Discovery-based Functional Genomics Laboratory for Biology Program

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ABSTRACT

At HKUST, the biological science programs are often the pride of our faculty members and graduates. Our active and productive research is often cited as a major achievement in Hong Kong. Our current practice in both the Biology and Biochemistry departments is to provide undergraduates with laboratory experience mostly through large class laboratory courses. The exercises performed there are often well planned out, using specific cookbook-like manuals. Students lack the opportunity to conduct or experience research until they reach their final year. It is only in their final year project that they can do this through apprentice-style research training.

To increase the quality and range of training for our biology students beyond subject disciplines – and using an integrative approach - we launched a discovery-based molecular genetics course funded by the Center for Enhanced Learning and Teaching. This course enabled first year undergraduate students to gain hands-on experience in conducting experiments with undefined outcomes. They started with a genetic mutant screen with the nematode, C. elegans looking for a broad spectrum of developmental defects. The use of this simple model organism offers flexibility to explore a range of biological features. Students then characterized the screened mutant of their choice by developing their own hypotheses and, with the advice of post-graduates, critically thought out their research foci and strategy. The students were all enthusiastic and self-motivated about their individual projects. Within a short space of time, they learned different genetic, molecular and cellular techniques, bioinformatics as well as literature mining.

Another aspect of training involved the learning of time management. This was an extracurricular course taking up considerable amount of out-of-class time. Typically each student spent around 10-15 hours a week on it. Experiments had to be planned carefully, since live animal experiments could only be done at certain developmental stages of the samples.

The course was run for four semesters with a small class size of around five to six making it possible for weekly one-to-one mentoring with post-graduates. One instructor was positioned full-time in the laboratory to facilitate continuous guidance. Students were *allowed to take from one semester to all three semesters, with informal one-on-one meetings, a biweekly group meeting, journal club and a formal presentation after each semester. At the end of the last semester, they had to write up a scientific report summarizing their work.*

This type of discovery-based training is unique in Hong Kong. It provides students anticipating a research career with a glimpse of the research lab operation. Our functional genomics laboratory course was such a success that it has been incorporated into a new interdisciplinary program for elite science students.

Keywords

Discovery-based learning, freshman undergraduate research, independent projects

INTRODUCTION

Discovery-based science education has been deemed an effective way to arouse students' interest in science education (1, 2). However, it has not been actively pursued in local or other tertiary institutions in the region since the effectiveness of such a program can only be evaluated over a long period of time and is often viewed as a project that demands both heavy human resources and supporting facilities.

Nevertheless, setting up such a program is not impossible. With funding from the Howard Hughes Medical Institute, problem-based courses have been developed since the end of the last century[1]. Successful projects involving a small group of students with one-to-one supervision have made their way into the regular university curriculum at the University of Delaware and the University of Alabama. Indeed, a similar project, but on a larger scale, has been launched at the University of California, Los Angeles under the support of the UC system and the HHMI[2]. In that study, close to 100 students successfully engaged in a genetic research course with a focus on fly eye development. It was run throughout the year[3]. We saw that the same model could be adapted at HKUST, should sufficient interest be identified in the program development team and the students themselves.

As members of a curriculum development team, we saw that many of our students deserved an earlier exposure to research experience. This notion was obviously echoed by our university administrators who launched the President Cup competition in 2002 to promote cross-disciplinary research and an Undergraduate Research Opportunity Program (UROP) in 2005 to provide additional incentives for students to work on research projects. The response to these activities was overwhelming. We saw through the UROP exercise that there was a huge demand from students, and such a research-oriented laboratory course would be welcome by them should they be thinking early on of developing a research career or to explore their interest in research. Such a course would complement the existing teaching laboratory courses run in large classes using a more traditional cookbook–style approach.

Project Objectives

In this project, we aimed to find out whether a discovery-based teaching approach could complement current traditional large class laboratory teaching, and see what it takes to implement such an approach. For simplicity's sake in this pilot project and to allow flexibility to develop a wide range of derived research projects, we initially adopted a large-scale genetic study. Such a genetic screen typically conducted in the research laboratory, using the nematode as the model organism, would offer no restrictions on the area selected for follow-up experiments. Students could develop their own directions of research interest and gain unique laboratory experience under the confined framework of a biological question. The training ranged from genetics, cellular and molecular biology, biochemistry and developmental biology to bioinformatics and behavioral science. They could develop their own hypotheses and make decisions about the appropriate experiments under the guidance of the instructor and teaching assistants.

Lab space, basic equipment/facilities and managerial assistance were required for the operation of the project. Its specific objectives included:
(A) setting up a small functional teaching/research lab facility with a research capability for 10-15 undergraduate students and test running this genetics course
(B) producing an experimental manual with multiple chapters, each of which is dedicated to a specific experimental approach/technique
(C) understanding specific issues of the operation of this course, to streamline the administration, to solve the problems encountered and to develop a scaled-up version for long term implementation in our biology curriculum

The course involved conducting a genetic screen of a microscopic nematode, *C. elegans*, to identify mutants with specific developmental defects. Each student went through the "discovering" process by isolating their own mutants in a mutant screen. Since each student had his/her own mutant, this gave them a sense of ownership and enhanced their motivation towards learning and characterizing their own subjects. The students learned various molecular biology and genetic techniques by doing actual research. Before this course, we did not have a laboratory dedicated to such combined genetics, cellular and molecular studies. Test running also served as a pilot scheme to teach genetics with a more integrative approach, which at the same time promotes enthusiasm and helps develop an inquisitive mindset.

Course Format

There were three connected parts to the course, starting with BIOL200 A in the first semester taken in the first or second year, whereby students could choose to continue with 200 B and C in the following semesters (Figure 1). Two credits were assigned for each course with a pass or fail grade. We did not introduce a letter grade here to avoid imposing a strong criteria-dependent assessment of their achievement. Instead, we aimed for the acquisition of the ability to be independent during research, which was monitored through various evaluation tools, such as group discussion, literature reading, project presentation, instructor-student communication, etc. On completion, three complete rounds of the course were run for BIOL200 A, B and C.

The participating students were initially selected based on their academic performance and this was followed by a brief interview after a prior course briefing session. The purpose of this selection interview was not to identify elite students, but to ensure that all participating students were committed to the course as part of their extra-curricular time. In doing this, we ensured that there was no need to cope with students who came and went semester by semester, which would have made the evaluation of the operation difficult.

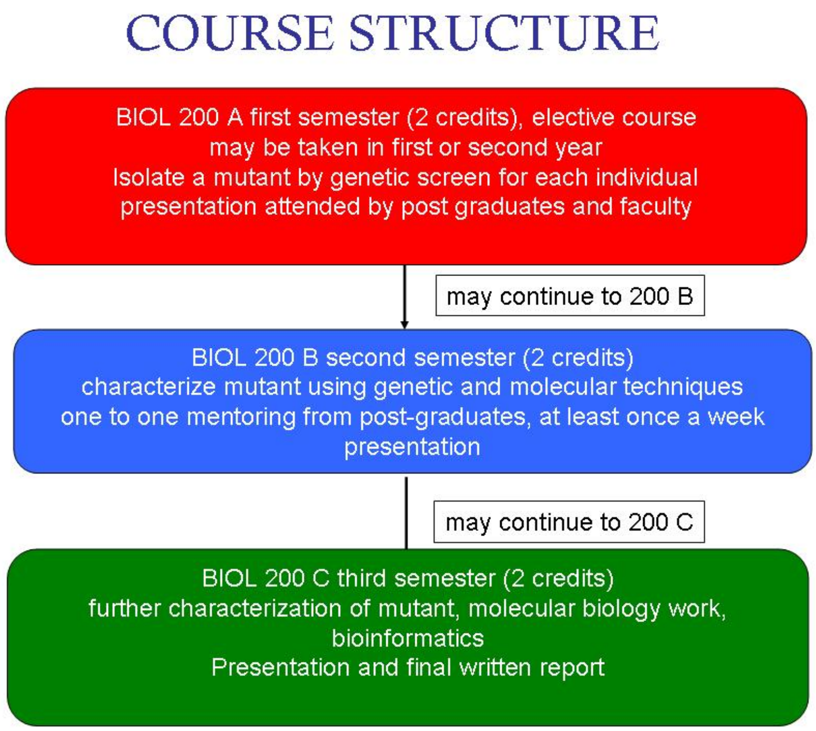

Figure 1 Course structure.

After students screened and identified a mutant, they had to characterize the mutant with help from their post-graduate teaching assistants (TAs), instructor and Principal Investigator (PI) in charge of this project (Figure 2).

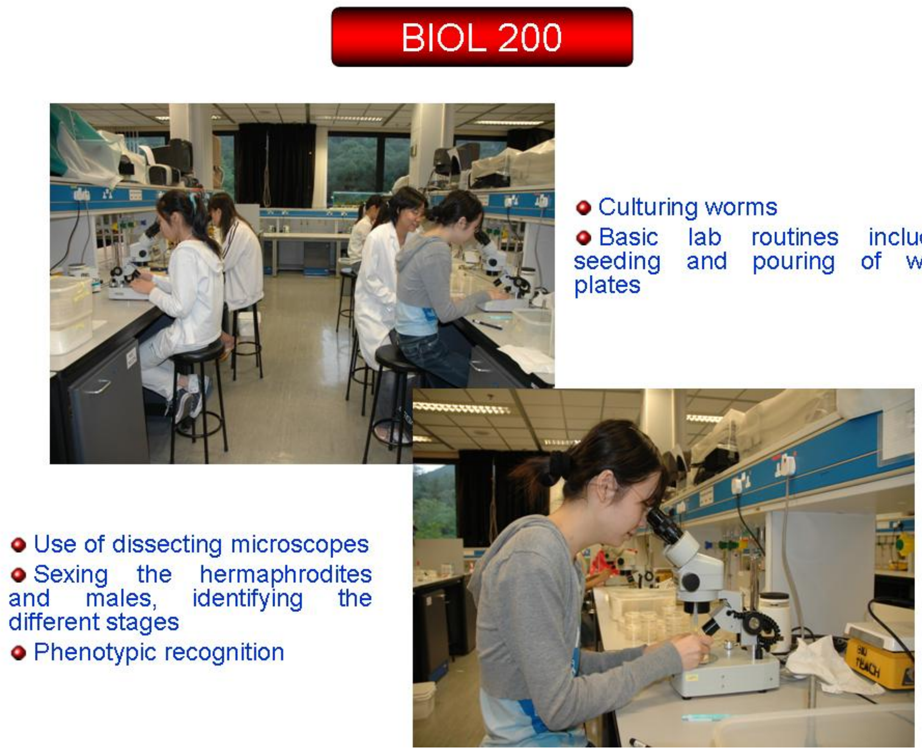

Figure 2. Students working in the lab trying to identify their favorite mutants.

In the genetic screens, five students generated 50 mutants after two rounds of screening. The intake of students was kept low to keep the course manageable. Some did not continuously take all three courses, because they had to participate in an exchange program abroad. This did not affect their research project, however, since the worms were frozen and thawed out again when they returned. A laboratory manual was written to help students design their experiments. The instructor was based in the laboratory and helped with technical problems. Advice was given for the direction of research from preparation, planning to gathering data, documentation, evaluation, interpretation and finally a presentation, from TAs who acted as mentors. A weekly discussion was initiated between the mentor TA and student pairs. A journal club was held bi-weekly in which the students were set a topic for discussion in the first semester related to genetics in general. In the second semester students were allowed to choose any topic to broaden their scope of reading in science. At the end of each semester, they had to present their results in an oral presentation session, and post-graduate students, professors from the department, the Dean of Science and evaluators from CELT (the Center For Enhanced Learning and Teaching) were invited to attend. At the end of the three courses, a formal written report was required for documentation, and more importantly to enhance their scientific writing skills.

Evaluation

Two interviews were held in the Spring semesters of 2006 and 2007 by CELT evaluators in separate sessions with the students, PI, instructor and TAs. Informal discussions between the students and the PI were also held throughout the semester.

In general, the students said they had developed a totally new perspective in research through the course. They learned how to be patient, to focus on the subject of study, to ask precise scientific questions, learning to think critically, how to cope with problems and frustrations and to come up with a solution. They all indicated that they had made a significant improvement over the length of this project in coping with such issues which demand independence, organizational skills, literature research, communication/presentation skills, and most importantly time management. Time management was an important factor since they had to fit the research work into their schedules. During the examination periods, it was quite difficult to spend the desired amount of time on their research projects. Outside these times however, students felt they were quite self-motivated and wanted to engage in the experimental work in the laboratory as much as they could.

The exposure to research literature also opened their minds in terms of the preparation of basic knowledge and the demand of both the depth and breadth of understanding. The bi-weekly journal club helped tremendously to enforce this aspect and brought about encouraging results. The end-of-semester oral presentations as well as the lab reports were important for the students to learn how to convey scientific information in a succinct manner with sufficient elaboration.

As a result, students enjoyed their research experience so much they have all selected to join research labs in their final year.

It proved a good learning experience for the TAs as well, since this was the first time many had acted as mentors. They learned how to lead the student to think instead of giving out the answers straight away. This experience enabled TAs to appreciate what education was about from a totally different perspective and to have a better understanding of the student and PI relationship. The experience offered them a good opportunity in personal growth as well as some essential skills to enhance their own career development should they be considering a research career.

A poster describing the course was presented at an international conference of the Society of Developmental Biology (2006) in the education section, to promote discovery based teaching. It was assembled together with a number of presentations from various institutions on the theme of promoting undergraduate education through research activities, and it was well received.

Problems Encountered

No project in its first trial would run smoothly without encountering some difficulties. We had to overcome major hurdles, including space and personnel issues.

Laboratory Space - The set up of the lab took time with administrative measures, funding equipment, etc. needing to be initiated. Thus, the laboratory was not ready from the very beginning and the project was pilot-run in the existing teaching lab shared with other teaching activities. Such an arrangement made it difficult for students to do their experiments whenever they wanted since they did not have their own lab. They were required to work their experimental schedule into available time slots throughout the week. The operation of the teaching lab under the management of the teaching technician team was more restrictive than regular office hours. Both these problems resulted in a slow start, when only limited time could be fitted in for experimental work. Eventually, a research lab was renovated specifically for this course, where students had the freedom to come in to do experiments any time during the day. The new laboratory was used as a place where students could spend time when they did not have classes. The arrangement promoted more interaction and discussion among the students on various scientific and academic issues. It served as an additional function, not considered as one of the objectives when this project was conceived.

TA/student Meetings - The undergraduate project students did not meet with the TAs as often as planned since it was up to the individual students to schedule the meetings with their TAs who were stationed in their own research lab on a different floor. Students found it more convenient sometimes to consult with the instructor who was based in the laboratory. The physical separation also prevented the TAs from visiting them often. Thus, some discussion sessions might need to be implemented should this physical isolation problem not be resolved. It is also conceivable that when the course develops over time, the continued supply of TAs with the appropriate background knowledge to act as mentors could be a problem. Each student is developing his or her own project, which may not necessarily match with the specialty of graduate students assigned as TAs. The training of versatile TAs could turn into a demanding task, although it is not insurmountable. Recruitment of permanent TAs trained in research using the different genetic model organisms used in this course would be the ultimate solution. Having senior undergraduates to participate in the mentoring process of juniors would also be beneficial. These measures should be considered in the next phase of the project's development.

Development of more discovery-based courses

Due to the course's success and the convincing educational rationale behind it, the project has been well recognized, and has been incorporated into the new Molecular Biomedical Sciences undergraduate program. This new mode of operation provides an elite program for students wanting a career in research and, as a discovery-based genetics course, gives them a head's start in conducting research as a freshman. To sustain the course and to further develop the program to include diversity of exposure apart from the worm module, additional modules using yeast and zebrafish will be developed as an extension package. This means other members of the Biology, Biochemistry and Chemistry Departments will be involved. This program should be a major attraction for students wishing to follow a career in science and should be sustainable when the four-year system is in place by 2012.

Since our university's mission is to train students to solve real life problems, provision of more opportunities for students to learn in novel ways is in demand. While participation and support from all levels of the institution are required in designing new learning approaches, staff commitment is essential. At this point, the high workload in designing discovery-based courses is inhibiting to faculty engagement in the process. Institutional commitment may help in terms of allocating the necessary resources, including manpower, funding and available teaching space, to support effective teaching. It will provide additional incentive for faculty to develop more courses that include undergraduate research in junior or sophomore years. Moreover, to expand this discovery based teaching mode into more and larger classes, it is of the utmost importance to have this pedagogy promoted and integrated into the institution's strategic academic plan. It is only in this way that we will we be able to ensure sustainability and long-term impact.

In summary, we have shown that it is feasible to set up a discovery-based course with limited resources to nurture a small cohort of students with a research interest. At the early university years, they can engage in active research driven by their own interest, instead of serving as followers. The sense of ownership of the project certainly provides a strong driving force for their pursuit of knowledge and to better equip themselves. While this discovery-based course is unique in Hong Kong's tertiary education, we strongly believe in the effectiveness of this pedagogy to develop scientific curiosity and bring the best out of our students. We hope that with its success, more discovery-based courses will be developed in our university as well as other universities in the region. When the four-year tertiary education system kicks in, more room is bound to be available for the growth and maturation of this teaching mode.

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