ACS Synthetic Biology
Viewpoint
pubs.acs.org/synthbio

Designing the Scientific Cradle for Quantitative Biologists

Qi Ouyang,* Luhua Lai, and Chao Tang

Center for Quantitative Biology, Peking University, Beijing 100871, China

Among scientists, biologists and non-biologists alike, it has become a consensus that after a glorious century of physics and chemistry, the 21st century will be a century for life science. In the past couple of decades, we have witnessed much exciting progress in life science; it is quickly changing from qualitative to more quantitative, from studies of isolated functional parts to a more systems-level description and the understanding of living systems as a whole. Gradually, it has become clear that the breakthroughs in life science are increasingly dependent on interdisciplinary approaches; mathematics, physics, chemistry, engineering, and information science each play an essential role. These interdisciplinary endeavors not only provide new engines for the growth of life science but also feed back to other scientific disciplines and push forward their frontiers. Thus, training students to meet the challenges of the interdisciplinary research plays a crucial role in the development of next generation scientists, engineers, and medical workers; new curricula and training programs have to be designed and implemented.

Over ten years ago, a few professors at Peking University from the schools of life sciences, mathematics, physics, chemistry, and engineering, were among the first in China to realize this situation. With the support of the President of Peking University, the school administration, and physics Nobel laureate Prof. T. D. Lee, they founded the Center for Theoretical Biology (CTB) in 2000, which became the Center for Quantitative Biology (CQB) in 2012. The objective of CTB is 2-fold: to join forces to conduct interdisciplinary research at the interface of life science and other quantitative disciplines and to create new education programs to train graduate and undergraduate students in interdisciplinary research. The center focuses on two research areas: quantitative systems biology and synthetic biology.

As many researchers in the interdisciplinary field can testify, a true marriage between life science and other disciplines requires special efforts. An even harder task is to create a nurturing environment for students coming from diverse backgrounds. There are three challenges in putting forth an interdisciplinary education program: (1) how to select suitable students, (2) how to design a curriculum that maintains a student's current academic level in his/her major discipline while providing intensive training at the interface of their major and biology, and (3) how to create a research environment that engages students and helps them thrive in their interdisciplinary research.

To meet these challenges, the CTB developed an education program independent from the current schools and departments at Peking University. Each year, about ten graduate students are selected nationwide, along with the same number of undergraduate students from Peking University, to join the CTB. Keeping in mind that the program does not involve simply teaching the biology students quantitative skills or teaching students of other disciplines biology, we carefully select students to ensure that all major disciplines, including biology, mathematics, physics, chemistry, engineering, and computer science, are adequately represented in the student body. Individual student offices are within one big open office to encourage the easy exchange of ideas and perspectives and to help students learn from each other. Since motivation is the key to success, we select the students who are willing to work hard in order to expand their knowledge, both in their own majors and in biology. Some have already decided to pursue interdisciplinary research, while others have completed double majors in their undergraduate training. In addition, the majority of selected students have been seriously involved in different research projects during their undergraduate training, some of them having already published papers in various scientific journals. Not all students are suitable for interdisciplinary studies - selecting highly motivated students is the first step toward a successful program.

Formulating a suitable curriculum and training program is the second challenge. Due to the limited duration of the program, one runs the risk of having students acquire just the surface knowledge of each discipline, which is not sufficient to be competitive in this field. We believe that true interdisciplinary research stems from a collaborative effort and strive to avoid converting students into pure biologists, turning them away from their current disciplines. Thus, our training program is formulated as follows.

First, all students are enrolled in a host department where they complete at least half of the core courses in their respective discipline. This way, each student focuses on biology and one other discipline, concentrating their efforts to one particular interface.

Second, depending on the background of the newly recruited students, basic courses are provided. For those students that

Special Issue: Synthetic Biology: Research Perspectives from China

Received: April 24, 2012
Published: July 20, 2012

lack rigorous quantitative training in their undergraduate study, we provide two introduction courses, "Basic Physics and Chemistry in Life Sciences" and "Applied Mathematics in Life Sciences and Medicine". These courses are tailored to the students with biological backgrounds. For those students who lack training in biology, we offer two basic level courses, "Cell Biology" and "Molecular Biology", along with a laboratory class that helps students get acquainted with basic experimental skills. Before joining a research group, each student rotates in three laboratories of unique disciplines, for three months each. The prescribed coursework along with the laboratory experience ensures that our students establish the solid knowledge base required for their future research endeavors.

Third, we organize seminars where professors from different disciplines analyze biological systems, each from a different angle or perspective. For example, a professor in biology may give a detailed description of a regulatory network and provide genetic evidence of the network control from an evolutionary point of view; a professor in chemistry may discuss the chemical bases of DNA–protein and protein–protein interactions of different players in the network and provide a quantitative description of kinetics of biochemical reactions; a professor in physics may discuss the nonlinear dynamics feature of the network, introducing some basic concepts, such as the network's structural stability, state stability, non-equilibrium phase transition, and dynamic bifurcation; a professor in mathematics may teach the students to analyze the network dynamics as a stochastic process, while others may discuss the design principles in a system that can robustly perform a predetermined function such as that of forward engineering. In this way, students are exposed to an integrated view of the biological systems.

Lastly, we designed a discussion course, "Selected Papers in Quantitative Biology", where students discuss classic papers in which quantitative methods are used to address a biological problem. In class, the teacher presents only some background material and spends most of the time stimulating and steering the discussion towards critically analyzing and understanding the paper. In the last few classes of the course, students take over as discussion leaders. It is inspiring to see how quickly students develop the leadership skills needed to be a professor!

Science is about imagination, creation, and passion. Interdisciplinary research relies even more on these characteristics. Unfortunately, the Chinese education system is exam-centric. Having always been told to focus on achieving that high score in an examination, imagination and creativity is curbed in most students. The biggest challenge we face is how to create an education and research environment that fosters imagination, creativity and passion in our students. One possibility is self-education. Together with the "Frontiers in Life Sciences" program of University of Paris and with the University of California at San Francisco, we organize brainstorming workshops. Students form small groups where they discuss scientific problems they wish to solve and scientific technologies they wish to create. Professors guide the students, pointing out existing technologies. Several good ideas are generated in the workshop, students become excited about the sciences, and they realize their research potential.

The iGEM (International Genetically Engineered Machine Competition) program is another method of self-education. The iGEM competition is an international program that encourages undergraduate and graduate students to independently create a functional biological machine. This program is included in our curricula and involves two sections: brainstorming and experimental realization. The brainstorming section lasts for three months. During this time, the students are asked to gather basic information regarding synthetic biology, on the basis of which they propose their dream machines. Following this, students vote for the best idea. After three rounds of voting, heated discussions and a lot of compromise, a final project is decided upon. The experimental work then begins, with students having just five months to complete their designs for participation in iGEM. This highly competitive environment sparks students' creativity and generates excellent ideas for synthetic biology research. In fact, the synthetic biology program at CQB is largely based on the creative ideas generated during the iGEM process.

In summary, over a period greater than ten years, we have accumulated much experience that has helped us design a cradle for future quantitative biologists. As science advances, the boundaries of traditional disciplines will become increasingly blurred; creating new training programs to meet new challenges and opportunities will be an on-going task for us educators.

AUTHOR INFORMATION

Corresponding Author

*E-mail: qi@pku.edu.cn.

Notes

The authors declare no competing financial interest.