AC 2007-961: INTEGRATING CALCULUS AND INTRODUCTORY SCIENCE CONCEPTS

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Integrating Calculus and Introductory Science Concepts

Abstract

During their first two years, students often fail to make connections between related concepts in their calculus and introductory science courses. This disconnect early in their curriculum can hamper engineering majors in their ability to understand how these courses relate to their discipline and can serve as a "turn-off" for students who fail to engage in these courses. Here we present how we have tried to address this problem by integrating basic calculus concepts into the introductory freshman and sophomore biology, chemistry and physics science laboratory courses. In this paper, we will feature a biology laboratory experiment where students examine a growth curve for algae, a chemistry lab involving an instantaneous rate calculation for a rocket launch, and a physics lab experiment where students approximate the instantaneous speed of a cart on an inclined plane. This work has been sponsored in part by NSF CCLI A&I grant #0311481.

Background

Traditionally, science and mathematics content are taught as discrete courses. Consequently, students often fail to make connections between disciplines. Integration between disciplines has been advocated as a solution for this "mismatch" by NSF advisory committees[1], in teacher preparation[2], by engineering schools[3,4], as well as by mathematics departments[5]. Our approach has been to integrate content between the mathematics and science laboratory courses in the freshman and sophomore curriculum. The primary focus of our curriculum is a 6-course mathematics sequence and an introductory science (chemistry, biology and physics) laboratory series. The mathematics sequence consists of calculus, differential equations, along with just-in-time algebra and trigonometry topics and a unit on statistics.

One of the primary goals of our project is an improvement in student connections between science and mathematics course content. The science laboratory course materials focus on more complex scientific problems requiring application of concepts/ techniques from each of the science disciplines, as appropriate, and the use of mathematics in context. The science laboratory series (chemistry, biology and physics) operates in a single cooperative, technology supported laboratory designed to make possible appropriate content integration among the three science disciplines, as well as the utilization of appropriate mathematics content. In addition, the laboratory was designed to support the use of student teams.

Because of state limitations on the number of credit hours that can be required for a bachelor's degree, the specific curricular requirements did not change with the implementation of the integrated curriculum. Instead, *the curriculum has focused on revising the content and course materials, as well as implementing minimal course sequencing requirements.* Content is integrated based on minimal co- and pre-requisites. For example, students in the introductory science labs should, at a minimum, be enrolled in their first calculus course. Because the integrated science lab series develops common laboratory and research skills that build upon those from previous integrated science lab courses, it is desirable that students take the science lab courses in the correct sequence (biology, chemistry and physics). Some students do interchange the biology and chemistry labs without too much difficulty. Because not all students are not ready to start in calculus at the beginning of their freshman year, we offer the courses every term during the academic year. Therefore, students can take remedial mathematics courses and start the integrated curriculum in the winter or spring terms, as appropriate.

While our curriculum has focused solely on courses for math and science majors, the ideas presented here easily expand to these same introductory science laboratory courses for engineering majors. Indeed, at most institutions, the math, science and engineering majors take the same introductory math and science courses. We have plans to expand these revisions to at least some of the introductory science labs that the engineering majors take at our own institution. Our hope is that other institutions might consider doing the same.

Integrating Calculus Concepts into Science Labs

A team of mathematics, biology, chemistry, physics and engineering faculty met over a period of three years to explore their current introductory laboratory courses and their vision for how these courses could be enhanced by integrating content between the disciplines. A smaller sub-team of math and science faculty reviewed each of the existing laboratory experiments for the three science disciplines (biology, chemistry and physics), discussing and modifying them to better integrate content and/or skills between the courses. Here we outline some examples that resulted from this effort. Our goal here is to present examples of how to integrate calculus concepts into each of the introductory biology, chemistry and physics science laboratory courses. These examples were selected because in each case we were able to take an existing laboratory experiment in the course and extend it in a simple fashion to incorporate basic concepts from calculus. Note that we were able to accomplish our goal of integrating content without major rewriting of these existing laboratory experiments and without significantly increasing the amount of time needed to complete the experiment. Both of these factors make this approach a viable one for many institutions looking to integrate their curricula.

Biology

In the introductory biology lab course, students complete a laboratory experiment on environmental pollution. In this experiment students treat and grow four algae samples into which they have introduced different pollutants and different list treatments. They measure the growth of their samples by collecting optical density data over a period of 14 days. Students then plot the 2 weeks of "days vs. optical density data" for their algae samples and connect the points with a curve. We were able to easily build on this foundation and incorporate the basic concept of derivative or rate of change from their calculus course. Namely, we selected one of the algae samples, Control A, and asked students to estimate the growth rate at days 3, 7, & 11 by drawing a tangent line to the growth curve at each of these points. They are then asked to calculate from their sketch the slope (a common homework problem in their calculus course) at each of these points by estimating the coordinates of two points on each tangent line. We then asked the students to answer the following series of questions which help them connect concepts from calculus class about slope, tangent lines, and graphs of functions (in this case, their growth curves) with the data about the growth rate of the algae, their treatments of the algae sample, their calculated growth rates and other related concepts from the accompanying biology lecture course:

1. What does is mean for the growth rate to be large?
2. What does is mean for the growth rate to be small?
3. Can a growth rate be negative? Why or why not? What would the curve look like if these were so?
4. Can a growth rate be zero? Why or why not? What would the curve look like if this were so?
5. Looking at your graph for Control A, how are the growth rates changing for Control A over time (from Day 0 to Day 11)? What did you do to Control A that caused this to happen?
6. What might the growth rates look like for each of your treatments? What did you do that made them look this way?

Chemistry

In the second chemistry lab course, the most popular laboratory experiment with students involves making and launching a rocket. We extended this laboratory to take advantage of students' knowledge of projectile motion and the role of the derivative or rate of change (again, a very common and repeated theme in homework problems from their calculus course). In this lab, during the launch process, we asked each student team to measure the initial angle, height above floor at launch for their rocket, time of flight, and distance from the launch pad at initial impact. Using their measurements and the equations of motion they learn in calculus class, they must calculate the initial velocity of rocket. Students are again asked a series of questions aimed at helping them analyze their results, think about the underlying assumptions of this model, and explain possible sources of error:

1. Using the initial angle, α, the time of the flight, t, and the distance, $x(t)$, from the launch pad at impact and the height, $y(t)$, above the floor at impact, use these equations to calculate (and double-check) the initial velocity of your rocket for each trial.
2. Are your answers reasonable?
3. What assumptions are you making about the motion of your rocket with this type of model?
4. What types of error might there be in using these equations to model the position of your rocket?

Some of the data required for this lab has proven challenging for students to collect with a reasonable degree of accuracy. Consequently, we are considering other revisions to this laboratory.

Physics

In the two-course introductory physics lab sequence, the labs have been revised to incorporate computer-interfaced lab sensors and modifying the lab manual to accommodate the new technology, better guide students through the physics concepts, and increase the level of critical thinking required to complete the lab experiments. These provide multiple opportunities to incorporate mathematics into the laboratory experiments. One of the more interesting laboratory experiments from a calculus standpoint comes in the first physics laboratory course where students are asked to approximate the instantaneous speed of a cart on an inclined plane. In this lab, students must determine the amount of time it takes a cart to travel between 2 photogates on inclined plane, where the center between the two gates serves as the reference point. They repeat the experiment using four or more smaller intervals, then plot average speed vs. distance. Using this data, we were able to again incorporate derivative or rate of change concepts frequently explored in their calculus homework assignments. Namely, we asked students to first predict then utilize their data to estimate the instantaneous speed of the cart at the reference point. They are then asked a series of questions which focus on analyzing their answer and error and exploring the relationship between average and instantaneous speed. For example:

1. Which of the average speeds that you measured in do you think gives the closest approximation to the instantaneous speed of the cart at the center of the track?
2. Are there ways to measure instantaneous speed directly, or is instantaneous speed always a value that must be derived from average speed measurements?
3. One of the two conditions in which this experiment was performed (large angle and small angle) give you the larger error when compared to calculations, which one? Is that reasonable? Why?

Evaluation

We are in the process of collecting a full academic year of assessment data, using control sections of each of the introductory biology, chemistry and physics laboratory courses, to determine if there appears to be any difference in student performance in the areas of course content, laboratory research skills and laboratory safety skills between the integrated and non-integrated sections. Anecdotal evidence from instructors indicates that students who transfer into an integrated section of, say, chemistry II lab, after having completed a non-integrated section of chemistry I lab, are behind those students who have taken the integrated sections and thus require some remediation. Preliminary data on pre- and post-test performance of integrated sections only (collected during the process of course revision as a formative evaluation) shows the greatest improvement in laboratory safety skills, with data on mastery of course content varying from discipline to discipline. While this likely reflects the fact the differing rates of implementation of the course revisions in each of the disciplines during the time frame this data was collected, differences in use of graduate teaching assistants in the labs and the varying degree of training they receive also may be contributing to this behavior. Data collected this year, after full implementation of content revision, should provide a clearer picture of student performance.

Conclusion

Traditionally, math and science courses are taught as stand-alone courses which do very little to help students grasp the underlying connections between these disciplines. In our work, we have found many opportunities to naturally and easily help students make these connections, most often by simple modifications of existing course materials. To accomplish this goal it is important to sequence the courses so that students are at least taking the first calculus course either as a pre- or co-requisite with their introductory science lab courses. For most science (and engineering) majors, this is not a problem. Mathematics courses can also benefit from incorporating examples from science lab courses, along with or instead of textbook-type problems.

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