Quantitative Biology for Undergraduates: Integrating the Basic Sciences at the Introductory Level

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Abstract

As a field of study, biology is becoming more interdisciplinary and quantitative in nature. Consequently, the effective integration of core courses in mathematics, chemistry and physics into the undergraduate biology curriculum has become even more important. There are three general approaches to connect and integrate disciplines for undergraduate biology majors: (1) rely on existing course structures and individual instructors to illustrate the connections throughout the curriculum, (2) use a capstone experience in conjunction with advanced material during the senior year and (3) provide introductory courses where topics and concepts in mathematics, physics, chemistry and biology are integrated and organized in a fashion that reflects how science actually works. The University of Wyoming uses the first two options, largely in an informal fashion, to integrate mathematics and the basic science disciplines into the various biology majors offered. While difficult to quantitatively document, the success of the UW approach can generously be described as mixed. There are two goals of this proposal, and the first is to adapt the integrated science curriculum as developed at Princeton and Harvard Universities for the realities of the University of Wyoming. The second goal is to develop a fourth alternative for integrating the core disciplines of mathematics, chemistry, and physics more fully into the biology curriculum through the development of a linked 1 credit seminar course that keys on the topics of concurrently enrolled chemistry and physics courses. The motivation for this effort is to tie seemingly diverse scientific topics in chemistry and physics to diverse biological principles, emphasizing quantitative problems and solutions. Through the development of these two related but distinct course proposals, we seek to create opportunities for interdisciplinary training of students interested in biology that will appropriately prepare them for a productive career in their chosen field.

"… we need numbers, not adjectives."

David McKay [1]

I. Description of Proposed Project

A. Modernizing Biology Education through Integration of the Science Curriculum

Biology as a discipline is rapidly evolving. The field is being driven by the development of molecular and quantitative tools, requiring true interdisciplinary skill-sets from those wishing to participate. While biology has had, and probably always will have, a descriptive component as an important feature of the discipline, the advent of the modern molecular toolset has brought to biologists the opportunity – even necessity – to become more experimental and more quantitative in their studies. Certain sub-disciplines of biology have always strived to be quantitative: enzymology and population genetics are two obvious examples. Other related sub-disciplines such as cell biology, gene expression, and simple genetic analyses, have until recently been relatively subjective and descriptive. However, with the recent advent of techniques such as whole-genome transcript profiling, proteomics, and quantitative trait analysis, no longer are soft qualitative observations sufficient to wring research dollars out of granting agencies or convince peer reviewers of manuscripts that the data is convincing. In large part, this proposal stems from my personal journey – realizing that the training I received in biology was no longer cutting it and then putting in the effort to correct those deficiencies. The other motivation for this proposal comes from teaching General Biochemistry at the University of Wyoming for the last 10 years and realizing it was the rare student who was prepared for the new era of biology – and that rare student was probably just inherently good at math and nothing we had done had actually prepared them for the future. The goal of this proposal is to develop two alternative approaches that will foster skills necessary for assuring that the graduates of our undergraduate biology programs are ready for a future in biology – which more and more means competency in the quantitative aspects of biology and comfort with chemical and physical principles.

The call for appropriately preparing undergraduates in the quantitative aspects of biology has been circulating among the academic community, both informally and at educational sessions at national research meetings. Dr. David Botstein, Professor and Director of the Lewis-Sigler Institute for Integrative Genomics at Princeton University has long been an advocate for adapting the undergraduate science curriculum to achieve this goal. The program that he and his colleagues have developed centers upon the integration of science and mathematics during the "introductory" phase of the undergraduate curriculum [2]. This program at Princeton University goes under the name of "Integrated Science" and is designed to break down the barriers that separate the core sciences of biology, chemistry, physics and connect them through the common language of the sciences, mathematics. The freshman science curriculum, for those students opting for this approach, combines introductory chemistry and physics and weaves in plenty of biology, using calculus and computational methods to tie the seemingly disparate concepts and ideas together. The "double course" lasts the entire year and formally results in a full years credit of General Chemistry and Introductory Physics and a semester credit of Computer Programming. Much of the material is provided using the "just in time" concept, meaning that important physics concepts that support chemical principals are provided at the appropriate time to link the topics, and that physical and chemical principles are presented in support of mechanistic explanations of biological phenomenon. The second year travels along much the same track, but using the chemical, physics, and computational foundation built during the first year to support an in depth inquiry into biology, genetics, and biochemistry. The third year provides a capstone experience in an integrative laboratory course where students are involved in an authentic research experience, one in which they are intimately involved in the design, data collection, and interpretation. This program serves students who are not just interested in majoring in biology, but also those who ultimately chose to major in chemistry, physics, and engineering. And as much of scientific investigation occurs at the intersection of the disciplines, it is important that science be taught in the way that science is practiced [3].

The pre-requisites for the Princeton University Integrated Sciences Curriculum include significant fluency in the language of calculus, equivalent to a score of "5" on the AB or BC Advanced Placement Calculus exam. The expectations are high and the workload significant. Even at this elite school, this program is not designed to serve all would be biology, chemistry, and physics majors. An alternative approach has been adopted by Harvard University, combining chemistry and biology in a single course throughout the introductory year, Life and Physical Science 1 and Life Science 1a [4]. These courses are of sufficient rigor to allow students who complete them to enter into mid-level courses in either chemistry or biology (e.g. – physical chemistry, microbiology). In contrast to the Princeton's Integrated Sciences Curriculum, these courses only require fluency with high school algebra. This course has proven to be immensely popular at Harvard, generating the largest enrollment for any single science course ever. Ultimately, the idea behind the two approaches is similar – introduce young scientists to two disciplines in a way that reinforces the connections and quantitative nature of the natural sciences.

Goal #1. <u>Develop a proposal for a new course that integrates freshman biology and chemistry.</u> While the Integrated Science Curriculum as envisioned and practiced by Princeton University – building a deep base of quantitative and computational skills through entwining chemistry and physics in the first year – is compelling with respect to the goal of graduating biologists with quantitative and interdisciplinary, the anticipated target student population at UW is not sufficiently prepared mathematically for this approach. However, developing a double course in which the chemical and biological principles traditionally introduced separately are instead intertwined and connected in a way reflective of modern science will synergistically reinforce the basic concepts of each discipline and build the quantitative skills necessary to be successful in either chemistry or biology. From the perspective of both students and faculty, the similar approach taken at Harvard University has proven both successful and popular [3].

A course proposal will be developed using materials obtained from the Princeton University Integrated Science Curriculum and the material I expect to obtain from Harvard's Principals of Life Science course sequence. The goal of the course proposal is to create an academic tool that serves the interests of Chemistry and Biology majors and faculty. For both students and faculty associated with either major, intertwining the concepts will reinforce their importance and interdependence. Looking at it from the biologist's perspective, it provides a forum for both illustrating the important connections between biological phenomenon and the chemical principles that help explain them and creating a culture where introductory biology is more than just descriptive, it can also be quantitative and mechanistic.

Goal #2. Create a proposal for a 1-credit seminar course that links introductory courses in physical sciences to biological phenomenon. This goal is seen as an alternative to the creation of a combined course, but with the same intended outcome: an opportunity to demonstrate and emphasize the physical and quantitative concepts that serve as the underpinnings of biology. This course will be designed for students interested in biology and to be taken concurrently with an introductory chemistry and/or physics course. In coordination with the instructor of the chemistry or physics course, the "concept of the week" from those courses will be addressed from a biological perspective, relating the physical principal being considered to a role in biology. As an example, bonding orbitals in chemicals can seem quite abstract or even irrelevant to many biologists, but placed in the context of enzyme activity, intelligent drug design, and their role in DNA structure, the topic quickly becomes more palatable for your average biologist.

Such a seminar class approach to connecting the core scientific disciplines of chemistry, physics, and mathematics directly to biology lends itself to utilizing the proven "case study" method during class meetings and assignments. Using case studies is common in law, social sciences and medical programs but has been used less often in teaching basic sciences. However, there are resources available to facilitate the incorporation of case studies into science courses, many directed at the interface between biology and chemistry [5-7]. The choice of case samples will be critical, as the purpose of this course is two-fold: making clear the connections between the sciences and reinforcing mathematical and computational skills.

The materials required for the course proposals will be assembled through analysis and adaptation of course materials obtained from Princeton University (already in hand) and Harvard University (anticipated). Furthermore, I intend to make a site visit to Princeton to attend lectures in their first and second year Integrated Science courses and meet with students, faculty, and staff. The Integrated Science program at Princeton has been very responsive to my inquiries and is anxious to share what they have developed and learned while implementing their program. After the initial data gathering process and synthesis of the ideas and material into draft proposals, I will establish a working group of biology, chemistry and physics faculty to modify and debate the merits of the alternative proposals, perhaps even synthesizing a new model. These two alternative approaches for integrating sciences and developing quantitative skills in our biology majors have taken form after many hours of research and discussion with colleagues, trying to anticipate the hurdles and opportunities that are specific to the University of Wyoming. By no means do I feel I've anticipated all roadblocks or recognized every opportunity. This process has to begin soon or we will fall behind in biology education, hence my submission of this proposal.

While it would be a personal victory if through the introduction of either one of these integrative science courses more students reaching General Biochemistry would be competent in the simple algebraic manipulations I ask of them, it will ultimately be important to stress the importance of calculus and statistics with which we ask our students to be familiar with in more advanced courses in biology. Although it is not a direct goal of this proposal, the development and implementation of an integrated science curriculum should lead to more aggressive advising of biology students into appropriate mathematics and statics courses, increase the interest in quantitative and computational aspects of biology among undergraduate students, and allow faculty responsible for upper division biology courses to include more quantitative information and techniques in their lectures and labs.

II. Relationship to Space Grant and NASA Goals

This proposal directly addresses the Space Grant goal of promoting science and math education at the University level. Furthermore, it also addresses the goal of promoting interdisciplinary research by improving the training of our future scientists through the development of an integrated science curriculum.

III. Products

The intended products of this proposal are two alternative, detailed plans for courses that will integrate science education during the introductory years at the University of Wyoming. The supporting documents for these course proposals will include a statement of need, a rationale for the chosen approach, and detailed syllabi. These materials will be used to gauge and develop faculty interest. As I have learned, new educational and training initiatives at the University of Wyoming require considerable faculty support before administrators become engaged. While resources for implementing either of these alternative educational initiatives should be small, additional support can and will be sought from the National Science Foundation Directorate for Education and Human Resources. NSF routinely supports programs seeking to improve the quality of science and mathematics education at the undergraduate level (Course, Curriculum, and Laboratory Improvement funding opportunity) [8].

IV. Timeline

July – August, 2009

- Collect, analyze, and adapt course material from integrated science curricula offered at Princeton and Harvard Universities.

Fall Semester of 2009:

- Visit Princeton University for several days to interview students, faculty, and staff. Attend first and second year Integrated Science course lectures.

- Finalize working draft of course proposals

Spring Semester, 2009:

- Assemble committee composed of faculty from Biology departments, Chemistry, and Physics to debate merits of proposals
- Engage Administration, submit new course proposal

V. References

[1] From David McKay's treatise "Sustainable Energy – without the hot air" (UIT Cambridge Ltd., Cambridge, England; ISBN 978-0-9544529-3-3, 2009). Dr. McKay's admonition that discussion of energy policy needs more facts and less hyperbole strikes me as being true in the field of biology.

[2] http://www.princeton.edu/integratedscience/

[3] Chemical and Engineering News, Vol. 84, 43-45

[4] http://lifescience.fas.harvard.edu:80/icb/icb.do?keyword=k5526&tabgroupid=icb.tabgroup12721

[5] http://ublib.buffalo.edu/libraries/projects/cases/case.html

[6] http://jchemed.chem.wisc.edu/JCEDLib/DataDriven/index.html

[7] http://www.actionbioscience.org/education/herreid.html

[8] http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5741&org=EHR&from=home

4. Budget:

Faculty Salary (summer) for Peter Thorsness:	$5,015.00
Benefits:	$3,485.00
Travel to Princeton University:	$1,500.00

Rationale: I will be spending substantial effort assembling documents, adapting ideas derived from their analysis to fit UW's specific needs, and creating a set of draft course proposal materials. For that I ask for partial support of my summer salary. I've also requested funds to travel to Princeton University in order to visit with students and faculty and to attend several Integrated Science lectures. I will schedule the trip at a point in the development of the course proposals that will allow me to address critical questions that have arisen during the synthesis of the proposals. The Integrated Sciences Program at Princeton is almost evangelical in their eagerness to share their materials and experiences. I anticipate that fostering a relationship with their program will prove to be extremely valuable in achieving the goals of this proposal.

5. Description of Previous Space Grant Funding:

None.