Report Of The Committee On The Core Curriculum
Division Of Biological Sciences

Summary

At the request of Deans Rost and Wise our committee has undertaken an examination of the core curriculum with a view to determining whether, in principle, a core still makes sense for the division and, if so, whether the present core ought to be modified. We believe there are sound reasons for the division to have a core curriculum, but we recommend substantial changes that will better prepare students for contemporary and future biology, and allow them to start biology earlier than is generally the case now. The present core consists of three lower division and four upper division courses. Our proposed core would consist of three lower division courses (*genes and genomes, principles of evolution*, and *generation of organismal diversity*), two upper division biology courses (*structure and function of biological molecules*, and *cellular biology-energy and control*), plus a two-unit course on biological modeling that would show students how to use math in biology.

The content, organization and style of the proposed core is intended to reflect the fundamental changes in biology that have occurred in the last decade and are continuing. Among these changes are four especially important trends. First, facts in biology are being generated at an accelerating pace. This requires that we be very selective in what we include in the curriculum and that our paramount goal should be to give students the intellectual tools to organize and interpret new information. Second, biology is becoming more integrated. We should endeavor to show students the deep connections between different areas of biology and integrate different levels of explanation in our teaching. Third, biology is becoming more reliant on quantitative models. Students have to be given the means to understand and construct models. We recommend, in addition, that further examination of our math, physics, statistics and chemistry requirements be conducted to evaluate whether they still serve our students well. Lastly, the sequencing of whole genomes and our improved understanding of gene function has the potential to provide a common language that can unite all biology. Our students must become fluent in this language.

Consistent with our view that the core should integrate across taxa and levels of explanation, we propose that the new courses consist of a carefully integrated sequence building one on another, developed and taught by teams. To facilitate this we recommend that a ladder rank faculty member be given the responsibility for leading, organizing and monitoring the core.

Introduction

It has been said by many, and is undoubtedly true, that we are living at the beginning of the age of biology. Biology is likely to shape human affairs in the 21st century as much as physics did in the 20th century. Our students will live in this new world, and some of them will make the discoveries and inventions that will guide its direction. As biology faculty we have a unique opportunity to influence the future, not only through our own science but also by the way in which we define biology for our students. With the growing importance of biology, the best students will increasingly gravitate to our discipline. We should be considering, now, how best to attract the very ablest students to our campus. Developing the best curriculum in biology must be the major component in any plan to do this and, as faculty, we should insist that it is.

Biology is changing very rapidly but our curriculum has changed rather little in the last ten years. We are not alone in this. In fact, at most major research universities inertial forces have kept the biology curriculum virtually unchanged even though there can be no doubt that change is necessary, and it will inevitably come. We have an opportunity now to get ahead of the pack, to do something creative and original that capitalizes on the very significant strengths we have here at UC Davis. If we do it right, there will undoubtedly be many who will want to follow our lead. The alternative is that we wait until other major institutions plow the furrow for us, as we have done too often in the past. Either way though, change will not be painless. Many of us will have to rethink our teaching and find solutions to the practical problems that significant curricular change brings with it. But these inconveniences and practical difficulties, as well as unavoidable missteps along the path, must not be allowed to obscure the central point that if we want the best curriculum in biology, we have to change.

One strategy that is doomed to failure is to imagine that we can continue indefinitely with our present curriculum with just the addition of a few more classes to take care of the most recent developments. Not only is the nature of biology changing rapidly but the magnitude of the discipline has grown and continues to grow at an accelerating pace. Now would be a good time to confront the fact that students cannot know everything about biology; indeed, they cannot even know something about everything in biology. We are obliged to consider seriously what are the most important elements of biology and what can be left out. Regrettably, this means that we must lose some beloved parts of the curriculum, but just as good writing requires ruthless discipline to excise the unnecessary, so it is in designing a curriculum. There is another, more general aspect to this point that we might want to bear in mind. Largely through the popularity of the Internet, knowledge today is essentially free. While we might once have thought of research universities as retailers of knowledge, we must now carefully reevaluate what special and valuable product we provide to students.

Fortuitously, while our committee was being set up, the National Research Council, a branch of the National Academy, came out with a report “BIO 2010: Transforming Undergraduate Education for Future Research Biologists” that is available in electronic form at the website http://www.nap.edu/books/0309085357/html/. This report is the product of an all-star committee headed by Lubert Stryer. Although its focus is on future research biologists, a subset of our students, many of its recommendations are nevertheless consonant with the changes we propose here. We agree in particular with this opinion expressed in their executive summary: “In contrast to biological research, undergraduate biology education has changed relatively little during the past two decades. The ways in which most future research biologists are educated are geared to the biology of the past, rather than to the biology of the present or future. Like research in the life sciences, undergraduate education must be transformed to prepare students effectively for the biology that lies ahead."

Task of the Committee

Executive Associate Dean Rost charged the committee, in a letter reproduced in the appendix, with commenting on the external reviewers' report as it concerns the core curriculum. The more substantial part of our charge was to evaluate whether a core curriculum was still desirable in the division and, if so, what it should consist of. The committee was encouraged to start from first principles and not to give consideration to political consequences, such as the relative distribution of resources to the sections.

In approaching our task, we first comment briefly on the external report. We describe our present core and also comment on it briefly. Next, we set out the reasonable goals of a core and give our reasons for thinking a core is desirable. To help us design a modern core, we have explicitly set out the ways in which biology has changed and is likely to continue changing in the next decade. From this starting point, we have developed specific proposals for a curriculum. Our course proposals are fleshed out to the extent that they include topics to be covered, but we are very aware that, if adopted, these courses will require much more work to translate these ideas into an actual course of instruction. In this translation, additions, deletions, rearrangements and modifications will be necessary. This is particularly true for the proposed lab component of the core. Organizing a successful lab class requires practical experience of what does and does not work, and in several areas the committee lacked that experience. Rather than leave the lab content completely blank, we have suggested some lab activities as a way of illustrating the kind of approach we favor, but we realize these descriptions are very sketchy and will need more expert input. One consideration we have not viewed as a constraint is who might teach which courses. Because we are a large and very diverse faculty we have presumed that we will have enough able instructors for any reasonable curriculum.

We have included appendices at the website http://www.dbs.ucdavis.edu/undergrad/internal/review.html, containing material examined and discussed by the committee, such as the curricula at other major universities, which were not explicitly mentioned in this report but nevertheless contributed to our thinking.

Comments on the report from the external reviewers.

The committee found the external reviewers report to be remarkably perceptive considering that the reviewers spent only two days on campus. An astute observation made by the external reviewers is that our present core represents a political compromise assembled from courses already existing at the time of the reorganization of the division eleven years ago. The external reviewers make no particular recommendations to either preserve the core curriculum in its present form or to change it. Instead, their comments raise questions that the faculty ought to address before any decisions might be made on these issues. They point out that a primary question on which the faculty must be clear concerns the goals of a core, and even more fundamentally, the guiding philosophy behind our teaching. As they say on p.6 of their report, "…as consultants we detect no overarching shared vision of what education in the life sciences should be and should accomplish. We recommend that either revision or stasis of the Core proceed out of such an overarching shared vision rather than in advance of it**."** The committee is whole-heartedly in agreement with this. Furthermore, the committee believes strongly that, as emphasized by the external reviewers, these fundamental decisions about the core curriculum cannot be delegated but must instead involve the whole faculty.

The external reviewers ask us to consider whether our present core reflects contemporary biology. Though they offer no answer to their question, their assessment of present biology (p.1 of their report) is worth repeating. "The life sciences of the 21^{st} century are much more integrative and multidisciplinary than previously. Leading edge research requires that life scientists integrate concepts, techniques, and information from the entire breadth of biology. For example, genome-enabled gene discovery draws its power from the application of evolutionary and comparative biology, functional genomics and systems biology require routine application of functional biology (e.g., biochemistry, physiology, and like approaches), and organismal and population biology is becoming highly molecular and genetical. Breakthroughs come through the development of new organismal models, which requires the ability to access the diversity of organisms. Over specialists are at an increasing disadvantage. It is appropriate, therefore, that undergraduate education in the life sciences resonate with the science that forms its subject matter."

A brief assessment of our present core.

We have not attempted a detailed assessment of our present core, but some brief remarks are in order.

Presently our core consists of seven courses: BIS 1A-1C and the upper division core BIS 101-104. The detailed offerings in this present core are given in appendix 3: Syllabi for UCD Core Courses. We identified the following points as the strengths of the present core.

1. The core courses are taught well and some of them are taught outstandingly well.
2. The core offers an excellent exposure to animal and plant diversity.
3. The core touches on most of the essential concepts in biology.
4. The core has some rigor to it.

On balance the core is done well.

There are, however, aspects of the core as presently constituted that might be improved. In our judgment they are as follows:

1. The core is good preparation for the biology of the past but is not sufficiently forward looking.
2. The four upper division offerings are probably too much for all students. It is doubtful if EVE majors need to take BIS 104 even though this is an excellent course.
3. For most students the core does not begin until their second year. This is a missed opportunity. We should make every effort to start students thinking about biology in their freshman year. Many students are keen to do this and are frustrated at having to defer biology until their second year.
4. BIS 1A introduces students to material that many of them have already covered in high school.
5. BIS 1C and to a lesser extent BIS 1B are essentially botany and zoology survey courses from which they were derived.
6. There is not enough material about evolution considering its centrality in biology.
7. There is almost nothing about genomes.
8. The core could do more to help critical thinking, communication skills and teamwork.
9. The courses could be better integrated with each other and there is evidence of unplanned content drift.

Do we need a core curriculum?

Given that the division has numerous biological sciences majors, rather than a single major, a real possibility is that the concept of a core could be dispensed with and individual majors be allowed to pick and choose from among the many course offerings, as they think most appropriate for their students. There are some significant practical advantages to this free market approach but we favor the idea of a core curriculum. We have first identified the reasonable goals of a core and then identified three practical advantages.

The reasonable goals of the core are:

1. To give students a solid foundation in the questions, concepts and vocabulary of contemporary biology.
2. To show students the deep connections between genetics, biochemistry, organismal biology and evolution.
3. To ensure that students are exposed to the breadth of organismal diversity.
4. To introduce students to the scientific method as applied to biology.
5. To attract and enthuse students about biology.
6. To illustrate the relevance of biology to the contemporary world.
7. To foster the essential and transferable skills of an educated person. These include observational ability, quantitative and analytical skills, critical thinking, ability to construct an argument and effective communication.

Three practical advantages of a core are:

1. It allows students to defer or change majors readily.
2. It provides instructors a readily discoverable common basis for all subsequent courses.
3. It allows the development of courses with a broader perspective than would be easily possible otherwise.
4. It is probably the most efficient way to deploy divisional resources.

As described in the external reviewers' report, the practical advantages listed above are not fully realized at present, and there are some actual disadvantages to having a core; nevertheless, on balance we believe that these are outweighed by the advantages, and we support the general notion of a core. The trend in biology is for areas to become less insular and more connected and, for this reason, the large canvas possible in core courses is likely becoming increasingly valuable to students.

How will the biology of ten years hence be different from the biology of ten years ago?

In determining the optimal composition of a core curriculum we have tried to identify ways in which biology has changed and is likely to continue changing over the next ten years. We have identified six important ways in which biology is and will be different.

1. *Facts in biology will be generated at an increasing speed.* This implies that any attempt to cover even a specialized area of the discipline comprehensively is futile. Furthermore, facts that now appear important will be displaced by new facts. An undergraduate degree in biology several decades ago was an adequate preparation for research towards an advanced degree. This is no longer the case, and most Ph.D. programs in biology now require at least one year of course work before graduate students can embark on a research project. The explosion in factual material forces us to be highly selective in the material we teach. Conscious decisions, made now, are necessary to reverse the trend of accretion that has characterized our curriculum over the last few decades. The goal of the curriculum, especially the core, should be to enable students to deal with the torrent of information in which they will be swimming. To do this requires that we equip them with the fundamental concepts of biology, the habits of mind, the practical and the intellectual tools for organizing and interpreting new information. These intellectual tools and habits of mind correspond closely to the notion of "critical thinking".

2. *Biology will be increasingly reliant on mathematical models to explain phenomena.* Biology is now entering its third phase, having changed from a descriptive science in the 19^{th} century to an experimental but qualitative science throughout most of the 20^{th} century it is now becoming a fully quantitative science. There are many indications that this is happening. For example, many of the crucial problems in such diverse fields as cell biology, neuroscience and

immunology will only be understood with the help of quantitative models. In this regard population biology is already ahead of other areas in its heavy reliance on quantitative models. Generally speaking, although our students are given formal instruction in math and physics, their ability to use and construct quantitative models is very limited.

3. *Biology is becoming a much more integrated discipline.* From the time of Darwin until relatively recently, biology has fragmented into separate fields. Since the molecular revolution in biology though, there has been an accelerating counter-acting trend in which explicit connections between different areas have been forged. The development of courses that integrate different aspects of biology both horizontally across taxa and vertically between levels of explanation is increasingly important.

4. *The sequencing of genomes will cause a major reorientation of biology.* The consideration of genome structure and our accelerating knowledge of gene function are becoming increasingly central in biology.

5. *The technology required to answer problems in biology is increasing rapidly.* In order for our students to understand these technologies, the physical sciences must continue to be a strong requirement in our curriculum.

6. *Biology will be increasingly conducted by teams, rather than individuals.* Students should be given significant opportunities to acquire the skills necessary for teamwork.

A new core

Before considering what might constitute a new core we must emphasize that our proposed core does not preclude particular majors from requiring additional courses of their students. For example, we expect that the plant biology major will require a course covering plant diversity in addition to the coverage of that topic in our proposal for the core. Similarly, the NPB major, and probably other majors too, will require animal physiology, which is not dealt with in our proposed core. We emphasize that in designing a core curriculum we have included only a minimal set of concepts that prepare students for the biology of the present and future and with which all biology students should be familiar. Our intention has not been to fashion an exhaustive list of topics from which our students could benefit. Many readers of this report are likely to ask: “Why isn’t my area part of the core?” We suggest that this question might be asked in other ways: “What part of the proposed core is unnecessary for my students?”, or “What part of the proposed core could be swapped for my area and would improve the coherence of the core and its appropriateness for all students?” The committee spent many weeks discussing the content of the core and, while we claim no special wisdom, we note that although individuals on the committee are drawn from different areas, the proposed core is our unanimous consensus recommendation.

A second disclaimer is that we have designed the core primarily with Division of Biological Sciences majors in mind. We are aware that there are other programs reliant on our course offerings for their own majors and to whom we therefore have a responsibility. The profound changes in biology that have been the foundation for our recommendations will touch every area of science in which biology is an element and for this reason we believe that the broad new courses we propose should be good preparation for any major inside or outside the division. Nevertheless, we appreciate that different colleges have different missions, so rather than try to anticipate how our proposed changes might be received by this diverse clientele, we have chosen to articulate our proposal and then solicit comments from all interested parties. We do so with the understanding that our proposal might be modified to accommodate these comments or, alternatively, that additional courses specifically tailored to these client groups might be offered.

A number of constraints have influenced our thinking about the content of a core. Chief among these has been the necessity that students have some familiarity with chemistry before they can tackle biochemistry, cell biology or molecular biology. Since the organic chemistry 118 series are upper division courses and under senate rules lower division courses may not have upper division prerequisites, biochemistry, cell biology or molecular biology can only be presented as upper division courses. We have considered at length whether an upper division component of the core is appropriate and we conclude that it is. A persuasive argument is that only by examining biological molecules and cells can it be seen that the ordinary laws of physics and chemistry underpin all of biology.

General approach

The new core we propose seeks to do the following:

1. We propose that students start the lower division core in their freshman year, with most of them starting in their second quarter. From then on we anticipate students will be taking a biology course of some sort every quarter with few interruptions.
2. Courses have been designed to reflect contemporary biology.
3. The first biological science course that students take is designed to stimulate enthusiasm and will be different from the courses many will have taken in high school.
4. We intend that the core should consciously back away from cramming a maximum number of “facts” into students and encourage them to think. This is emphatically not a call to “dumb down” our teaching but is instead a reflection of our belief that helping students assimilate the intellectual process of science is a paramount goal.
5. Courses are designed, as far as possible, to move seamlessly between taxa and levels of organization.

6. Teamwork, interpreting data, thinking critically and communicating ideas will be an integral part of the lab courses.

We propose a core consisting of three new lower division courses each with an associated lab comprising a mix of wet lab content, computer exercises and discussion; plus two upper division courses. We propose also, as a part of the core, a novel two-unit course on modeling in biology that would show students how to apply mathematical ideas to biological problems. As we conceive it, the core would be carefully integrated and would have to be taken as a sequence so that courses build on each other. For the lower division series we recommend five units for each course, comprising three units of lecture, one unit of lab and one unit of discussion. The upper division courses would be 4 units each.

There are several possible entry points into a core curriculum. We have chosen to begin with genes and genomes for the following reasons.

1. The language of genes, gene expression and genome structure is now the Lingua Franca of biology uniting many areas of the discipline.
2. By introducing this material early on, we can adopt a more contemporary approach to subsequent material.
3. This is an exciting area that can capture the imagination of our students. Because high profile work is going on in this area, for example the chimp genome project and human haplotype mapping, topical results can be artfully woven into the course as they are reported.
4. This approach reflects the increasing nature of biology as an informational science.
5. We believe that by treating the genome as a text, students can be introduced to important ideas without the requirement for chemistry. A molecular treatment of much of the same material is part of the upper division core when students have some understanding of chemistry.
6. It allows easy transition to the key concepts of phenotypic variation, Mendel's laws, evolution and phylogeny.

Lower Division Core Courses

Three courses of 5 units each. Three units of lecture, 0ne unit of lab and one unit of discussion/problem-solving.

Genes and genomes

Key themes. All organisms share an arbitrary instruction code and code reading machinery. The genome is a record of evolution. The relationship between genotype and phenotype can be subtle and indirect. Genetic variations produce much of the observed phenotypic variation. Control of gene expression in development can be highly conditional. Throughout this and the other two lower division courses, examples of unsolved problems will be presented along with examples that are securely understood.

- What is life?
- Evolutionary transitions
- The genome as a poorly-edited instruction manual for making an organism
- What information is in a genome and how much information is stored there
- Sequencing and sequence databases, bioinformatics
- Cells as the units for storing and reading instructions
- The genetic code and the central dogma
- Executive function of proteins
- Compact genomes of viruses and bacteria
- Gene duplications, gene families, paralogs
- Alternative splicing, introns and exons
- Regulatory DNA and control of gene expression
- Non functional DNA, repeating DNA, transposable elements
- Genotype to phenotype
- Genetic diseases
- Genes control development
- Master genes, homeotic genes, transcription factors, gene interactions
- Mitosis, a mechanism for faithful duplication of the genome
- Mutations and DNA repair
- Genetic variation, micro and minisatellites, SNPs

Principles of evolution

Key themes. This course picks up the theme of individual variation and uses the molecular concepts established in the previous course to put Mendel's laws on a solid molecular footing. Time is given to the introduction of probability and statistics in evaluating genetic data. Population thinking and competition are introduced as a prelude to a complete statement of Darwin's concept of evolution by natural selection. The slippery but essential notions of adaptation, design and evolutionary constraints will be discussed in depth. A discussion of population genetics leads to the concepts of reproductive isolation and speciation. Lastly, the evolution of social organization is tackled with the concept of inclusive fitness.

- Sources of phenotypic variation
- Mendelian inheritance, dominant and recessive genes
- Molecular basis of Mendel's laws, meiosis, recombination
- Linkage, Chi squared test, probabilities and expectations
- Quantitative inheritance
- Population growth, exponential functions, Malthus
- Competition
- Darwin's algorithm

- Modes of selection, natural, sexual and kin
- Adaptations and constraints on evolution: physics, physiology and history
- Molecular evolution
- Basic population genetics, Hardy-Weinberg equilibrium
- Heterozygote advantage, sickle cell disease: a comprehensive example
- Speciation and reproductive isolation
- Altruism and inclusive fitness, social organization

Generation of organismal diversity

Key themes. This course has the twin goals of exploring the diversity of life and explaining how this diversity has arisen. The concepts of selection, genome structure, developmental and molecular genetics from earlier courses will be employed to examine the mechanisms by which diversity has been generated. The course starts with a critical examination of the kinds of evidence used in the reconstruction of phylogeny, then develops a history of the major developments in life. These developments are examined from both the phenotypic view point, i.e. the exploitation of new opportunities with novel adaptations etc., as well as, to the extent possible, the genetic basis for this: Hox gene duplication, exon shuffling etc. Examples will be drawn from microbes, plants and animals. This course will be tightly integrated with its lab component in which students will see the organisms discussed in the lectures.

- Phylogeny reconstruction from different kinds of evidence
- RNA world and the origin of life
- The domains of life: Archaea, Eubacteria, Eukarya
- The major transitions: symbiosis: mitochondria, chloroplasts and their genes
- The major transitions: multicellularity, societies
- The fossil record, branching, radiations, extinctions
- Micro- versus macroevolution as explanations of diversity
- The main branches of the tree of life: exploring diversity among the domains of life
- Biogeography and plate tectonics
- Evolution of development, Hox genes and body plans

<u>Upper Division Core Courses</u>

Two courses of 4 units each. One unit could be a discussion/problem-solving session.

Structure and function of biological molecules

Key themes: The key theme of this course is the structure of biological molecules and the way in which this determines molecular function. Many of the topics, such as the control of gene expression, ribozymes and mutations have been touched on lightly in previous courses but can now be dealt at the level of chemistry. The course begins with proteins and shows how a one-dimensional string is converted to a three-dimensional structure. Catalysis, receptor-ligand interaction and protein-protein interactions are examined as important examples of specific interactions. The interaction of proteins with DNA in the regulation of transcription and in replication leads on to an examination of mutations that brings the course back again to proteins.

- Functional groups of amino acids
- Peptide bonds and protein assembly
- Protein folding
- Common structural motifs
- Weak forces govern interactions
- Protein-protein interaction uses conserved modules
- New functions possible with evolutionary capture of a new module in a protein
- Catalysis, reaction rates and equilibrium
- Carboxypeptidase A: an example of catalysis viewed at atomic resolution
- Modulation of protein function by covalent and non-covalent modifications
- Receptor-ligand interactions
- Tyrosine receptor kinases: structures for bringing proteins together
- Proteins bind DNA; common DNA binding motifs
- Base pairing in nucleic acids
- Proteins control transcription
- Chromatin structure
- Proteins replicate DNA, detect and repair mistakes
- Nature of mutations, somatic and germ line
- Molecular mechanism of recombination
- Bacterial genetics provides the tools for recombinant technology
- Information storage and catalysis by ribozymes and the origin of life

Cellular Biology- Energy and control

Key themes: This course deals with the cell as the unit of biological organization. The properties of lipid bilayers and their role in compartmentalization of biochemical function leads to an examination of different strategies for energy capture, storage and expenditure. The treatment of the control of cellular processes by internal signaling builds on the understanding of protein structure and function gained in the previous course. Lastly, systems of signals between cells are shown to organize the development of multicellular organisms.

- Phospholipid bilayers; composition and physical properties
- Self assembly
- Cellular compartments
- Membranes as reaction surfaces

- ATP as energy currency
- Gibbs free energy
- Coupled reactions
- Glycolysis and TCA cycle
- Thermodynamics and concentration gradients
- Passage of ions and molecules across membranes
- ATP synthesis
- Strategies for capturing and storing energy
- Energy from light
- Signaling pathways within cells
- Control of the cell cycle
- DNA replication, recombination, and repair
- Multicellularity implies different cell types from the same genome
- Signals between cells: sevenless
- Notch-Delta signaling creates even spacing

Laboratory Courses for Lower Division Core

General Goals of Lab courses.

We believe that labs should accompany all three lower division courses. We envision these as mixtures of wet lab experiments, opportunities for learning at the computer, group discussions and problem solving. We intend that lab assignments should be as technically simple as possible but require students to think carefully. We identify 5 pedagogical goals of these labs:

1. To make abstract ideas more concrete. For example, showing students that DNA is real and can be read.
2. To complement the lectures with specific examples. This is particularly true for the third course in which the lab illustrates diversity with living exemplars.
3. To allow students to practice important skills such as graphing data, using databases, making a statistical argument and presenting results.
4. To promote scientific habits of mind, such as attention to details and skeptical interpretation of results.
5. To teach the scientific method of observation, hypothesis, experiment and interpretation of results.
6. To foster the skills required in teamwork.

Course 1 Laboratory: Genes and Genomes

These labs are intended as a mix of wet and computer labs. We would like this to be a lab that "builds" over the course of the quarter rather than consisting of independent canned labs.

Specific goals are:

1. To introduce the properties of DNA through its extraction and isolation, manipulation and sequencing.
2. To illustrate and reinforce the connection between genotype and phenotype.
3. To introduce students to databases.

Module I- finding the genetic basis for phenotypic differences

In this module students will be given mixed cultures of *E. coli* carrying one of three plasmids. Plasmid one has only an amp resistance gene. Plasmid two has an ampR gene and a wild-type beta galactosidase (lacZ) gene. Plasmid three has an ampR gene and a lacZ gene with either a STOP codon after the ATG or a human gene inserted to disrupt the reading frame.

Students will plate out serial dilutions on amp/X-GAL agar plates and observe discrete blue and white colonies. By replating, they can test the hypotheses that each colony is composed of the identical progeny of a single cell and that the original culture was a mixture of genetically different bacteria.

To find the genetic basis for this, they will purify both plasmid DNA and genomic DNA from blue or white cultures and run agarose gels. Differences in the plasmid DNA will be shown by three methods. Retransforming each plasmid into bacteria that are amp-sensitive and white. Restriction mapping plasmids. Sequencing of plasmids. Some white bacteria will not have the lacZ gene while others will have it but in a mutated form. Sequencing will be done for them. All data will be posted on a common server. BLAST searching should reveal the presence of a human gene disrupting the structure of the lacZ gene in some plasmids.

Students will do some Web-based studies of the human gene they have found inserted in their lacZ gene. They should hypothesize whether a human gene can be expressed and confer a phenotype in a bacterium. These ideas lead to module II.

Module II -complementation and the universality of the genetic code

Students will plate out *E. coli* strains defective in synthesis of an amino acid that can be complemented by plant, worm, *Drosophila* or human genes, on media lacking amino acids. They will find that some strains will not grow on medium without supplements. To figure out the genetic basis for this they will use complementation with plasmids carrying plant, worm, *Drosophila* or human genes that restore growth on minimal medium. Students will be given the sequences of the complementing plasmids and will do a BLAST search with their sequence and find that they have a human gene or a plant gene that can confer a trait on a bacterium.

Module III- human genetic diseases

In Web-based assignments on human disease genes, students will consider the type of data used to assign a DNA sequence to a particular disease (trait) and how that compares to their own data showing that DNA sequence Y causes trait Z. Students will compare DNA sequences between healthy and diseased individuals and identify the nature of the DNA change. Does it change protein and if so how? (Q expansion diseases would be great here.) How to determine if this change is responsible for disease? Group discussions will consider current approaches in humans, mice as human disease models and gene therapy in humans.

Course 2 Laboratory: Principles of evolution

Course goals: demonstrate mendelian and non-mendelian inheritance. Show how a trait can be selected for or against. Introduce quantitative genetics. Use population models to explore ways in which gene frequency can increase, decrease or remain in equilibrium and illustrate the concepts of reproductive isolation and speciation.

The following topics are for illustration purposes only.

1. Wet lab *Drosophila* crossing experiment. Different groups of students could be given different mating pairs to illustrate simple mendelian inheritance, sex linkage, etc. Fitting data to models. Generating hypotheses to explain the data: how are the various traits inherited?
2. Computer lab: mendelian inheritance: illustration/discussion of how our crosses could potentially come out using a computer simulation and/or by working through known examples by hand in small groups.
3. Population growth and carrying capacity of the environment illustrated with microbial cultures or seed plants. Goal here is the illustration that not all seeds (individuals) survive and there is some maximum density attainable. Thus there is the potential for selection to operate: can lead into a discussion of which will survive?
4. Selection wet lab. Artificial selection in fast growing *Brassica* might be suitable http://genbiol.cbs.umn.edu/activities/WFP/WFP.html. An alternative could be artificial selection applied to *C. elegans* to generate racing worms. http://academic.bowdoin.edu/courses/s02/bio216/labs/selection/procedures.shtml
5. Population modeling to predict gene frequencies and show that under some selection regimes genes can disappear or go to fixation in a population.
6. Exploration of Hardy-Weinberg in computer simulations.
7. Speciation and reproductive isolation. A suitable lab could be one in which experimental crosses between *Phytophthora* (blight pathogen) isolates are used to investigate prezygotic barriers to reproduction. A brief description of these simple experiments can be seen at http://www.people.virginia.edu/~meh2s/labhome/handouts/Speciation I.PDF. A complementary dry lab could be an examination of well-studied speciation

events. Suitable examples might be Hawaiian Drosophilids, Galapagos finches or Lake Victoria Cichlids.

8. Simulations of conflict, cooperation and altruism. The prisoner's dilemma and a discussion of optimal strategies.

Course 3 Laboratory: Organismal diversity

Course goals: The labs in this course will all be organized around key scientific questions or concepts addressed in lectures, many of which are currently unresolved, and will convey to students the active and dynamic nature of the field of organismal biology. Below are a few examples, undoubtedly more would need to be developed, but we leave that to those more expert than ourselves.

1. A fossil lab using fossil material and photographs of fossil material from which students could measure morphological characters. Combined with dating measures provided to students this should allow them to assess the tempo of evolutionary change. Suitable material might be *Bryozoa*. Comparisons with live material to view important structures and behaviors *in vivo* would be possible.
2. Life cycles and evolution. Sporophyte and gametophyte generations in the evolution of marine algae or other "lower plants". Phylogenetic issue: symbiosis and the evolution of different plant lineages: are algae plants? Are algae monophyletic? How important is endosymbiosis more broadly? The idea for this lab would be to show from what stock "land plants" evolved. Subsequent labs might then elaborate on the land plant theme.
3. Phylogeny of the Archaea and Eubacteria.
4. Symbiosis lab examining *Hydra viridis*, nitrogen fixation in root nodules or possibly lichens. The idea would be to assess the benefit accruing to the partners.
5. Evolution and development. Suitable material might include examination and discussion of the *Drosophila* homeotic mutants, ultrabithorax and antennapedia, hybridization examples in plants, polyploidy in plants and amphibia. Comparison of the larval stages of annelids, echinoderms and mollusks might also be included.
6. Deuterostomy and the evolution of the chordate lineage. This lab focuses on the Echinoderms / Hemichordates / Tunicates. Phylogenetic issues: From where did the chordate lineage arise? Is deuterostomy the ancestral condition for the triploblastic metazoans? What do you do when morphological and genetic characters conflict, or when two different sets of morphological characters conflict [Echinoderms].

   Other labs to be developed on higher plants would follow a similar model, and additional animal labs (including vertebrates) could be adapted from current BIS 1B laboratories, which already have a strong phylogenetic component to them.

Practical and administrative considerations

A practical problem posed by a core of the kind we suggest is that there are probably no textbooks that map to it very well. This is particularly true of the lower division courses where our limited sampling of textbooks indicates that all of them presume an acquaintance with organic chemistry and most of them put classical transmission genetics before molecular genetics and genome structure. Ten years ago, the absence of a suitable textbook would have been a serious impediment to teaching innovation for big lower division courses. Today, this is less of a problem since a great deal of material is available on the Internet and instructors can post material to the course website. Nevertheless, the examples used in the proposed courses will depend on the availability of material from the internet and will also require instructors to develop new material.

As proposed here a new core would be different from our present core not only in its content but also in its style. Important new style elements include

1. A greater consideration of the unanswered questions in biology
2. Presentation of the core as a coordinated sequence
3. Use of examples drawn from across kingdoms
4. Frequent movement between levels of explanation, proximate to ultimate
5. Encouragement of quantitative thinking even at the lower division level

In general, we believe these style innovations can be implemented if the faculty teaching the core are allowed time to develop and coordinate these courses as a group effort. This concept is a little foreign to our teaching culture and though some lip service has been paid to it, instructors typically feel no pressing need to listen to their colleagues' opinions and receive little obvious benefit from doing so. If this proposed core is to be made to work it is essential that the administrative structure of the core be changed to facilitate the changes in style.

Main goals we wish to achieve

1. Ensure that high quality instruction be offered in all core courses.
2. Improve content oversight and coordination between the core courses
3. Establish a clear line of responsibility for the core
4. Facilitate change and revision within the core

Mechanisms for achieving this.

1. In general, the most appropriate instructors, regardless of their sectional affiliation, will be asked to teach in the core.
2. One person, reporting directly to the dean, must be given responsibility for the core. This position, in addition to having managerial responsibilities for the core, is one of leadership and requires a clear vision of the discipline of biology and a willingness to undertake change.

3. The appointee must have the authority to set up and chair oversight and coordination committees, to recruit the most appropriate faculty to teach in the core, and when necessary drop faculty from teaching in the core.
4. To do this the appointee must be ladder faculty and be given some bargaining chips with which to negotiate with section chairs.
5. Since this position involves a large amount of work it cannot be undertaken as an overload. The position should have a 50% administrative appointment and the status of a section chair, and ideally an endowed, named chair.
6. Faculty teaching in the core should receive an incentive. An obvious incentive would be additional teaching credit.

Preparatory Subject Matter

Along with our own lower division core offerings there is presently a requirement for B.S. majors to take three quarters of calculus, three quarters of physics, three quarters of general chemistry, two or three quarters of organic chemistry and a quarter of statistics. In our judgment this is neither too much nor too little but there are several reasons to think the content and structure of the courses might be amended to serve contemporary biology students better. We identify the following issues as starting points for careful examination.

1. In many areas of biology, quantitative models are increasingly integral to understanding. Although in the context of a math course our students can recognize an equation and remember how to solve it, very few would know how to take a set of data and write an equation to model it. Put simply, most of our students fail to make a connection between math and biology, and many complain that math is irrelevant. Help in overcoming this problem lies in the availability of easy to use, high level programming languages that now make it practical for students to explore quantitative ideas even without much mathematical knowledge. Quantitative ideas that were once the esoteric domain of the mathematically sophisticated are now available to anyone with a personal computer.
2. Math, as it is presently taught to our students is appropriate to physics but not exactly appropriate to biology. Clearly some ideas, integral and derivative calculus for example, are common to both but some key ideas underpinning contemporary biology are missing and fall into the cracks between present math, physics, chemistry and statistics. These include: algorithms, stochastic behavior, information theory, dynamical systems and data structures.
3. Chemistry is, for many students, a rate-limiting factor in their progress through the biological sciences.
4. Many of our students report the Physics 7 series to be pedagogically ineffective.

Recommendations

1. A two-unit course on modeling biological systems should be required of all our students and taken in the freshman or sophomore year, perhaps after some exposure to calculus. The course should deal with the formulation of hypotheses to explain data, translating hypotheses into appropriate quantitative models and comparing predictions with data. The emphasis throughout should be on practical methods rather than theory or mathematical rigor. The course should familiarize students with the use of a mathematical toolbox such as Matlab, the standard toolbox used by engineering students or Mathcad, a more user friendly and intuitive software package described on the website http://www.mathcad.com/products/Mathcad.asp.
2. A committee should be established to draw up a detailed set of recommended modifications to the math, physics, chemistry and statistics presently taken by our students. These could then be the basis for negotiation with the appropriate departments. The objectives of the committee should be to suggest how best to cover important ideas that are not presently taught; to explore ways in which chemistry might present less of a holdup to our students, perhaps by presenting organic chemistry earlier; and lastly to assess how well the various offerings perform in teaching our students what they need to know.

Sample course schedules, freshman and sophomore years.

The limiting factors in creating a DBS lower division schedule are the required six quarters of chemistry: general chemistry (2ABC) and organic chemistry (118ABC). Both chemistry (CHE) series offer each course in the series only twice during the year (both CHE 2A and CHE 118A are offered only in fall and winter). We have chosen CHE 118ABC for the organic chemistry requirement as it is the only series that is common to all our majors. Most of our students also choose this series because of general medical school requirements.

Other restrictions: Organic chemistry has a prerequisite of CHE 2C, Physics 7A has a prerequisite of MAT 16B (concurrently is permissible).

Assumption: half our freshman fit into chemistry in one quarter and the other half fit into chemistry the second quarter. This has been true for the past several years.

We often advise freshman to take 2 science courses and 12-13 units for their first quarter on campus.

The proposed 2-unit “biological modeling” course is not shown in these schedules but could be taken in the freshman or sophomore year.

A. Starting chemistry in their first quarter; BIS started in winter; math started in spring

Fall	Units	Winter	Units	Spring	Units
CHE 2A	5	BIS	5	BIS	5
STA 13	4	CHE 2B	5	CHE 2C	5
				MAT 16A	3
Fall	Units	Winter	Units	Spring	Units
CHE 118A	4	CHE 118B	4	CHE 118C	4
MAT 16B	3	MAT 16C	3	PHY 7B	4
BIS	5	PHY 7A	4	UD BIS	4

Finish Physics 7C in summer, or fall of junior year

B. Starting chemistry in their first quarter; BIS started in winter; math started in fall

Fall	Units	Winter	Units	Spring	Units
CHE 2A	5	BIS	5	BIS	5
MAT 16A	3	CHE 2B	5	CHE 2C	5
		MAT 16B	3	MAT 16C	3
Fall	Units	Winter	Units	Spring	Units
CHE 118A	4	CHE 118B	4	CHE 118C	4
PHY 7A	4	PHY 7B	4	PHY 7C	4
BIS	5	STA 13	4	U.D. BIS	4

C. Students who need preparatory courses for math or chemistry (start chemistry in second quarter)

Fall	Units	Winter	Units	Spring	Units
MAT 12	3	MAT 16A	3	MAT 16B	3
pre-Chem	W	CHE 2A	5	CHE 2B	5
				BIS	5
Fall	Units	Winter	Units	Spring	Units
CHE 2C	5	CHE 118A	4	CHE 118B	4
BIS	5	BIS	5	PHY 7A	4
MAT 16C	3	STA 13		UD BIS	4

Finish CHE 118C in summer, or fall quarter of junior year. Statistics in summer, or fall of junior year. Physics 7B same, 7C second summer session, fall or winter quarter of junior year.

Respectfully submitted,

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