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# Learning developmental biology has priority in the life sciences curriculum in Singapore

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**ABSTRACT** **Singapore has embraced the life sciences as an important discipline to be emphasized in schools and universities. This is part of the nation's strategic move towards a knowledge-based economy, with the life sciences poised as a new engine for economic growth. In the life sciences, the area of developmental biology is of prime interest, since it is not just intriguing for students to know how a single cell can give rise to a complex, coordinated, functional life that is multicellular and multifaceted, but more importantly, there is much in developmental biology that can have biomedical implications. At different levels in the Singapore educational system, students are exposed to various aspects of developmental biology. The author has given many guest lectures to secondary (ages 12-16) and high school (ages 17-18) students to enthuse them about topics such as embryo cloning and stem cell biology. At the university level, some selected topics in developmental biology are part of a broader course which caters for students not majoring in the life sciences, so that they will learn to comprehend how development takes place and the significance of the knowledge and impacts of the technologies derived in the field. For students majoring in the life sciences, the subject is taught progressively in years two and three, so that students will gain specialist knowledge in developmental biology. As they learn, students are exposed to concepts, principles and mechanisms that underlie development. Different model organisms are studied to demonstrate the rapid advances in this field and to show the interconnectivity of developmental themes among living things. The course inevitably touches on life and death matters, and the social and ethical implications of recent technologies which enable scientists to manipulate life are discussed accordingly, either in class, in a discussion forum, or through essay writing.**

KEY WORDS: *embryology, life science, curriculum, education, developmental biology*

## Background Information

### *Scholarly Interests of the Author*

The author does his research in the field of developmental biology. He has worked on the subjects of neuronal development in chick and zebrafish embryos and pigment pattern formation on fish epidermis; more recently he has focused on the other end of development - aging. He is now studying neuronal cell death triggered by age-related apoptosis that leads to neuronal degeneration.

### *Representative Publications*

The author has been involved in the compilation of the *Life Sciences Guide Book* for upper secondary and preuniversity levels (ages 15-18), published in 2001 by the Curriculum Planning and Development Division, Ministry of Education, Singapore. The guidebook contents serve as resource materials to help teachers integrate elements of the life sciences into the various science disciplines. As developmental biology is multifaceted, the life sciences interface with the domains of chemistry, physics, mathematics, computer science, materials science, engineering, and even philosophy, moral reasoning and ethics. It is the author's belief that students should learn to see the connectivity in depth and breadth among various fields so that they can appreciate and integrate complex issues such as those from embryonic development to life and death. The author is also involved in the development of an e-learning package for high school biology teaching. He serves on committees set up by the Ministry of Education to advise on life sciences curriculum review and implementation issues. He has organized many life sciences teaching workshops for teachers and parents.

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***General Teaching Philosophy***

As developmental biology often involves complex mechanisms and morphogenetic events, the author always encourages students to picture how embryogenesis takes place using imagination, schematics, improvised props and body language. Once the students can figure out for themselves how microscopic and molecular events take effect in an embryo, they will find it easy to follow through scientific experiments and hence gain a grasp of hypotheses and theories proposed in the ever-expanding field of developmental biology. Students are also expected to learn through self-directed study: students propose a topic of interest to research in depth and then present to fellow students in a seminar format. The author believes in learning through communicating ideas and asking questions. The scope of developmental biology is very large and it is expanding rapidly. He therefore challenges students to learn beyond what is taught in the course, and he practices a Confucian way of teaching: "Given one example, students are to bring back three more." The teaching philosophy of the author can be summarized simply as "To provide students with a firm foundation and make them so interested in the subject that they will be intrigued and want to learn more even after the course has ended."

**Fig. 1. Studying three-dimensional embryo models helps students understand two-dimensional pictures presented in textbooks.**

The author has taught developmental biology to university undergraduates for more than 13 years. He has also given many guest lectures to schools to enthuse students about the life sciences, especially through developmental biology topics such as embryo cloning, genetically modified organisms, stem cell biology, tissue engineering, and aging and anti-aging. He believes in bringing out the beauty of developmental biology, and that the powerful technologies associated with knowledge of developmental biology will intrinsically amaze students.

## General Features of the Developmental Biology Course

Two categories of students study developmental biology at the National University of Singapore. The first comprises students who are part of the University Scholar Program, which enables bright students to learn cross-disciplinary subjects spanning a wide range of interests. In teaching such students, who often are without prior knowledge of biology, the purpose is to help them comprehend how each of them as a multicellular individual developed from a single fertilized egg. Through the amazing journey of embryonic development, these students come to understand themselves better as a biological entity, and hence to value life more from a biological perspective. In the subject module named "The Biomolecular Revolution," they are introduced the principles of molecular genetics, and they learn how genetic engineering and associated technologies are used to alter development and enhance life. These students can take the subject module anytime during their three or four years in the university, and there is no prerequisite other than that they must qualify for the University Scholar Program. There are, on average, 60 students per cohort.

The bulk of students learning developmental biology are those who are majoring in the life sciences. The course is taught during years two and three of the university life sciences curriculum. In year two, developmental biology is covered under Cell Biology, whereas in year three, a stand-alone module named "Developmental Biology" is offered. The year-three module integrates both animal and plant development. The course aims to teach students scientific approaches to the study of embryonic development using model organisms; and to enable them to link molecular genetics to the development of morphology, structure and function in a plant or animal. The class size has increased in recent years from about 40 to close to 100 per cohort. The recent emphasis on the life sciences in Singapore will likely result in a further increase in enrollment, perhaps to as many as 300 per cohort.

Students taking developmental biology as part of their major in the life sciences must have taken and passed modules in genetics, molecular biology, cell biology and general physiology at the first- and second-year level. Chemistry and biochemistry at the first-year level are also compulsory modules that a life sciences major should also pass before moving on to higher level modules. Hence, students entering year three should have a relatively strong foundation in all of the areas mentioned above.

## Course Structure and Content

The two modules, "The Biomolecular Revolution" and "Developmental Biology," are each worth 4 modular credits, and each is composed of 26 lecture hours, 18 laboratory or seminar project hours, and 6 tutorial hours. Only the former module has small group learning sessions, and the course content covering developmental biology is about half the total of 50 hours, with the other half covering principles in molecular biology and genetics. Because of the large number of students in the year-three "Developmental

Biology" module, the past practice of small group learning has recently been terminated and replaced with student miniprojects and term papers. In both modules, lectures are delivered in a lecture theatre as PowerPoint presentations. The university has an Integrated Virtual Learning Environment (IVLE) system that allows intranet users to log on via the university Web site. Students can download all lecture presentations through the net. In addition, there are also online forum discussions posted by teachers and students in the IVLE.

In "The Biomolecular Revolution" module, developmental biology is taught as a journey, starting from the meeting of sperm and egg, to the formation of the embryo, to birth and then death. Students are taught the specialized organization of the sex cells and how they employ unique strategies to ensure their successful union. Students then follow the saga of embryogenesis from cleavage, to gastrulation and neurulation, and then to axis and pattern formation and organ development. Some fascinating concepts such as positional information, embryonic induction and competence are introduced along the way. Many of these embryonic events are illustrated with selected video presentations produced by the British Broadcasting Corporation or the British Open University, or purchased from the Carolina Biological Supply Company.

The study of developmental biology passed its centenary mark some years ago. In the past 15 to 20 years, rapid advancements have been made in the understanding of how genes control development. Genes involved in shaping an embryo are introduced to the students as maternal and zygotic genes. Using *Drosophila* as a model, some of the established molecular epistatic events are illustrated. Relevant homologous systems in mammals and other vertebrates are also highlighted to demonstrate the significance of such genes. Bearing in mind that students taking "The Biomolecular Revolution" are without a strong foundation in biology, the above topics are approached with much deliberate explanation of basic molecular biology. The subsequent portions covered in the module are purposely slanted toward the understanding of technology applications, and how the advent of transgenics and embryo cloning has social and ethical implications in our modern world. As all the students are selected scholars in the University Scholar Program, they are expected to become learned people with adequate knowledge of the life sciences so that they can make informed assessments and decisions in the future, when they are in leadership positions.

In the year three "Developmental Biology" module, students are progressively taught the subject in depth, starting with an overview of mechanisms that enable the development of a single cellular zygote to become a multicellular individual with patterns and structures. One of the central questions about developmental mechanisms has to do with how cells endowed with all of the zygotes genes come to differ from one another and hence contribute to tissue, organ, system and pattern formation in a developing individual. Students are taught the concepts of embryonic induction, competence, positional information, embryonic field, morphogen, and gradient. The questions related to cell differentiation, determination, specification and gene expression are correspondingly dealt with at the molecular level. A separate series of lectures is also built in to the module to deal specifically with plant development, from pollination, to seed formation and embryogenesis, to leaf and flower development, including tissue culture aspects. As the lectures unfold, one after another, students are constantly reminded that there are many ways to study developmental biology, as they will discover for themselves by reading various textbooks and learning from Web-based materials.

The module covers both animal and plant development, and laboratory sessions both complement the lectures and teach specific skills. During laboratory sessions, students learn about embryonic events and developmental processes through video shows and the examination of starfish, frog, chick and mammalian embryos, either as whole-mounts or as sectioned and stained materials, or as clay models (Fig. 1). Students also learn to dissect chick embryos and to prepare whole-mount samples, after first learning how to use the intact egg as a natural culture chamber for experimentation. In another session, students use the zebrafish embryo to study developmental gene expression patterns using *in situ* hybridization methods. Staining the chromosomes from the salivary gland cells of the *Drosophila* larva is also taught in laboratory classes so that students can observe chromosome puffs and relate them to selective gene expression during development. Plant anatomy and plant tissue culture techniques are also covered in the laboratory.

The course is designed to give students a strong foundation in the basic concepts in developmental biology and to teach them how to approach the subject using various scientific methodologies. Students are stimulated to learn on their own, and the course prepares them for independent research, which they will use during their fourth year of studies, should they qualify, when they must do a thesis based on a research topic.

**Fig. 2. Students simulate embryo morphogenetic movements using Plasticine modeling clay.**

***Example of a Lab-Based Assignment***

"You have learned how to open the eggshell and observe the developing chick embryo in it and then reseal it under sterile conditions. Given a series of caffeine solutions, design and conduct an experiment to test the effect of caffeine on embryonic development. In your lab report, state your experimental hypothesis and describe your experimental design. You should divide your report into the following sections: Introduction and Objective; Materials and Methods; Results and Discussion, and References."

***Example of a Hands-On Activity to help Students learn about Gastrulation***

"Gastrulation is a very complex morphogenetic event that includes orchestrated and coordinated cell movements. In order to understand the 3-D movements that transform a ball of cells in an early embryo to an embryo that has the external, middle and innermost germ layers for organ formation, students are to use three different colors of Plasticine clay to simulate the putative ecto-, meso-, and endoderm (Fig. 2). Using your hand to provide the force needed to move cells, learn to simulate the complex process of gastrulation and convince yourself that a ball can indeed be transformed into a 3-layered structure. After the molding process, cut the "embryo" into halves and see how the three layers are positioned in relation to one another."

***Example of a Seminar Presentation Assignment***

"Read the paper from the *Nature* or *Development* journals that you have been assigned and assume you are the main author; give a 15-minute presentation to the class in a simulated symposium session. The seminars will be organized with the themes "Limb Pattern Formation," "Maternal Effect Genes" and "Embryonic Induction." You are to read and digest the contents of paper so that you can handle the Q&A after your presentation."

***Example of a Small-Group Discussion Topic***

"From genes to cells, from single cell to many cells, from cells to many cell types, from cell types to tissues, and then to organs, systems, and, finally, an individual—development is directional, and hence it is conceptually possible to draw fate maps for the cells that are taking part in development. What are possible ways of mapping the fate of cells? What is the significance of knowing the fates? How will the fate map help in scientific investigation? How can the fate of a cell be altered?"

***Examples of Writing Assignments***

Writing assignments are given with the following goals:

1. To sharpen analytical skills by moving from close reading to comparative analysis to counterargument exposition.
2. To learn how to use evidence to demonstrate and elaborate a thesis.
3. To become comfortable using scientific terms and language in writing.

**Essay 1. How has Ian Wilmut advanced our knowledge about cloning? *(What is so great about Dolly?)***

This is a short essay assignment to be typed in 2 pages, A4 size, double-spaced, font 12, Times Roman. Some materials will be given to students for close reading before writing the essay.

"Dolly the cloned sheep created headline news all over the world in the late 90s. What is she all about? What questions come to you when you read the newspaper reports on her? What do you understand or not understand about this breakthrough in life science research? This assignment is designed to trigger the student's thinking about issues that will be reflected in the final term paper. It also serves to help students focus on some technical aspects that the course will develop."

**Essay 2. Given that many of our traits and behaviors can be attributed to our genes, what is the role of nature vs. nurture? *(Is it all because of our genes?)***

This is also a short essay assignment to be typed in 2 pages, A4 size, double-spaced, font 12, Times Roman. The emphasis is on comparative analysis.

"In the lectures and from your reading, you may be impressed that many of our traits and behaviors can be attributed to our genes. What are genes and how do they affect an individual? Are we completely the result of our genetic makeup? What evidence is there to support each point of view in the nature vs nurture debate? What about novelty-seeking and risk-taking behaviors? Do some people have an innate tendency toward such behaviors or do they acquire that tendency later in life? This essay introduces another dimension that will be important for the final term paper. It may lead students to think about topics from life science to metaphysics, from technology to humanity."

**Essay 3. Proposition: advances in genetic engineering will inevitably lead to a genetic underclass. *(Genetic engineering—is there a U-turn?)***

This is the final term paper for the course. It should be written in 4 pages, A4 size, double-spaced, font 12, Times Roman. This essay should feature argument-counterargument with scientific knowledge reflected in a concise and accurate manner.

"The power for man to manipulate and to engineer genes has opened up endless possibilities by creating new "creatures." How much do you understand the science of this power and how far do you think it will take us? Are genetically modified organisms (GMO) threats to us? Is the "Brave New World" a desirable and controllable destiny? If you had the authority to chart the course of genetic engineering, how would you go about it, especially in view of current public awareness and understanding and people's feelings of hope that scientists can solve serious human problems intermixed with their fear of the moral, ethical, and practical implications of the new technologies."

***Examples of Examination Questions***

1. Many patterns in an embryo relate to morphogens or chemical gradients. What is the theory behind the action of a morphogen? Retinoic acid, a Vitamin A homologue, has been proposed as a morphogen that can affect several aspects of embryonic development. Design an experiment to test the effect of retinoic acid on the development of a tetrapod limb. In your experimental design, include the control experiment and state the hypothesis that you set out to test. Use figures or drawings when appropriate.
2. What are embryonic stem cells? What are the characteristics of stem cells? What are some potential practical applications of stem cell research? What are some of the concerns that might arise from such research? Use appropriate examples when applicable to illustrate your understanding.
3. What is your understanding of the concept "molecular epistasis"? Use appropriate example(s) to illustrate how this concept can explain embryonic development.

4. A cell in a limbbud is instructed to contribute to a part of a hand or a leg. How might the instruction(s) be passed on to the cell? You may restrict your explanation to defining a single structure such as a digit, or the upper or lower arm, or the palm or paw pad.
5. In the 1920s, Spemann and Mangold were awarded the Nobel Prize for the discovery of the "organizer." Over the past 80 years, much progress has been made in the understanding of this organizer. What do you think is the significant lesson(s) learned from this discovery journey about animal development?

## Recommended Textbooks

*Analysis of Biological Development* (1996) by Klaus Kalthoff. Publisher: McGraw-Hill.

*Developmental Biology* (1997, 5th Edition) by Scott F. Gilbert. Publisher: Sinauer.

*Human Embryology* (1993) by William J. Larsen. Publisher: Churchill Livingstone.

*Molecular Biology of the Cell* (1994, 3rd Edition) by Bruce Alberts *et al.* Publisher: Garland Publishing.

*Patten's Foundations of Embryology* (1996) by Bruce M. Carlson. Publisher: McGraw-Hill.

*Principles of Development* (1998) by Lewis Wolpert *et al.* Publisher: Current Biology Ltd.

## Visual Aids

The Science Library houses many videotapes and CD resources that cover fish, frog, chick, and human embryology, as well as some special topics such as cell movement, morphogens, differentiation, and genetic control of development. They are produced by the British Broadcasting Corporation or the British Open University, or purchased from the Carolina Biological Supply Company. An in-house produced videotape on chick embryo dissection and how to make a window in the eggshell for experimentation purposes was recorded as the author demonstrated during one laboratory session.

## Relevant WWW Addresses for Supplementary Information

http://www.res.bbsrc.ac.uk/molbio/index.html
A BEGINNER'S GUIDE TO MOLECULAR BIOLOGY

http://zygote.swarthmore.edu
A WEBSITE FOR DEVELOPMENTAL BIOLOGY

http://www.cellbio.com/
A USEFUL WEBSITE TO LINK TO MANY ON-LINE BOOKS ON CELL & MOLECULAR BIOLOGY

http://www.ucalgary.ca/UofC/eduweb/virtualembryo/
VIRTUAL EMBRYOLOGY TEXTBOOK