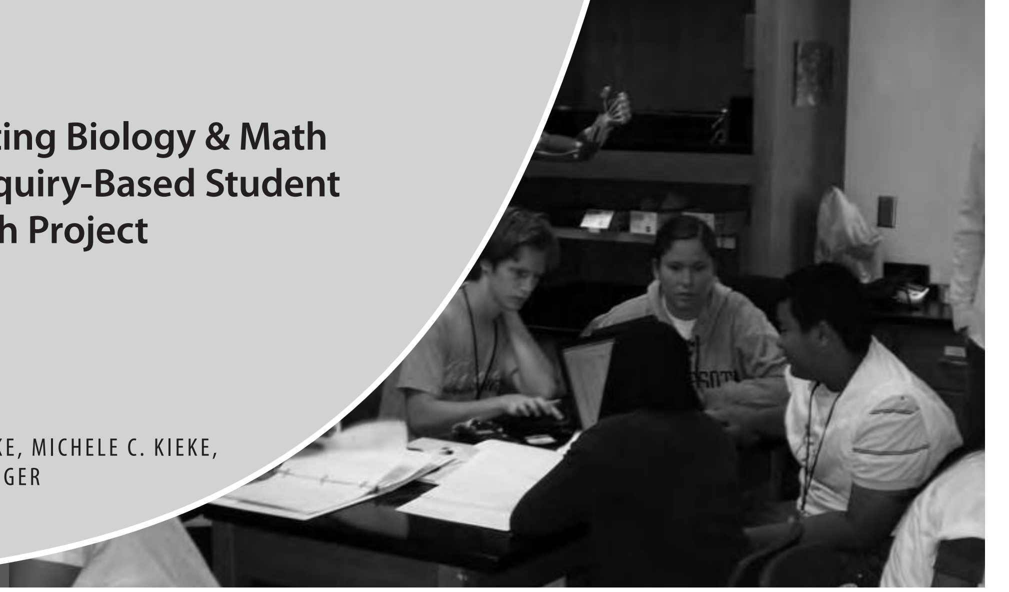
RESEARCH ON LEARNING

Integrating Biology & Math in an Inquiry-Based Student Research Project



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Abstract

In daily life, students are allowed to use words such as "more," "some," or "increase–decrease" to describe the relationship between two events. In science, concise description is necessary, which requires the contribution of math. In the summer component of the Science Research Institute program, students integrated essential math concepts with their research questions. Students designed experiments using data-acquisition units to monitor heart rate and pulse in order to obtain enough statistical power to mathematically use the words "more" or "increase–decrease." Overall, students gained an appreciation for the requirement of math to support the scientific question and research design.

Key Words: *Integrating science and math; inquiry-based projects; statistics; caffeine; heart rate.*

In *BIO2010: Transforming Undergraduate Education for Future Research Biologists* (National Research Council, 2003), the authors discuss the rapidly changing nature of biological research – biological concepts and models are becoming more quantitative, research is becoming critically dependent on concepts and methods from other scientific disciplines, and the connections between biology and other fields (such as mathematics) are rapidly becoming deeper and more extensive. They also point out that although most universities require their biology majors to enroll in math courses, faculty often do not integrate math and quantitative thinking into the biology they teach. The *Vision and Change* report sponsored by the National Science Foundation and the AAAS also highlights the ability to use quantitative reasoning as essential, because "biology relies on applications of quantitative analysis [including statistics] and mathematical reasoning" (AAAS, 2011, p. 14).

With this in mind, our group of three faculty members (two from biology, one from math) set out to design inquiry-based student "mini-projects" that would incorporate the use of math with biology. The experiments were chosen on the basis of faculty members' areas of expertise, which were physiology and mathematics. The first experiment (Experiment 1) was designed exclusively by the faculty members and did not incorporate math, because the results provided a "yes" or "no" answer. A Western blot with various rat tissue samples was probed with an anti-troponin I antibody. Troponin is a protein found in muscle that helps regulate the interaction between actin and myosin. The second set of experiments (Experiment 2a and b) – which, unlike Experiment 1, were primarily designed by the students with faculty members' assistance – aimed to integrate biology with statistical analysis. The students used iWorx data acquisition units (http://www.iWorx.com) to collect heart-rate data after either drinking caffeine (2a) or exercising (2b). Data acquisition units are used to collect physiology-related data, such as blood pressure, heart rate, pulse, and electrocardiogram, from humans and other animals. Through this process, we realized that although we focused on providing a strong statistical background and spent a significant amount of time refining the experimental design for Experiment 2a involving caffeine, it wasn't until the final experiment (2b) involving exercise that we truly integrated math (statistics), an improved experimental design, and science.

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The projects were conducted over the span of 4 weeks during the summer, with students participating in the Science Research Institute (SRI), a year-long program that encourages urban high school students of color to pursue careers in science and math. High school participants were placed into groups of three or four students led by a college-student mentor. Although we conducted the projects in the context of the SRI program, it could easily be adapted to other formats and used in a more formal setting such as an introductory or advanced biology course.

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○ Learning Outcomes

In completing these experiments, students will

- understand basic concepts and skills in biology and math;
- investigate questions and use the most current methodologies;
- develop research skills, specifically troubleshooting and research design; and
- gain a better appreciation for the work of mathematicians and scientists.

○ Experiment 1: Biology

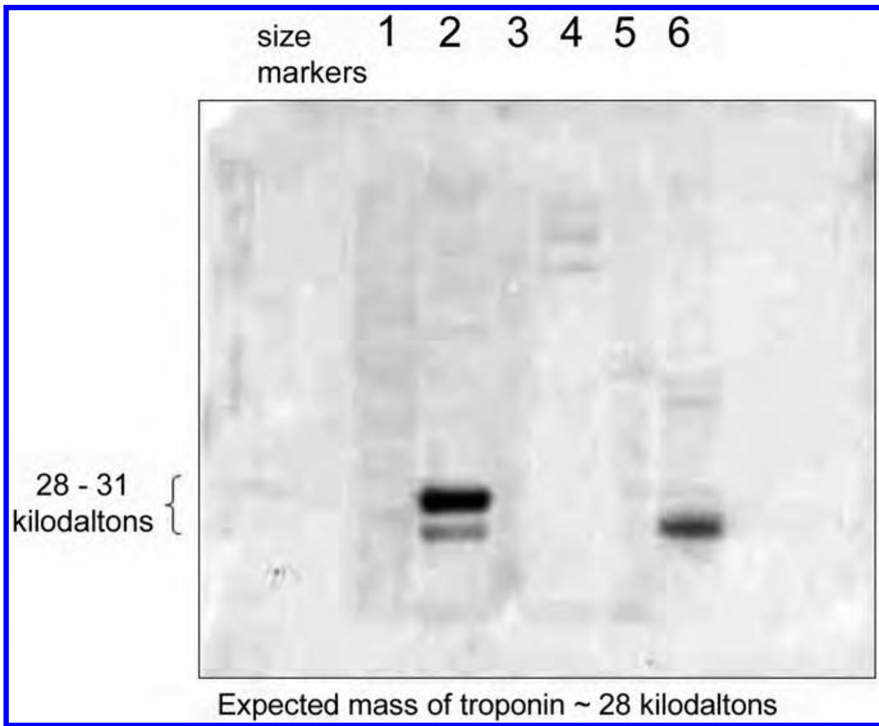
The first experiment was designed by the faculty members with the goal of orienting the students to experimental design, hypothesis formation, and laboratory technique. It was designed to show a clear "yes–no" answer to the question. Students isolated protein from rat brain, heart, kidney, small intestine, liver, and skeletal muscle. Following Western blot analysis, students were asked to make statements about the levels of troponin I protein in the different tissues. As shown in Figure 1, students were able to clearly make "more–less" statements regarding the levels of troponin protein in rat tissues. There are definitively increased amounts of troponin I in heart tissue compared with skeletal muscle (Figure 1, lanes 2 and 6).

○ Experiment 2a: Math

The next series of experiments involved the use of iWorx data acquisition units to collect data indicating a student's heart rate and pulse. After having such clear "increase–decrease" results in Experiment 1, it was time to incorporate math into the experimental design. Because the students were comparing heart rates of each individual in Experiment 2, they were testing the difference of means for dependent samples (i.e., a paired t-test). Prior to the experiments, students worked with the math faculty to understand the basics of statistical analysis in order to incorporate statistics into their experimental design and data analysis. They learned about hypothesis testing as well as how to use an Excel spreadsheet to find the mean difference and the standard deviation for use in the t-test. After choosing the null and alternative hypotheses (see below), as well as the level of significance ($\alpha = 0.05$), they were ready to conduct the experiments.

Following each experiment, the students read the data produced by the data acquisition units, entered it into the spreadsheet, and eliminated all students from the data pool (data mining) who did not have two discernible heart-rate outputs. The critical value was determined from the t-distribution table, the test value was calculated, and these numbers were used to determine whether the null hypothesis could be rejected or not rejected. Finally, the students were able to state whether or not there was enough evidence to support their claim.

The students wanted to determine whether drinking a caffeinated beverage would raise their heart rate. They had all "felt" the effects of caffeine, so they were confident that there would be a difference between the resting heart rate and the heart rate after drinking a caffeinated beverage. There was a lot of discussion about the amount and type of beverage to be consumed, and the time we needed to wait between the initial heart rate and subsequent data collections. It was decided that we would take an initial heart rate and then drink eight ounces of Coca-Cola (Coke) in the next 2 minutes. Exactly 20 minutes after the initial heart rate check, we would take the heart rate again. We also took a pulse reading after an additional 20 minutes. Because we had only three iWorx data acquisition systems, the students and faculty came up with an intricate data collection method to stagger the initial readings, beverage consumption, and following heart-rate readings. With their new



Lane	Tissue	Troponin present?
1	Brain	no
2	Heart	yes
3	Kidney	no
4	Small intestine	no
5	Liver	no
6	Skeletal muscle	yes

Figure 1. Western blot of rat tissues probed with anti-troponin antibody: Experiment 1.

found understanding of hypothesis testing, the following hypotheses were chosen:

Null Hypothesis: Drinking Coke does not raise the heart rate after 20 minutes.

Alternative Hypothesis: Drinking Coke will raise the heart rate after 20 minutes.

During the experiment, the students were diligent with their time keeping, were in the right place at the right time, drank their Coke in the allotted time, and waited to see their heart rate jump. The data acquisition units systematically monitored and graphed each student's pulse. After 20 more minutes of waiting, the third data collections were made. Although this was not part of our hypotheses, we were interested in the lingering effects of the caffeine consumption. Finally, we were ready to begin the analysis.

When the students began to check their heart-rate graphs, word started to spread that some students actually had lower readings after 20 minutes than the initial figures. The surprising result was that more than half of the students had a lower heart rate after drinking the Coke (Figure 2). The result of the paired t-test confirmed that we could not reject our null hypothesis. Discussion arose as to why this happened. The excitement of the event, the boredom that ensued, varied tolerances to caffeine, and experimental error with the equipment were suggested as possibly accounting for the unexpected results. However, with a little research, it was discovered that there wasn't necessarily evidence to show that a *small* amount of caffeine would have the results the students expected. Again, students were faced with the importance of numbers in science. We had successfully incorporated math with the science; now it was time to further improve the science by working on the experimental design.

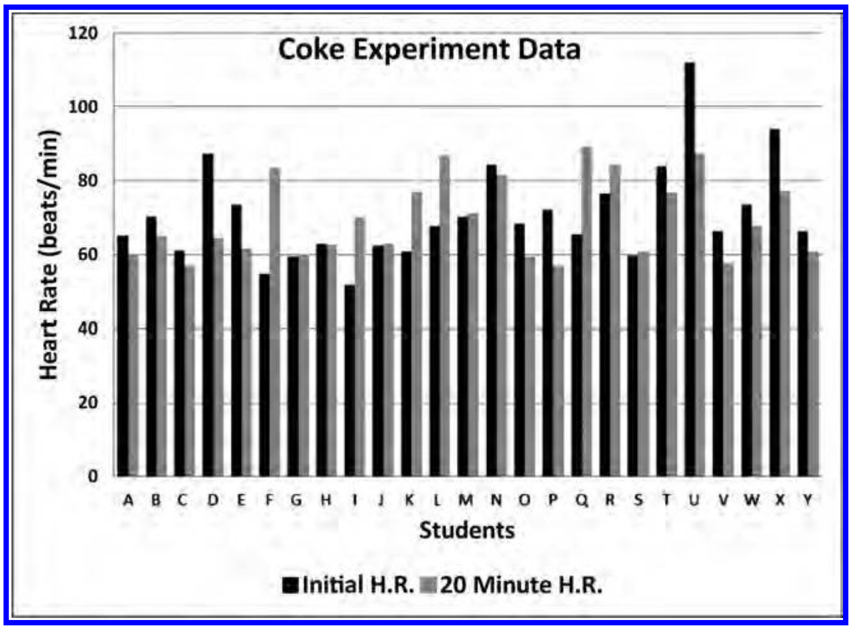


Figure 2. Initial heart rate (H.R.) and H.R. 20 minutes after drinking Coca-Cola (Coke): Experiment 2a.

○ Experiment 2b: Biology + Math

In the final experiment, the students recognized that they needed to make sure the science was in order, as well as the technical and mathematical pieces. After a little research, the students found plenty of literature about exercise and heart rate. Subsequently, they designed an experiment to test whether moderate exercise raised heart rate. There were still several questions to answer. What improvements could be made in data collection? How would the participants exercise? How long would they exercise before collecting data? The hypotheses chosen were as follows:

Null Hypothesis: Exercising for 4 minutes will not raise the heart rate.

Alternative Hypothesis: Exercising for 4 minutes will raise the heart rate.

The students determined that it was important to have a resting heart rate to accurately test whether exercise would raise heart rate. As with Experiment 2a, a detailed plan was devised to collect the data at the appropriate 4-minute cycles. The students decided that they would walk briskly throughout the entire 4 minutes, including climbing the stairs twice during the 4-minute period. The data were collected, the graphs were deciphered, and the paired t-test was conducted; the statistical methods used were the same as described above for Experiment 2a. As expected, based on the analysis of the data (Figure 3), the null hypothesis could be rejected and the alternative hypothesis accepted.

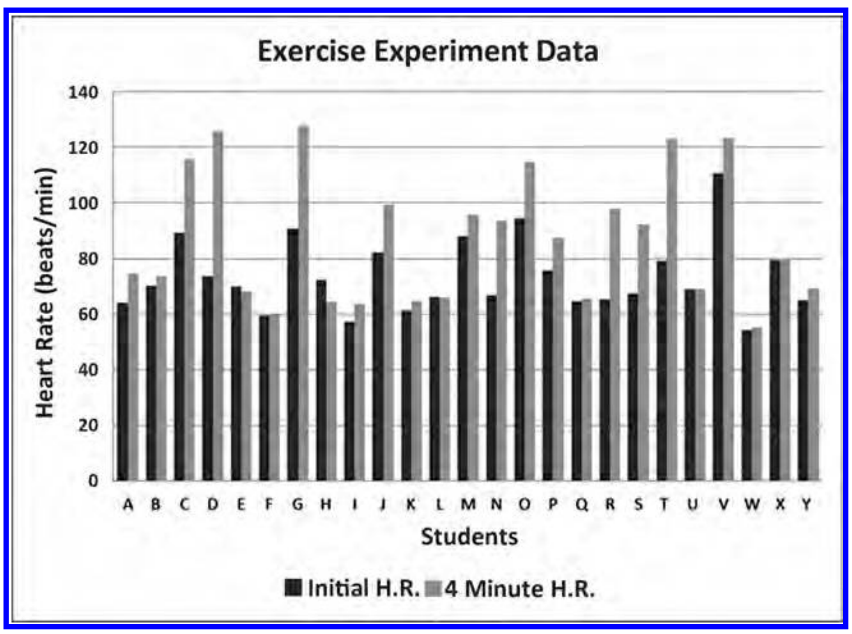


Figure 3. Initial heart rate (H.R.) and H.R. after exercising for 4 minutes: Experiment 2b.

Table 1. Average pre- and post-test scores for Experiment 2 (Statistics Content Knowledge).

Experiment 2	Average Pre-Test Score (out of 10 points)	Average Post-Test Score (out of 10 points)
High school students	1.38	6.06
College student mentors	2.67	8.42

There was enough evidence to conclude that exercising for 4 minutes raises the heart rate.

○ Assessment

In our experience as college professors, many students majoring in biology are somewhat intimidated when complex math is introduced in the curriculum. Yet a solid understanding of statistics and other mathematical concepts is important for those working in the life sciences. In order to quantify the students' understanding of the math concepts utilized during the Experiment 2, a pre-test was administered on the first day of the 2-week experiment and then again on the last day. As expected, all 24 high school students and six college-student mentors showed an improved post-test score (a statistically significant increase). A few high school students showed small increases, and many others showed great improvement in their post-test scores. Interestingly, all six mentors showed very similar individual score increases, even though two were majoring in math and the other four were majoring in biology. The average pre- and post-test scores for each group are summarized in Table 1.

○ Feedback from students after Experiment 2

- "The experiment with exercise and heart rate was exciting and rewarding because we were able to put together everything we learned and analyze our data."
- "I felt that a highpoint was getting a look at new math I haven't done before."
- "During the Coke and Heart Rate experiment, I finally understood the statistics."

○ Discussion & Conclusions

Although we encountered some technical difficulties along the way, anecdotal and assessment data suggest that integrating math and science during the SRI program was a beneficial experience for the students. This is evidenced by the increase in scores from pre- to post-test in content related to statistics (see Table 1), by feedback from the students (see above), and anecdotally by faculty members' observations that students improved in their ability to design experiments by the end of Experiment 2b. In the past, SRI research projects covered biology or math as separate components, not as integrated concepts. We feel that integrating these subjects helped students to see the practical applications of math and increased their confidence in using math to analyze scientific data – so they get beyond descriptions like "more," "some," and "increase–decrease."

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References

AAAS. (2009). *Vision and Change in Undergraduate Biology Education: A View for the 21st Century.* Available online at http://visionandchange.org/.

National Research Council. (2003). *BIO2010: Transforming Undergraduate Education for Future Research Biologists*. Washington, DC: National Academies Press.

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