An Experience Teaching an Undergraduate Level Course in Biophysics

Mitra Shojania Feizabadi

Physics Department, Seton Hall University,South Orange, NJ
Email: shojanmi@shu.edu

Abstract: The importance of including concepts, examples, and techniques from mathematics and the physical and information sciences in biology courses to fulfill the need of today's undergraduates has been the principle motivation for developing interdisciplinary biology-focused courses. Although this movement started many years ago, developing and offering courses like biophysics is still new in many liberal arts colleges. Taking advantage of the experiences gained by introducing an interdisciplinary course, simply titled Biophysics, this paper was developed to present the adapted structure, challenges, and useful factors to further develop such a course in order to heighten students' retention of the material.

Introduction

Traditional undergraduate science courses provide backgrounds in mathematics, biology, chemistry, physics, or computer science, often without demonstrating how these fields overlap. In contrast, interdisciplinary courses select and develop materials that promote student understanding of how different sciences and technologies integrate with one another. The importance of including concepts, examples, and techniques from mathematics and the physical and information sciences in biology courses in order to serve today's undergraduate biology students has received much attention recently (National Research Council, 2003; Goldestein, Nelson, 2005; Varmus, 1999; Mielczarek, 2006). At present, developing interdisciplinary courses is strongly encouraged and a variety of teaching methods exist (KANE, 2002; Biophysical Society, 2009; Physics Department, Haverford College, 2009; Biology Department, Beloit College, 2009; Physics Department, Simon Fraser University, 2009).

A biophysics course (PHY303) was developed at Canisius College with the support of a grant received from the Howard Hughes Medical Institute (HHMI) to establish an undergraduate interdisciplinary program. This course was developed by the physics department and approved by the departments of physics, biology and chemistry and taught in the fall of 2006. Two faculty members, one from the physics department and one from the biology department were scheduled to team-teach this course. However, the first round was taught by the author alone due to the sabbatical leave of the biology faculty member at the time that the course was offered. This paper describes the experience gained while teaching this interdisciplinary course in biophysics at a small liberal arts college.

Course Description

Textbook and Lectures Structure

There is a variety of different books and web resources available covering a broad range of topics for this class (Boal, 2002; Berg, 1993; Kane, 2003; Howard, 2001; Nelson, 2003; Tuszynski, & Kurznski, 2003). Since the course was designed to include a detailed quantitative and qualitative description of structures, functions and biochemical interactions to express the cellular mechanics, the three main books used were Jonathan Howard's *Mechanics of Motor Proteins and the Cytoskeleton* (Howard, 2001), Philip Nelson's *Biological Physics: Energy, Information, Life* (Nelson, 2003), and Jack Tuszynski's *Introduction to Biophysics* (Tuszynski, & Kurznski, 2003). These books include all the topics covered in this course; however, the level of mathematical usage was significantly adjusted to meet the students' background.

In order to address different teaching methods and provide more dynamic illustrations, lectures were presented via a combination of PowerPoint™ and chalkboard. Movies, animations and web links related to the topics introduced in the presentations were compiled to present the concepts of biophysics more effectively. The final evaluation of the students' performance was based on their grades in two written in-class examinations and their presentation of the assigned research project. The class met in a lecture format for fifty minutes, three times per week.

Lecture Outline

The main goal of this course was to study cellular biophysics with an emphasis on the investigation of the physical concepts behind the process of mitosis and the roles of biofilaments and other proteins in connection with it. To understand such a complex system, the topics covered included:

- Biofilament Structure: The nature, structure and functions of cytoskeleton filaments like microtubules and actins. To better understand the physics behind cell-mitosis, the nucleation of microtubules in microtubule organization centers was explained to express the ways in which they formed aster microtubules. This process presents a key component in mitosis (Boal, 2002; Kane, 2003; Howard, 2001).
- Biofilament Statics: filament deformation, bending energy, stiffness, and persistence length as well as single molecule manipulation techniques (Boal, 2002).

-
- Biofilament Dynamics: polymerization and depolymerization of biological filaments, dynamic instability, and the steady state of biofilament assembly based on current experimental results and theoretical models (Physics Department, Simon Fraser University, 2009; Howard, 2001; Nelson, 2003; Tuszynski, & Kurznski, 2003; Walker et al., 1998; Dogtrom,. 1993).
- Biofilament Dynamics and Biological Significant: The effectiveness of dynamic instability by calculating the time required for a collection of microtubules growing from a centrosome to find a target (Holy, & Leibler. 1994).
- Force Generation: the physics involved in pushing or pulling chromosomes caused by polymerization and depolymerization of microtubules as well as Brownian motion (Howard, 2001; John Hopkins, The Cell Mechanics and Motility Lab, 2009).
- Motor Protein Motility: an introduction to different types of motor proteins including kinesin, myosin and dynein, and the structures and functions of motor proteins associated with their motilities (Boal, 2002; Howard, 2001; Nelson, 2003).
- Based on the concepts developed during the course, the various stages of mitosis were studied (Brust-Mascher, 2004).
- For the remainder of the course lectures, the biophysics of organs and their various roles in human biological systems were studied. The cardiovascular, respiratory, kidney and excretory systems were also discussed (Tuszynski, & Kurznski, 2003).

Along with the in-class lectures,, students were expected to research a specific topic relevant to the course in groups of two. A presentation was prepared and delivered during class using Microsoft PowerPoint™. Topics included the physics of laser tweezers (Ashkin, Dziedzic, 1987; Biophysical Society; Smith. et al., 1999; Sterba, Sheetz. 1998), the paradox of persistence length in microtubules (Pampaloni et al. 2006), the motility of taxol in microtubule bundles (Ross, Fygenson. 2003), the interaction of the motor proteins with microtubules as a ratchet mechanism (Brokaw. 2001), the stability of chromosomes (Campas, Sens. 2006), the immunotherapeutic effect on cancerous tumors (De Pillis, Gu, Radunskaya. 2006), and biological self-regulation and self- organization (Tuszynski, & Kurznski, 2003). In addition to the in-class PowerPoint presentations, all of the research topics were presented to the faculty members of the School of Science in the form of a poster presentation. This event, named "The Biophysics Research Day", was an excellent opportunity for students to experience the scientific presentation of their work. It also allowed them to receive feedback and grades from the faculty members and comprised ten percent of their final grades

Discussion

There is an extensive network of educators and professional societies working in the area of biophysics and curriculum reform (Mielczarek, 2006; Biophysical Society, 2009). However, teaching an interdisciplinary course,, such as biophysics, is exciting because of the novelty of such courses in undergraduate curricula. Having been the sole instructor in one of these courses, there are a number of thoughts and suggestions for future offerings.

One challenge in implementing an interdisciplinary science course at the undergraduate level is developing opportunities for students to apply new technology capable of solving interdisciplinary scientific questions. For example, many of the concepts presented in lectures of PHY303 referred to the use of laser tweezers to measure and analyze the static and dynamic properties of biofilaments and motor proteins.

For one group of students, the physics underlying the design of laser tweezers was grasped readily, while the application of the technology to cell biology questions was challenging. The opposite was true for another group of students, who struggled with the underlying physics of laser tweezers design. Thus, it appears that an important step in advancing their understanding and clarifying the concepts of biophysics would be to implement a biophysics laboratory in conjunction with the lecture.

The lab would allow students to be engaged in the hands-on application of experimental biophysics instead of being limited to just the abstract nature of theoretical biophysics. This new laboratory also reinforces the fact that theory and experiment are related to one another in the pursuit of a scientific explanation. Students are, therefore, provided with the opportunities to design experiments, find ways to test it, collecting and analyzing data and peer review each other's works.

Building an interdisciplinary laboratory as a complementary component of the lecture requires sufficient funding for basic essential equipment. However, developing a biophysics laboratory to support biology-focused interdisciplinary courses has, in fact, already been started in research institutions as well as liberal arts colleges (Biological Physics Laboratory, The University of Arizona, 2009; Department of Physics, Pomona College, 2009; Department of Physics, Brown University, 2009; Physics Department, Haverford, College, 2009).

Cross-institutional collaboration with research oriented institutions that have well-established interdisciplinary programs and well-equipped laboratories can also provide students with opportunities to be involved in a biophysics laboratory; especially if the research institution is in close proximity. Likewise, this allows for the exchange of ideas and perspectives during the resulting interactions. In our situation, following discussions with the Administration of the Center for Single Molecule Manipulation of University at Buffalo, there is hope that such a collaborative opportunity can be made a reality for our students when this course is next offered.

Canisius College students have expressed a great interest in interdisciplinary courses such as biophysics. However, they experienced a different structure in this biophysics course as compared with the structure of traditional courses which usually include practice of the material in terms of the regular use of homework and/or quizzes. In this course, however, different types of problems were assigned to students.

One group of assigned problems could be treated mathematically. For example, when the static properties of biofilaments were taught, a typical problem consisted of finding the energy required to bend a biofilament, such as a microtubule, into an arc when the persistence length (i.e., the length of the microtubule) and the radius of the arc were known. The source for these types of problems was chapter two of *Mechanics of the Cell* by David Boal (Boal, 2002). However, locating adequate problems that met the mathematical background of the students was challenging. Another problem set was mainly based on analyzing graphs and conceptual questions. Samples of such problems can be found in chapters nine and ten of *Mechanics of the Cell* (Boal, 2002).

Assesment

The main goal of offering this course was to expand the structure of interdisciplinary activities across the college. The "sub" goal of this course was to investigate biological systems that can be explained and clarified by employing concepts of physics and mathematics. This knowledge and experience will enable our students to be more competitive as they pursue advanced goals.

To facilitate the students' access to the material, all the lecture notes, prepared in PowerPoint™, were systematically posted on the internet via the Blackboard™ learning system. As evident from the Blackboard™ web server statistics, 652 hits from students showed this method to be a successful and effective in distributing the course material.

A survey prepared by the Canisius College HHMI Interdisciplinary Survey Committee was distributed at the end of the semester. The results are expressed below. In this survey the students rated each of the following questions on a scale of 1-5. For each question rating 1 or 2 were combined, 4 or 5 were combined, and 3 represented neutral. Also, the percentages in the tables are rounded off to one significant figure which is more appropriate for the number of responses.

1. Did the interdisciplinary nature of the course (i.e., combining Biology and Physics in one course) help your learning of the course material? Table 1

	Helped Very Little	Neutral	Helped Very Much
Frequency (n=14)	0	3	11
Percent of Students	0%	21%	79%

In general, due to the limited number of problem-answer sets, students were restricted to fewer problem sets. Consequently, students experienced not a traditionally structured course with a good collection of "end of chapter" problem sets, but an interdisciplinary course with much greater emphasis on dealing with ideas and qualitative questions.

The syllabus outlined for this biophysics course may not be suitable for every institution. Depending upon the goals of the institution and the student requests, the course may emphasize differing topics. Students in this course who were pursuing medical careers, for example, expressed an interest in the study of a biophysics more closely linked to medicine and disease. This can be addressed by introducing another course, which emphasizes medical physics in particular and the design of medical equipment as a complementary component. This approach has also been taken in other undergraduate institutions (Physics Department, Haverford College, 2009).

2. Do you agree or disagree with the following statement: "The nature of this course comes very close to what I think of as 'interdisciplinary science'"? Table 2

	Strongly Disagree	Neutral	Strongly Agree
Frequency (n=14)	1	4	9
Percent of Students	7%	29%	64%

3. Do you feel you were adequately prepared by previous Biology courses for the combination of Biology and Physics that you encountered in this course? Table 3

	Felt Poorly Prepared	Neutral	Felt Well Prepared
Frequency (n=14)	1	2	11
Percent of Students	7%	14%	79%

4. Do you feel you were adequately prepared by previous Physics courses for the combination of Biology and Physics that you encountered in this course? Table 4

	Felt Poorly Prepared	Neutral	Felt Well Prepared
Frequency (n=14)	0	5	9
Percent of Students	0%	36%	64%

5- Choosing and exploring a research topic enhanced my research skills in this field Table 5

	Strongly Disagree	Neutral	Strongly Agree
Frequency (n=14)	3	1	10
Percent of Students	21.4%	7.2%	71.4%

One of the main goals for interdisciplinary programs is rooted in research. Today, those who graduate with a background in interdisciplinary activities and were engaged in doing research in an interdisciplinary program can be productive in a shorter time if they choose to further their education in an interdisciplinary field. Applicability of assigning research projects at an undergraduate level as well as the positive response of students to this approach expressed above illustrates that this approach to offering the course was positive.

In conclusion, the different structures of the biophysics course offered to undergraduate students in liberal arts colleges and different approaches of assessing them complicates the comparison of the success of this particular course with similar courses offered at other schools. For the future growth of interdisciplinary programs in science, a consistent standard and a reliable assessment needs to be established. Therefore, offering such courses while continuously improving their quality should be a positive academic approach.

Acknowledgments

The Howard Hughes Medical Institute provided support for developing of this course.
I would like to thank the following Canisius College students for their contributions to this work: Katharine Dobson, Janelle Tryjankowski.

Refrences

ASHKIN, A., DZIEDZIC, J. M. 1987. Optical trapping and manipulation of single cells using infrared laser beams, Science 235: 1517-1520.

BIOPHYSICAL SOCIETY, 2009. http://www.biophysics.org/education/resources.htm.

BIOLOGY DEPARTMENT, Beloit College, 2009. http://beloit.edu/~jungck/#papers.

BOAL, D. 2002. Mechanics of the Cell, Cambridge University Press, 406p.

BERG, H., C. 1993. Random Walks in Biology, Princeton University Press, New Jersey, 164p.

BRUST-MASCHER, I., CIVELEKOGLU-SCHOLEY, G., KWON, M., MOGILNER, A., AND SCHOLEY, J. M . 2004. Model for anaphase B: Role of three mitotic motors in a switch from PNAS, 45: 15938-15943.

BIOPHYSICAL SOCIETY, 2009. http://www.biophysics.org/education/williams.pdf Tweezers.

BROKAW, C. J. 2001. Protein-protein ratchets: stochastic simulation and application to processive enzymes. Biophysics Journal 81: 1333-1344.

BIOLOGICAL PHYSICS LABORATORY, The University of Arizona, 2009. http://bmpi.web.arizona.edu/BioPhyForce.html.

CAMPAS, O., SENS, P. 2006. Chromosome oscillations in mitosis, Phys. Rev. Lett. 97: 128102-128106.

DOGTROM, M., LEIBLER, S. 1993. Physical aspects of the growth and regulation of microtubule structures, Phys Rev. Lett., 70:1347-1350.

DE PILLIS, L.G, GU, W., RADUNSKAYA, A.E. 2006. Mixed immunotherapy and chemotherapy of tumors: modeling, applications and biological interpretations, Journal of Theoretical Biology 238: 841-862.

DEPARTMENT OF PHYSICS, Pomona College, 2009. http://www.physics.pomona.edu/faculty/prof/KWOK/Research.htm.

DEPARTMENT OF PHYSICS, Brown University, 2009. http://biophysics.physics.brown.edu/.

GOLDESTEIN, R. NELSON, P., AND POWERS, T. 2005. Teaching biological physics, Physics Today: 46-51.

HOWARD, J. 2001. Mechanics of Motor Proteins and the Cytoskeleton, Sunderland Sinauer Associates, Inc, USA, 384p.

HOLY, T.E., LEIBLER, S. 1994. Dynamic instability of microtubules as an efficient way to search in space, 12: 5682-5685.

JOHNS HOPKINS UNIVERSITY, The Cell Mechanics and Motility Lab, 2009. http://www.jhu.edu/cmml/emph_ListSteps.html.

KANE, S. A. 2002. An undergraduate biophysics program: curricular examples and lessons from a liberal arts context. Am. J. Phys. 70: 581-586.

KANE, S., A. 2003. Introduction to Physics in Modern Medicine, Taylor and Francis, London, 336p.

MIELCZAREK, E. V. 2006. Resource letter PBFi-1: physical frontiers in biology. Am. J. Phys. 74: 375-381.

NATIONAL RESEARCH COUNCIL, Bio 2010. 2003. Transforming Undergraduate Education for Future Research Biologist. National Academic Press, Washington DC, Accessed from http://books.nap.org.

NELSON, P. 2003. Biological Physics: Energy, Information, Life. Freeman and Company, NEW YORK, 600p.

PHYSICS DEPARTMENT, Haverford College, 2009. http://www.haverford.edu/physics-astro/course_materials/phys320/syllabus.htm

PHYSICS DEPARTMENT, Simon Fraser University, 2009. http://www.sfu.ca/~boal/4xx.html.

PAMPALONI, F. et al. 2006. Thermal fluctuations of grafted microtubules provide evidence of a length-dependent persistence length, PNAS, 103: 10248-10253.

PHYSICS DEPARTMENT, Haverford, College, 2009 . http://www.haverford.edu/physics-astro/Amador/Amador.html.

ROSS, J. L., FYGENSON, D.K. 2003. Mobility of taxol in microtubule bundles, Biophysical Journal, 84: 3959-3967.

SMITH, S. P. et al., 1999. Inexpensive optical tweezers for undergraduate laboratories, Am. J. Physics 67: 26-35.

STERBA, R. E., SHEETZ M. P. 1998. Basic laser tweezers. Methods in Cell Biology, 55:29-40.

TUSZYNSKI, J., KURZNSKI, M. 2003. Introduction to Molecular Biophysics, CRC, Canada. 584p.

VARMUS, H. 1999. The impact of physics on biology and medicine, APS News August/ September, 8.

WALKER, R. et al. 1998. Dynamic instability of individual microtubules analyzed by video light microscopy: rate constants and transition frequencies. The Journal of Cell Biology, 107: 1437-1448.