to the variable being tested.

We found that after completing the Cell Biology Lab Course (CBLC), students often had difficulty identifying experimental controls; they often confused positive controls with experiments or negative controls. Positive controls were often not recognized as necessary.

To address these issues, we designed and incorporated learning activities into the Spring 2010 CBLC; these "tutorials" required students to explicitly identify experimental, positive and negative controls necessary within experiment scenarios.

Outcome: Students' understanding of controls showed significant improvement as measured by a set of questions administered at the beginning and the end of the course.

Methods

CBLC characteristics: MCDB 3140 is a 2-credit course taken by MCDB majors; typically these students have already taken laboratory courses associated with introductory course sequence. Each session contains between 15-20 students working in groups of 2-4 for 4 hours weekly (one session in Spring 2010 contained only 9 students). The first half of the semester emphasizes techniques (e.g., microscopy and SDS-PAGE), while the second half focuses on groups of students designing, conducting, analyzing, and reporting on their experiments. Teaching Assistants (TAs) work in pairs and each TA is responsible for four sections per week. The instructor meets with the TAs weekly to prepare them for the upcoming labs. In Spring 2010, the instructor (JP) and LS both met with the TAs to go over the course materials including the control tutorial activities.

Study participants (MCDB majors):

- Students have completed at least 3 of the 4 core courses. CBLC is the last lab course required of MCDB majors.

Assessment questions: We developed two sets of questions to probe student thinking. The first was designed to evaluate students' understanding of "negative control experiment." It also included a question to examine students basic mathematical reasoning skills with the context of experimental data. The second question set represented a typical experimental scenario.

The first set of questions (2.1 - 2.4) were asked both pre and post Cell Lab while the additional four questions (2.5-2.8) were asked only upon completion of the course. Students spent 15 and 10 minutes to complete the pre- and post-tests respectively.

Experimental Control Category

- 200 were given the drug and their symptoms improved
- 75 were given the drug and their symptoms did not improve
- 50 were given a placebo and their symptoms improved
- 15 were given a placebo and their symptoms did not improve

For each of the four categories above indicate whether it represents an experimental or a control group.

If it is a control group, what did it control for?

Q1 asks: Is there a positive control in this experiment?

Q2 asks: Is there a positive control in this experiment?

Q3 asks: Is there a positive control in this experiment?

Q4 asks: Is there a positive control in this experiment?

Q2 asks student thinking about controls. Figure 1 shows students had difficulty identifying the positive control (Q2.6) and a to a less degree, the negative control (Q2.1 and Q2.3). Their understanding was significantly improved following the intervention (p < 0.001). Students (Fall 2009) who did not do "control activities" had post-test scores similar to the pre-test scores of Fall 2010 students.

We examined students' textual responses for coherence and relevance (Table 1).

Survey question results: We asked whether student thought that the various control activity helped with their own research projects. 70% students thought that the various control activities helped in designing their own research projects.

Discussion

Our results suggest that after practicing with the "experimental tutorial" in the 2010 spring semester, students improved their ability to identify controls and explain their purpose. In addition, more students were able to differentiate a positive control from an experiment or a negative control.

Our conclusions appear to be reliable for two reasons. First, the Improvements observed were specific to the focus of our intervention; students did not show improvement on question 1, which deals primarily with mathematical reasoning. Second, we gave a similar version of the assessment to TA students who taught the 2009 cell biology lab; 47% and 66% of TAs failed to identify positive and negative controls, respectively.

The same trends were also observed by students in the 2009 fall course (Figure 1).

Conclusion and future studies

There is a limited literature on attempts to help student understand experimental design. One of these studies, Brickman et al. (2) found 2% improvement of science process skills after two semester lab exercises. We took an more focused approach concentrating on experimental design and the control experiments, both critical components in the scientific research process.

We will continue to study the effectiveness of control questions and improve the control activities by better align with the lab topics. We hope to develop more online control tutorials so that students can study the tutorials outside of class, and discuss the tutorial questions in class.

References: