

# Integrating undergraduate laboratories into the curriculum

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BURNETT, LOUIS E. *Integrating undergraduate laboratories into the curriculum.* Am. J. Physiol. 260 (Adv. Physiol. Educ. 5): S25-S28, 1991.—Developing a curriculum that integrates laboratory, field, and nonlaboratory experiences requires solid planning, cooperation, and compromise among the faculty members in a department. This is especially true for laboratory experiences where basic skills and familiarity with the different groups of plants and animals carry over to upper-division courses. In an introductory Principles of Biology laboratory, for example, exercises can be designed to give students a clear idea of a statistical distribution and the consequences of random molecular motion. Both concepts are used in nearly all upper-division courses to some extent. Some important but “mechanical” features of courses within a curriculum, such as adopting within the department a single format for writing a scientific paper, will go a long way in tying together different laboratory experiences. Other similar but simpler ideas are to develop appendixes to laboratory exercises that can be used in introductory and upper-division courses, e.g., how to do dilutions, the use of SI units, etc. The latter may be a good way to stimulate departments to think more carefully about continuity and consistency in the design of the overall curriculum. Continuity of instruction from lower-division to upper-division courses and among upper-division courses requires communication between instructors at all levels.

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NEARLY ALL DISCUSSIONS of what a curriculum should contain and how it should be structured engender a lively debate among faculties charged with educating particular populations of students. The structure of a curriculum depends not only on the target student population but also on the faculty available to administer the curriculum. There is no right and no wrong way of fulfilling a particular pedagogical mission, but there may be less or more effective ways of achieving specified goals. In all cases, the goals should be made as explicit as possible. It is only then that a faculty can intelligently discuss the most effective means of achieving the goals given the available resources. This is a statement of the obvious, which is perhaps a good way to begin.

In my experiences as an educator, I have found it very useful to observe the structures of the curricula in other departments at other universities in general and then to focus on how students were instructed in laboratories in particular. The structure of a curriculum within a department reflects, of course, the expertise and the breadth of experiences of the faculty. Courses listed in the catalog may be a result of active planning by the whole faculty or simply the availability of a faculty

member to teach a specialty course, which can often enrich the curriculum. When I attend professional meetings I tend to discuss in great detail issues of curriculum with my colleagues, and I actually come away with ideas that I can apply to my own situation.

It is in this spirit that I offer my comments on integrating laboratories into a curriculum. I recognize that the goals and resources of each institution are unique. There is no one “formula” for effective instruction in the lab that is right for all institutions. On the other hand, I take great pride in what my colleagues and I in the Department of Biology at the University of San Diego (USD) have put together over the past 12 years as we have experimented with different ways of structuring our curriculum. For us, as I am sure it is everywhere, the process of structuring our curriculum is ongoing and will continue to evolve as new faculty are hired and as new technologies and instrumentation become available. My comments below are designed to offer some ideas with the hope that some may be useful elsewhere. Some things we have tried are original, many are not. The combination of tactics that we currently use seem particularly effective.

One strength of our program is the extensive laboratory experience that students have when they graduate with a degree in biology. Biology majors are required to take a minimum of 8 laboratory courses in biology (including Introductory Biology), but the number of courses students take is typically 9–11. By laboratory I do not distinguish between field-oriented courses and more experimental courses taught in the confines of the laboratory. Our biology majors are also required to take a minimum of three laboratory courses in chemistry (typically they take 4) and a minimum of two laboratory courses in physics. Thus our students spend much time with their instructors in the lab over the course of 4 yr. This list does not include the internship experiences and independent research that are also stressed at USD. Our small class size and our emphasis on laboratory experience are points that distinguish us from the larger state-supported universities in our immediate vicinity and are reasons students often cite for coming to USD.

Like many private universities we have a good reputation for placing students in professional schools, but in addition, because of the emphasis placed on research by our faculty, we have a growing reputation for placing students in graduate programs. Because of our location in an area where there is a vibrant community of biotechnology companies, our graduates are in good demand because of their technical skills. Thus our goals are to offer our students the broadest and best possible training

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in practical laboratory and field techniques backed by a strong theoretical background.

#### INTRODUCTORY COURSES

Our curriculum foundation has two introductory courses that the students may take in any order, Principles of Biology and Biology of Organisms. In this section I emphasize the laboratory component of the Principles of Biology course, because, the way we have formulated it, it is more relevant to the experimental approach used in upper-division physiology courses. Principles of Biology introduces students to the concepts of basic chemistry with a strong emphasis on “what it means to be small,” i.e., small is defined as something the size of a molecule. There is also a strong emphasis on the important role of random molecular motion as a basis for protein structure and the diffusion of molecules (and ions) across membranes. These ideas then set the scene for developing notions related to cell structure, biochemical pathways, molecular biology, and immunology.

I describe briefly some of the laboratory experiences we provide the students in our Principles of Biology course and then discuss how other parts of the upper-division curriculum are structured around these key concepts.

*Concept of a distribution.* This concept is important for obvious reasons but can be especially useful in discussing the “average” shape of a protein molecule, which ties in with the importance of random molecular motion. This is where the students are introduced to the necessity and the usefulness of presenting quantitative information using simple statistics and graphic techniques.

*What it means to be very very small.* This is the concept of how things behave in the universe where things are the size of molecules. The implications of random molecular motion are explored with homemade machines that cause small plastic beads to move about randomly in a box divided in two by a plastic barrier with a small opening. The movement of beads from one compartment to another gives the student an appreciation for what happens at membranes. Furthermore, students are required to treat the flux of beads from one compartment to another quantitatively. The simulators can be turned off at specific time intervals so that students can measure the actual flux of beads from one compartment to the other. They plot the number of beads in one compartment as a function of time until an equilibrium is reached (the concept of a dynamic equilibrium). Students are shown how to convert this curvilinear plot into a straight-line plot using a simple logarithmic transformation. They don't all understand this; nonetheless, they are taught the mechanics of it. The students ultimately derive an expression for a diffusion coefficient using their own data.

The purpose of this exercise is manifold. The algebraic manipulations the students are asked to do are straightforward and sharpen their skills in dimensional analysis. It also allows them to observe a tangible situation and abstract it into mathematical terms. When the students derive a diffusion coefficient for a single-hole barrier and compare it with a similarly derived diffusion coefficient

for a double-hole barrier, it brings home the simplicity and the meaning of a number such as a diffusion coefficient. Instructors follow up this experience with examples in lecture, and these points are emphasized again when students take upper-division Animal Physiology, Plant Physiology, and Cell Physiology where they apply their knowledge of diffusion and permeability coefficients in a much more sophisticated manner.

*Diffusion applications.* Here we do some experiments with red blood cells as osmometers. We make some “macroscopic cells” with dialysis tubing, doing some traditional experiments by placing the “cells” in different sucrose concentrations. This is straightforward and rather traditional. An important theme of this lab, however, is the proper methods for making up solutions and performing dilutions, including which glassware is appropriate to use. We also find it helpful to do a demonstration of “bioelectricity” by showing the students that an electrical potential can be generated across dialysis tubing when differentially permeable cations and anions are added to one side.

*Urey-Miller experiment.* In the lecture part of the course we move from the basic properties of small molecules and matter to some of the consequences of the associations of matter under conditions where excess energy is present. Thus chemical evolution is presented as a precursor to a discussion of membranes and simple cells. There is nothing innovative about this approach; however, we put together a laboratory experience to parallel this, which we believe is successful at tying together a number of important techniques and ideas.

The Urey-Miller experiment builds on classic experiments of chemical evolution and lasts for three consecutive laboratory periods. The students set up simulations where water containing salts simulating primordial “pond” water is placed in an atmosphere of nitrogen, hydrogen, and carbon monoxide within a large vacuum flask and “sparked” using a Tesla coil for different periods of time. The students then take the “pond” water and perform some simple chemical assays to quantify the presence of ammonium and total amino nitrogen. The students find that with increased simulation time the quantities of these substances increase.

Using this theme, then, we introduce the students to the concept of a simple chemical assay (i.e., the ammonia assay) and the concept of a standard curve, and we give them lots more practice in making up solutions and performing dilutions. During the 1st wk we show them the mechanics of it all and present them with an “unknown” (to them) solution containing a specific concentration (known to us) of ammonium chloride. The challenge is to make the solutions required for setting up a standard curve and then to perform the assay. By *week 3* the students know their way around the laboratory bench and are quite good at performing the relatively simple (2 steps) ammonia assay and the more complicated (13 steps) assay for total amino nitrogen. Then they take the “pond” water from the simulations that have been running for different lengths of time and perform their assays.

A word of caution is necessary here. The instructor new to this approach may shy away, especially after the

first experience when students take nearly twice the amount of time allotted them to do their assigned tasks. However, it is incumbent on the instructor to “crack the whip” and to pace the students in their work. In this way the laboratories in this sequence, and indeed in all the exercises described, can be accomplished in the assigned time (4 h at USD).

*Separation techniques.* At this point the students are ready for some labs that are considered “more traditional” by our standards. Included in this group are a laboratory on enzyme kinetics, the isolation of DNA from bacterial cultures, and the measurement of the length of the genome in *Escherichia coli*. We also do a laboratory that is very visual, surrounding the theme of separation techniques using photosynthetic pigments.

In the separation techniques laboratory we do three kinds of chromatography: 1) paper chromatography, 2) column chromatography using cellulose, and 3) column chromatography using Sephadex. Correlations are drawn between paper chromatography, which is very visual, and the cellulose columns, which are much less visual. Students are shown how to take fractions off the column and then process the fractions on a spectrophotometer with scanning capabilities to generate an absorption spectrum.

Using the Sephadex column, we give the students the impression that by using a slightly different approach, molecules can be separated based on their size. This is also a fun experiment for the student because we chromatograph a mixture of compounds that have different colors as they run down the column. Nonetheless, students collect fractions, and using the spectrophotometer they determine the peaks of the fractions coming off the column.

*Laboratory practical.* Finally, in this course the students have a “laboratory practical” examination at the end of the course. They are told from the very beginning of the course what is expected in the lab practical. They must measure the total length of the genome in cells (usually whatever fresh liver cells are available) that we provide. They have already done a similar experiment using *E. coli*. This time, however, they must work entirely on their own. They may not communicate with their fellow classmates, and they have 3.5 h to complete the experiment with the possibility of 30 min overtime. They are graded on their experimental technique throughout the time period as well as on their data and calculations, which, when they hand them in, constitutes the completion of the exercise. We usually recruit heavily from upper-class students who have gone through this ritual to assist us in the evaluation. The process is a serious test for the students and works well. It drives home the point that students are responsible for learning good laboratory technique throughout the course. Most students through the years have performed well in this practical experience.

#### EXTENDING THE INTRODUCTORY EXPERIENCE TO UPPER-DIVISION COURSES

I turn briefly to another aspect of introductory-level courses. The other introductory course for majors that

we teach is called “Biology of Organisms.” This course is more traditional in that the major plant and animal groups are surveyed. It is also here that evolution, systematics, and ecology are introduced. We have found, to our dismay, that students leaving this course retained little of the information regarding relationships between plant and animal groups, as the distinction between different kinds of plants and animals became dimmer with time. Thus students entering an upper-division course in Invertebrate Zoology were hardpressed to identify the classes or even the phyla of some fairly common animals, e.g., snails, starfish, and worms. Some (many) were not able to place themselves (humans) in the proper taxonomic perspective. This complaint of faculty teaching upper-division courses required some corrective action on the part of all the faculty. The students were clearly being taught the details, but they were retaining rather poorly both the details and the generalities.

There are no trick answers to this dilemma. However, recognizing the problem led us to some corrective action. Instructors in this introductory course are currently stressing more often the larger relations between the major plant and animal groups. Perhaps of equal importance, instructors in upper-division courses are stressing the naming and relationships of the groups in the appropriate context of their particular upper-division courses. For example, in my upper-division Animal Physiology course I give a taxonomy quiz during the 2nd wk of classes. Students review the major animal groups they have already learned in the introductory biology course. Thus, when I discuss the physiology of a cephalopod, students will remember it as a class of molluscs. If faculty agree that this is a good idea, then the mechanics of the process are simple, i.e., a quiz at the beginning of the course. The follow-through and reinforcement of the relationships learned at the introductory level are important and can go a long way in assuring that the average student can articulate an understanding of the relations among the different kinds of organisms in the world.

#### EMPHASIZING BREADTH

I would like to end this discussion on curriculum with some thoughts on the kinds of students who are attracted to a biology major. At many universities, indeed probably most private universities, a significant number of students who are attracted to the biology major are premedical students. There are many different reasons for this, e.g., recruiters at private universities likely find this the easiest point to sell to high school students. My own university has historically attracted a large number of students with interests in the health professions. This has been largely a positive experience for us since this ploy has attracted many strong students. However, it has created some problems that are common to other universities.

One significant problem is that students who have interests other than the health professions have felt, putting it in their words, like “second-class citizens.” This result is not something that the faculty has propagated, at least knowingly. From a faculty prospective, the

opposite case could be made. Faculty in my department go out of their way to add breadth to their courses, and our advising philosophy is geared toward encouraging students to leave all options, or as many as possible, open in their career choices. Nonetheless, students often feel "that something is wrong with them" if they are not interested in pursuing a health profession. Our faculty has taken steps to address this problem. The results so far have been positive, and this has led to a better attitude among all students toward careers in all fields of biology.

The steps we took are simple. First, the faculty agreed to strictly enforce enrollment limitations in all upper-division courses. In the past, certain "popular" courses would be overenrolled at the discretion of the instructor while other courses would have low enrollments. Now, when an upper-division course closes, students are forced to shop around to find an open course. The result is that courses with traditionally low enrollments, such as Field Botany and Invertebrate Zoology, had larger numbers of students. Surprisingly, many of these students found that they like the "imposed" diversity in their course selection. Their enthusiasm for taking a variety of different courses, therefore, has made many more courses fashionable to take. Second, we enlisted the support of the students active in the preprofessional student organization Alpha Epsilon Delta (AED) to help us get the message across to all students that breadth in their coursework was the best strategy, regardless of career

aspirations. Third, we established a series of career seminars where we invited one or two speakers each term to discuss career opportunities in specific fields. Fourth, we established a Graduate School Advisory Committee to provide a highly visible and structured mechanism to assist students in gathering appropriate information on graduate careers. This committee facilitates the applications of students to selected graduate programs. Giving strong and positive direction to students interested in graduate school is something our faculty has always done; however, our intent in setting up this committee is to provide students with a more visible (and clearer from the students' perspective) mechanism to encourage student interest and applications to graduate schools. This committee, in fact, serves a similar function to the long-standing university-wide committee for students interested in applying to professional schools.

#### SUMMARY

The curriculum a department develops is highly contextual within the particular mission of the department and the university. The articulation of clear goals facilitates the design and the integration of introductory lecture and laboratory courses that are responsive to the needs of the more advanced upper-division curriculum. Refining and fine-tuning a curriculum is an ongoing process that demands open discussion and cooperation among all faculty members.