How to teach students to gain an understanding of genetics—thinking as a geneticist

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Abstract

This paper presents some proposals relating to the development of students' understanding of genetics. It briefly introduces the characteristics of Nanjing University and genetics and gives five reasons why we need to reform our teaching in China. It covers what I have done in China and what I have learned at The University of Sydney but focuses predominantly on what I want to do in China in the future.

Introduction

Nanjing University (NJU) is one of the most well-known universities in China. It is a key comprehensive university, and is ranked third to sixth among over 1000 universities in China. With 17 schools and 47 departments, NJU is running 70 undergraduate programs, 180 master's degree programs and 116 PhD programs. The university has 28 national key disciplines, 7 national key laboratories and 18 post-doctoral stations. NJU benefits from the concentration of scientists with national and international reknown and talented young and middle-aged scholars. Of the University's 2000 faculty members, more than 1,250 are professors and associate professors, among whom 23 are members of the Chinese Academy of Sciences, three are members of the Chinese Academy of Engineering and three are Fellows of the Third World Academy of Sciences. NJU provides a good environment for teaching and research. With a fine school tradition of 'being rigorous, truthful, diligent, and innovative', NJU implements the teaching policy of 'providing an all-round training, consolidating foundation, teaching according to students' aptitude, and building up vitality'. Its graduates have been known for their 'high starting point, solid foundation and great potential'. In 2004 NJU has 12,715 undergraduates and 8685 postgraduates. Many of them are excellent: some are talented. In our department, after graduation, 20% of undergraduates go abroad for further study, especially to the USA, 60% of them undertake a master's degree in China, the remaining 20% find employment (Nanjing University 2004).

Genetics is an interesting, but very difficult and analytical discipline. According to the students, genetics is the biggest challenge that they have encountered in their biological study, and I think it's also a big challenge for teachers. Genetics is an ongoing subject and one of the fastest developing subjects. Every year governments and pharmaceutical companies invest billions of dollars on research in genetics. Therefore new knowledge is generated every week. Some of the knowledge, such as the cloning of Dolly the sheep, the human genome project and gene therapy, are becoming familiar to the public. The coverage of genetics becomes larger and larger. Genetics has close connections with our everyday lives, and relates to medicine, agriculture, industry, technology, as well as ethics. Thus our students need to solve problems in the real world. Genetics also requires intellectual richness for people who learn and teach genetics and deal with the genetic problems. Sometimes it may be a real intellectual game for students. Besides an intellectual mind, other necessary skills are thinking, analysing and understanding: these are also the main goals in genetics teaching.

Genetics has different layers, ranging from molecular, chromosomal, cellular, tissue, developmental, population to evolutionary levels. Meanwhile genetics deals with different model organisms such as *E.coli*, bread yeast, *Zea mays*, *Drosophila*, mouse and *Homo sapiens*, as well as different life cycles (Ringo 2004). All these aspects make genetics more difficult to learn by the students and to teach by the teachers.

In my university, *Genetics* is a core course for third year students. It includes 54 lecture hours and 54 laboratory hours in one semester. Every year around 100 students with a good general biology background undertake this course. Eighty percent of them are from my department and 20% are from the Department of Intensive Instruction, which is one of the most famous departments in my university, and most of these students are talented.

Why do we need to reform our teaching in China?

Soon after we arrived in Sydney, in one seminar we were asked how do we conduct assessments in our courses. We listed assessment activities such as quizzes, examinations, assignments and attendance. Then we were asked which assessments are given to us? We listed personality, performance, opinions of other people, acceptance by the scientific community, research funding, publications and awards. After comparing the two lists, I realised that we need to motivate the students to learn many useful skills, such as lifelong learning skills, problem-solving skills, critical thinking skills, self-assessment skills, and self-directed learning skills. We can only teach the students for four years, in the following 40 or 50 years they must learn independently. As members of a 'top' university, some of my students want to go abroad for further study after they graduate. If they can master more of the new learning methods in China, they will benefit by adapting quicker to learning in a foreign country.

Most significantly, we need to teach students cooperation and communication skills. In my opinion, in western countries, students studying in secondary school accept cooperative education. In China, the students in middle school accept competitive education. However, globally universities advocate cooperative education and it is being adopted universally. So when they enter university, western students are more easily able to adapt to university education patterns. Chinese students often have more difficulty in adapting to them. Thus, we need to facilitate the transfer from competitive education to cooperative education.

Today we live in an era of ever-greater explosion of information in the history of human beings, the coverage of genetics becomes larger and larger, and the course curriculum expands accordingly (Griffiths and Mayer-Smith 2000). What should we teach our students? How should we arrange the curriculum of genetics? Last year when the genetics course finished, I revised my final examination. I gave only 10 questions for which 3 hours were allowed for answering them. When the students took their examination, I prepared the key points of the answer. To my surprise, I spent about 80 minutes preparing the answer guide. As an expert and knowing the answers to these problems, writing these answers out in a clear and logical way took almost half of the time the students had been allotted. Obviously, I had to ponder how I should change the situation. Now after I have studied here, I realise that I should eliminate selected topics from curriculum. After I return to China, reforming the curriculum is an urgent task. How to do it?: less is more.

The next reason we should reform our teaching is that teachers often teach what they are interested in and what they think is important, and sometimes what they teach is mainly facts, not knowledge and this may not be what students want to learn.

In my opinion, the facts do not equal knowledge. Here is an example. Bacteria can be divided into two types according to Gram's staining. One type is gram positive bacteria which develop a purple color after staining; the other type is gram negative bacteria which develop a red or a yellow colour. All of these are facts, but not knowledge. Why do bacteria develop different colours when staining? How are these facts related to the cell wall structure of different bacteria? How can we use this fact? I think the answers to these questions are knowledge.

For many students, accumulating a mass of facts about science is science, and scientists are people who know a great number of facts. Why do they think this? I think it's because we as teachers act as role models in presenting the material to the students, and we expose students to many facts, not real knowledge. It's time to change our students' view.

Finally, we need to stimulate the talented students to develop, and encourage the less able students to catch up.

What have I done?

Although we have so many reasons to reform, what we have done is not enough. Sometimes we want to attempt reform, but we really don't know how; sometimes we haven't enough time, because our research also demands time.

When I give a lecture the students just copy down their notes without thinking about what they mean. Actually the content of the notes is available in their textbooks. Shortly after their examinations, 99% of what had been taught was forgotten. Lecture-based teaching may also explain why some successful undergraduates who enter our graduate programs arrive with limited ideas of how to solve a practical scientific problem.

But the reality is that some students like to memorise and recall information in a simple, enjoyable and painless way. However, with this attitude, students can't be questioning and creative scientists. Having accepted this point of view, I made some changes to my teaching.

Firstly I introduced an excellent foreign textbooks to my teaching. I studied the books carefully, and then I copied some materials for my students. In most cases, they were interested in them, and learned better than before.

Secondly, I encouraged the good students to deliver some lectures. Many biology courses such as biochemistry, cell biology and molecular biology have some content overlapping with genetics. When I taught the relevant content, I required some students to give the lecture to the whole class (having had 2-3 weeks to prepare the lecture).

I also encouraged my students to do research—a real research project. I visited my colleagues, asking them if they needed students to work for them without pay. Last year about 30-40% of my students went to laboratories working for my colleagues. All the students commented that they gained so much and very much enjoyed the experience.

I also conducted peer assessment in my laboratory course. Forty per cent of the students' final marks were determined by their classmates. This approach stimulates students to do self-assessment. They knew how to evaluate each other's work, and also knew how to assess themselves. This will be quite useful in their lifelong learning (Norton, Tilley, Newstead and Franklyn-Stokes 2001)

Meanwhile, I used modern multimedia techniques in my lectures and increased the laboratory time, especially emphasising the laboratory skills.

All these initiatives have been useful in improving my students' learning, but they are not enough.

What have I learned here?

During my time at The University of Sydney, I attended many wonderful seminars and harvested so much. The most important thing is that I have changed my ideas about teaching. I know now that we must make the move from teacher-centred learning to student-centred learning, from behaviourist to constructivist, we must lead our students from passive learning to active learning, from university learning to lifelong learning, and from individual learning to group learning. I also learnt that we can never please everyone; the responsibility of learning is the learner's; the things that really contribute to successful learning are motivation in the learner, interest for the learner and relevance to the learner.

I have learned constructivism theory and methods, such as concept mapping, problem-based learning (Woods 1994), case studies, workshop tutorials (Sharma Miller and Seth 1999), group discussion, and, importantly, we should integrate all of these.

What do I want to do next?

Firstly, I must always remind myself that although my own focus is often the teaching, my objective is developing students' understanding.

Secondly, I'll present the essential learning outcomes of genetics to students. Why do I do this? Because students are often not clear about which parts of the course content represent essential core genetic knowledge and skills, and which parts are secondary. At the same time, a list of learning outcomes can serve diagnostic and remediation purposes to address the students' learning weaknesses.

Here is an example of outcomes relating to quantitative genetics (Griffiths and Mayer-Smith, 2001):

- calculate various statistics relevant to quantitative variation;
- calculate broad sense heritability from F1 to F2 variance, and from correlations between relatives;
- calculate narrow sense heritability from selection differential;
- discuss the relevance of heritability measurements to quantitative human behavioral phenotypes;
- identify QTLs from data;
- map a QTL from data; and
- calculate phenotypic ratios of phenotypes determined by polygenes/QTLs.

The third approach is that I will use concept mapping which has been proven to be a very useful skill for students and for teachers. Using concept mapping, students can deconstruct and reconstruct relevant mental models. There are many papers discussing the advantages of concept mapping (White and Gunstone 1992). Why should I want to use concept mapping? Firstly, the content of genetics is so difficult for the students to organise. Secondly, in genetics, the area of learning in which students need the most help is not in acquiring the facts of a subject, but in using these facts.

Figure 1 is a concept map of gene transcription and translation. All these concepts are important and fundamental for the understanding of biology.

Another strategy I'll use is problem-based learning (PBL). PBL is a very useful strategy. For the teachers, PBL makes the transition from the teacher as information-giver to the teacher as a coach, which is challenging and requires learning many new skills; it also requires a sound understanding of problem-based learning, curriculum, and suitable assessment for the teacher to design problem scenarios, but learning in a PBL environment is exciting for students and rewarding for teachers.

For the student, the related issues are:

- students who can be turned off by more traditional approaches can emerge as active, engaged learners;
- students can talk about a topic in depth, not simply answer factual questions;
- students ask for targetted lessons about what they need to know to solve a problem;
- students ask good questions that reflect an understanding deeper than any response to a teacher can demonstrate;
- students know how to locate, evaluate, and use information effectively; and, of course
- students learn and perform well on content tests.

Here is an example to show how to organise a PBL activity.

First, I will state the problem.
One day a woman was murdered in an apartment in Beijing. There was a lot of blood in the room. After receiving a request from the police, you, an expert of genetics, need to help them eliminate/confirm the suspect using modern DNA techniques.

Then, I would divide the class into groups, each group with one judge, two prosecutors and two defense attorneys (role play). Each student should have a copy of the case and copies of the raw DNA profiles (this requires students to

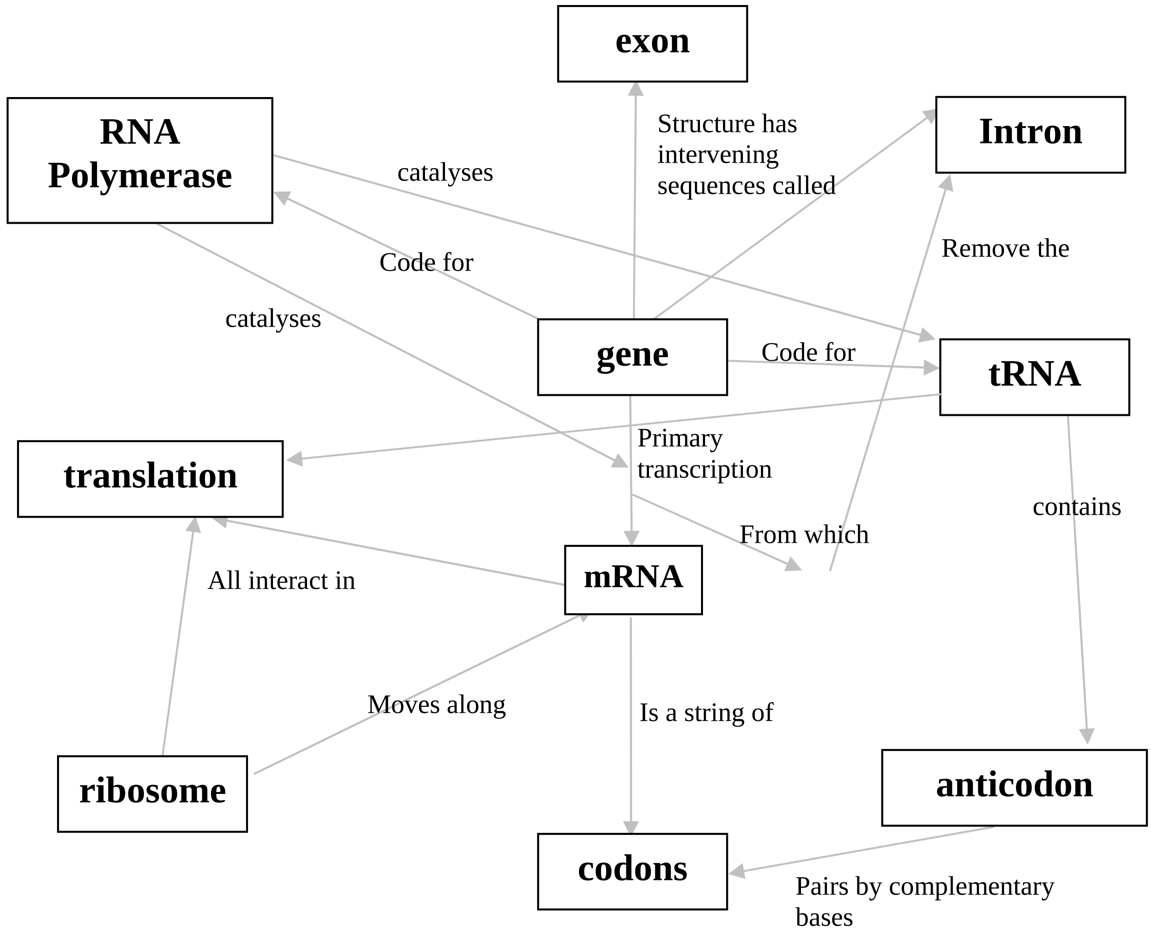

Figure 1. The concept map of gene, transcription and translation

obtain a selection of DNA-typing profiles such as Restriction Fragment Length Polymorphism (RFLP) autorads, Small Tandem Repeats (STR) electrophoretograms from the local police).

Each side (prosecutors/defense) must argue the evidence before the judge.

The third step is that students submit a brief written report along with a written decision from the judge to the instructor, and give an oral presentation.

This PBL demands that students help each other to thoroughly understand the genetics, and the proceedings should result in a more enjoyable learning experience. It is desirable to introduce some complexity, for example we included an autorad from blood off a knife that contained specimens from several people.

Finally, obtain feedback from the students.

The other techniques I want to develop include establishing collaborative study groups for improving university genetics teaching and learning, introducing web-based learning, and seeking suitable assessments.

Conclusion

Genetics is perhaps the biggest challenge that students encounter in their biology learning. It's also a big challenge for the teachers to teach. In order to motivate the students to develop lifelong learning skills, problem solving skills, critical thinking skills, self-assessment skills, self-directed learning skills, communication skills and cooperation skills, reform of teaching and learning is necessary in China. The objective is to transform teacher-centred learning to student-centred learning.

I have changed some of my ideas about teaching and learning and learned some significant constructivism theory and methods. After I return to China, I will practice as a constructivist by mixing approaches such as concept mapping, problem-based learning, case studies, workshops and so on, in order to enhance my students' understanding of genetics and cultivate their abilities to think like geneticists.

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