Published in final edited form as:
Science. 2012 December 21; 338(6114): . doi:10.1126/science.1216570.

Interdisciplinary Graduate Training in Teaching Labs

Ronald D. Vale[1,2,3,*], **Joseph DeRisi**[2,3], **Rob Phillips**[4], **R. Dyche Mullins**[1,2], **Clare Waterman**[1,5], and **Timothy J. Mitchison**[1,6]

[1]Marine Biological Laboratory, Woods Hole, MA 02543, USA

[2]University of California, San Francisco, San Francisco, CA 94143, USA

[3]The Howard Hughes Medical Institute, Chevy Chase, MD 20815, USA

[4]California Institute of Technology, Pasadena, CA 91106, USA

[5]National Heart, Lung, and Blood Institute, Bethesda, MD 20824, USA

[6]Department of Systems Biology, Harvard University Medical School, Boston, MA 02115, USA

Abstract

Intensive, short-term courses meld students and faculty and new techniques in pursuit of genuine research questions.

Modern research and training in the life sciences require cross-disciplinary programs, integrating concepts and methods from biology, physics, chemistry, and mathematics. We describe the structure and outcomes from an example of one such approach, the Physiology Course at the Marine Biological Laboratory (MBL) in Woods Hole, Massachusetts, and discuss how similar intensive, team-building research courses are also being applied to improve graduate education in universities. These courses are based on teaching laboratories that have students address contemporary research questions by combining ideas and approaches from biology, computation, and physics.

Bringing biologists and physical and computational scientists together does not automatically translate into collaborations and novel insights into biological problems. Perhaps the best solution is to merge physical and life sciences training during undergraduate studies (1–4). Yet there will always be a need to teach physical sciences to biologists, and vice versa, during graduate and postdoctoral training, as interests and motivations change over time. Learning scientific inquiry in a teaching laboratory has been implemented successfully for undergraduates (5–8), but is not common practice in graduate education, where lecture courses tend to occupy the first year followed by the pursuit of an individually directed thesis project.

Boot Camp and Real Problems

The summer Physiology Course at the MBL, founded in the 1890s by Jacques Loeb, has a rich history of training scientific leaders and gathering teaching faculty from diverse disciplines in ways that did not typically occur in university departments. Although focused on basic biological research, the Physiology Course has long admitted physicists, engineers, mathematicians, and chemists. In 2004, the interdisciplinary nature of the course became less adventitious and more deliberate when the course directors decided to draw an

*Author for correspondence. vale@cmp.ucsf.edu.

Supplementary Materials www.sciencemag.org/cgi/content/full/338/6114/1542/DC1 approximately equal number of the ~28 U.S. and international students from cell biology and physical science/computational backgrounds. Special interdisciplinary graduate training programs have been established to bridge gaps between disciplines [e.g., those funded by the Integrative Graduate Education and Research Traineeship (IGERT) from the U.S. National Science Foundation (NSF)], but the goal of the Physiology Course is to provide a short-term (7-week), intensive (6 days/week; ~14 hours/day) environment for interdisciplinary education.

Three ingredients have been particularly important for the Physiology Course: (i) promoting exploration of new techniques at the start of the course; (ii) focusing the laboratory on real research questions; and (iii) promoting collaboration and peer-to-peer learning, which creates benefits that extend beyond the course by fostering longer-term scientific social networks. The third component has been discussed elsewhere (9), so we focus on the first two elements below.

Boot camp: Leveling the playing field for learning

To expose students to new subjects and techniques, the Physiology Course begins with a 6-day “boot camp,” in which students rotate through intensive 2-day modules in “wet bench” biochemistry, light microscopy and image analysis, and MAT-LAB programming. Computational scientists find themselves dissecting squid optic lobes and purifying proteins. Biology students discover that they can write simple code for identifying subcellular organelles in images or using differential equations to analyze population dynamics. Although 2 days is too short to become expert in such skills, the boot camp allows students to appreciate the value of new approaches and encourages them to work outside of their prior area of expertise during the research section of the course.

The teaching laboratory: Solving real research questions

Missing in most teaching laboratories is the start of the scientific process: formulating interesting research questions and then developing a plan to answer them. By pursuing a research question with unknown answers and uncertain outcomes, students and faculty combine their wits and skills to design experiments, evaluate progress, and troubleshoot along the way. Curiosity, the excitement of possible discovery, and the challenge of problem-solving can be seductive for students. Real problems teach students that science is difficult and that nature does not yield its secrets easily. Such lessons are valuable and not necessarily discouraging.

Every Physiology Course student participates in three research modules, led by a faculty member and postdoctoral or graduate student teaching assistants, each consisting of 11 days for experimentation and analysis and a final day for presentations. The faculty members bring project ideas (usually nascent ideas never tested in their labs), and a given project is typically tackled by two to four students with mixed backgrounds in biology and physical science and computation. The course projects, which differ every year, are tailored to this time period, and many of the reagents (e.g., clones or cell lines) are prepared in advance. Students are encouraged to divert these initial projects in new directions or come up with their own ideas and approaches. The result is a “hybrid vigor” of ideas, which often improves upon the original experimental vision brought by the faculty.

Advantages and Outcomes

How might a graduate student benefit from a teaching laboratory when the majority of her or his training is already spent doing thesis research? A teaching lab of the kind described here emphasizes strategic decisions that are important for completing a thesis and becoming a professional scientist: how to formulate good research questions, develop strategies to answer those questions, and overcome the inevitable obstacles. However, the focus and intensity of the teaching lab differ from typical thesis work; students brainstorm and troubleshoot with faculty and peers on a daily basis in the lab instead of during sporadic thesis meetings in an office and discover that they can make considerable progress in a brief time span. Although intensive, a good teaching lab provides a playful setting for students to learn and experiment with new ideas and techniques, which can be difficult to do in their focused thesis work. Students also experience the intimacy of interacting with peers and faculty members in an unusual collaborative setting, which can generate a passion for the scientific profession that persists after the course ends.

A teaching laboratory also is effective for interdisciplinary training, as physics and biology students can become more motivated to grapple with a new method or principle when they see its relevance to a problem they are trying to solve. Physics and computational students experience firsthand the complexity and “messiness” of experimental biology. They learn how to identify a good biological question and set up controlled experiments to answer it, a process that differs somewhat from the “observations plus modeling” approaches at the core of many physical science disciplines. Biology students gain exposure to applying quantitative thinking and embracing a broader range of tools (e.g., microfluidics, mathematics, computer simulations, chemical kinetics, and optical trapping). By working intensively together, biologists and physicists better understand each other’s languages and how their approaches can complement one another.

To be successful in achieving such training goals, the laboratory course culture must minimize the fear of failure or of appearing ignorant, factors that impede students, as well as senior scientists, from venturing into new fields or learning new approaches. Risk-taking must be part of the course philosophy. Leading by example, the faculty stretch themselves to learn new material, as students watch them, too, fumble with a computer program or a microscope. Traditional roles that separate teacher and student become blurred, as the two groups work on a challenging research problem rather than being separated at opposite ends of a lecture hall.

Physiology Course students are encouraged to take risks and try new methods without aiming for publishable results. However, by focusing on interesting questions as the core philosophy of the Physiology Course, important ideas and fruitful research have emerged, as evidenced by the 23 research papers and 59 meeting abstracts that cite the Physiology Course, as part of the author affiliation or acknowledgments between 2005 and 2012 [supplementary materials (SM)]. In addition, 78 out of 176 students polled (44%) reported that they continued to work on some experiment or question to which they were initially exposed during the course (SM). Our surveys also show that students favorably view the research-based teaching lab (SM), but rigorous evaluation of longer-term career benefit remains an important future goal.

Influences, Translation, and Challenges

The MBL and Cold Spring Harbor Laboratory (CSHL) have become influential educational centers because they have dedicated and well-equipped laboratory space for teaching, on-site housing and meals for students and faculty, and public and private funding to enable advanced research. However, laboratory courses with the same flavor can be created for graduate education in a university setting.

The integrative Program in Quantitative Biology (iPQB) at the University of California, San Francisco, inspired by the project-based instruction at MBL and CSHL courses, provides an interdisciplinary laboratory experience for incoming Ph.D. students from physical science, engineering, computer science, and biology backgrounds. The first-year curriculum begins in a teaching lab with a week-long “boot camp,” followed by a team-based intensive experimental and computational course in which they pursue faculty-guided, genuine research problems. The curriculum includes “Team Challenges,” such as the construction of a “breadboard” fluorescent or hyperspectral microscope from basic glass lenses and parts, which they then use for single-cell analyses. In the second quarter, teams computationally model and explore the experimental data that they generated in the first quarter. With similar inspiration, the California Institute of Technology (Caltech) launched a 1-week Physical Biology boot camp with a research component. In addition to Caltech undergrad and graduate students, the course has attracted non-Caltech postdocs, professors, journal editors, and policy-makers.

Similar educational efforts can be tried in universities if scientist-educators are freed from traditional constraints of trimester or semester academic calendars where several courses run in parallel to make room for courses that operate on compact, intensive schedules (10). The spirit of the course (collaborative work between students and faculty to address real research questions, emphasizing experimentation, modeling, and active discussion) can be created without the resources available at the institutions described here. The degree of challenge (complexity of the questions being tackled) can be tuned to accommodate the resources and time available. If a dedicated teaching lab is not available, faculty might open up their labs to students as we (R.D.V. and R.D.M) have done for short (2-week) courses at UCSF.

A challenge for graduate education is to develop courses that excite both students and faculty and that pave the way for independent thesis work and subsequent careers in research. Graduate courses that break from the undergraduate lecture model should aim for three goals: (i) to signal the transition from absorbing knowledge (undergraduate) to creating knowledge (graduate school); (ii) to do a better job of teaching the skills needed to become a practicing scientist; and (iii) to energize and engage faculty members. The teaching labs we describe here represent one of many creative approaches that can be used to tailor education toward the unique needs of science graduate students.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The MBL Physiology Course is supported by grants from the NIH (GM085967), the Howard Hughes Medical Institute, and the Burroughs Wellcome Fund. The UCSF iPQB courses are supported by a National Institute of Biomedical Imaging and Bioengineering, NIH, Interfaces grant (T32 EB009383), and the CalTech boot camp receives funding from the Caltech Rosen Center for Bioengineering.

References and Notes

1. Bialek W, Botstein D. Science. 2004; 303:788. [PubMed: 14764865]
2. Labov JB, Reid AH, Yamamoto KR. CBE Life Sci Educ. 2010; 9:10. [PubMed: 20194802]
3. Chiel HJ, McManus JM, Shaw KM. CBE Life Sci Educ. 2010; 9:248. [PubMed: 20810957]
4. Pevzner P, Shamir R. Science. 2009; 325:541. [PubMed: 19644094]
5. Hanauer DI, et al. Science. 2006; 314:1880. [PubMed: 17185586]
6. Chen J, et al. PLoS Biol. 2005; 3:e59. [PubMed: 15719063]
7. National Research Council. Biol 2010: Transforming Undergraduate Education for Future Research Biologists. National Academy of Sciences Press; Washington, DC: 2003.
8. Bednarski AE, Elgin SC, Pakrasi HB. Cell Biol Educ. 2005; 4:207. [PubMed: 16220142]
9. Smith MK, et al. Science. 2009; 323:122. [PubMed: 19119232]

10. Bentley AM, Artavanis-Tsakonas S, Stanford JS. CBE Life Sci Educ. 2008; 7:175. [PubMed: 18519608]