Int. J. Dev. Biol. 47: 105-115 (2003)

Making developmental biology relevant to undergraduates in an era of economic rationalism in Australia

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ABSTRACT This report describes the road map we followed at our university to accommodate three main factors: financial pressure within the university system; desire to enhance the learning experience of undergraduates; and motivation to increase the prominence of the discipline of developmental biology in our university. We engineered a novel, multi-year undergraduate developmental biology program which was "student-oriented," ensuring that students were continually exposed to the underlying principles and philosophy of this discipline throughout their undergraduate career. Among its key features are introductory lectures in core courses in the first year, which emphasize the relevance of developmental biology to tissue engineering, reproductive medicine, therapeutic approaches in medicine, agriculture and aquaculture. State-of-the-art animated computer graphics and images of high visual impact are also used. In addition, students are streamed into the developmental biology track in the second year, using courses like human embryology and courses shared with cell biology, which include practicals based on modern experimental approaches. Finally, fully dedicated third-year courses in developmental biology are undertaken in conjunction with stand-alone practical courses where students experience first-hand work in a research laboratory. Our philosophy is a "cradle-to-grave" approach to the education of undergraduates so as to prepare highly motivated, enthusiastic and well-educated developmental biologists for entry into graduate programs and ultimately post-doctoral research.

KEY WORDS: *education, tertiary, university, science, biology*

Background Information

Scholarly Interests of the Authors

Brian Key's research interest lies in the developing vertebrate nervous system, particularly with respect to understanding the molecular and cellular bases of axon navigation (http://www.sbms.uq.edu.au/neurodev/). He has focused his attention on two model systems: the rodent olfactory system and the *Xenopus* and zebrafish prosencephalon. The rodent olfactory system is unique in that it is the only neural region in mammals which undergoes continual cell turnover throughout life. The underlying philosophy in our investigations is that if we can understand why this region of the nervous system is so plastic, then it may provide an insight into why the rest of the mature nervous system is so refractory to regeneration and repair. His interest in the embryonic brain provides an opportunity to understand the principal mechanisms guiding growing axons in naïve immature neuroepithelium.

Victor Nurcombe is interested primarily in trying to induce stable stem-cell phenotypic development through the manipulation of the microenvironment. He has spent many years purifying and testing heparan sulfate sugars derived from precursor cells for their ability to control growth factor signalling.

Representative Publications

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0214-6282/2003/$25.00

Printed in Spain
www.ijdb.ehu.es

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A Call for Change from the Government

The Australian Government's Higher Education Funding Act of 1988 set in place a mechanism for the funding of Australia's universities with the object of securing a higher education system that was, among other things, designed to ensure "quality, diversity and equity of access" and to enhance "national economic development and international competitiveness." What was to follow has been a process of economic rationalization that has resulted in a university system that services a mass influx of "clients" and is increasingly dependent on alternate funding for its continued survival. Growth in higher education participation rates has been greatest in the 20-24 age group, rising from 23.3% in 1985 to 32.8% in 1997. In 1997 14% of the Australian population had a Bachelor's degree.

If we examine some key statistics, the image of a higher education system in trouble begins to emerge. In 1988 the base operating grant for Australian universities was $3.6 billion (all dollar values are in Australian dollars; AUS $1 is US $0.54). In 2000 this had risen to $4.9 billion. However, if this figure is seen in the light of increasing student numbers, then there has been a drop in public expenditure per student from $12,050 in 1988 to $10,367 (at 2001 constant prices). If we just focus on that part of the base operating grant that is dedicated to teaching, then the level of funding of teaching activities has actually decreased markedly from $3.9 billion in 1992 to $3.3 billion in 1999. A natural consequence of these figures has been the progressive rise in the student-staff ratio. Over the last decade of the 20th century, this ratio increased considerably from 12.9 in 1990 to 18.8 in 2000.

The University of Queensland Response

The real challenge these bleak fiscal outcomes have posed for the individual teachers of developmental biology in Australia has been to maintain academic levels of quality in an environment that has provided large class sizes, reduced staff support and inadequate facilities for state-of-the-art practical sessions. The response at the University of Queensland was initiated at faculty level and led to the revision of all undergraduate courses at the beginning of 2000. Effectively, this meant that the number of individual courses offered had to be reduced, class sizes increased, and practical content reduced. Lecturers would be expected to teach across typical academic disciplines. Curiously, this proved to be a particularly exciting time as it meant that we were no longer shackled by boundaries imposed by such classical academic departments as Entomology, Zoology, Anatomy, Physiology and Biochemistry. What followed was a struggle to make sure specific scientific (rather than traditional) disciplines were incorporated into the curriculum. The university had, more by historical coincidence than design, a solid core of young and enthusiastic biologists with strong teaching and research records in developmental biology, spread across a number of different departments and centres, including Victor Nurcombe (Anatomy and Developmental Biology), Peter Koopman (Institute of Molecular Biology, IMB, and the Department of Anatomy and Developmental Biology), Joe Rothnagel (Biochemistry and IMB), Peter Noakes (Physiology), David Merritt (Zoology), Toshi Yamada (IMB) and Bernie Degnan (Zoology). Importantly, all were "charismatic" and energetic lecturers of roughly the same age, capable of enthusing and inspiring undergraduates. This group formed an Executive to manage a cross-departmental program dedicated to developmental biology and mounted a strong case to the Faculty for Developmental Biology to be a nominated track in the Bachelor of Science curriculum. This resulted in one of us (BK) moving north from the University of Melbourne to join this burgeoning program. The enormous benefits of this dedicated group of scientists to the curriculum was aptly summarized in this excerpt from a 1998 document submitted to the university administration:

> *"Recently the developmental biologists on campus, spread over a number of Departments and Centres, have come together to discuss curriculum development. It has become apparent that opportunities for extensive collaboration exist, especially in the application of "cross-over" technology: i.e., techniques applied to one system could be used to answer outstanding questions in other systems. We tend to be younger, less impressed with artificial divides like departmental boundaries, and more concerned with disciplines. We are all concerned with a continuous supply of the very best graduate students, and getting the message out to the most talented students that this is one of the major fields for both the present and the future. We strongly believe it has major potential to draw both interstate and international students to this campus. Beside the immediate direct contribution to research output, a major aim of the revamped Developmental Biology courses is to promote the use of animated computer graphics in teaching: the complex cell dynamics occurring during embryogenesis are ideally suited to this. As such, we plan to develop a major web site for student access, featuring the use of cutting-edge technology that will encourage student enrolments and post-doctoral enquiries, thus boosting the profile of Developmental Biology both at University of Queensland and further afield".*

The case was well received and the developmental biologists were invited to submit applications to develop new second- and third-year courses in the three-year undergraduate Science Bachelor's degree. The reason for introducing new courses in developmental biology was succinctly outlined in the next year as follows:

> *"Developmental Biology is at the core of all biology and as a discipline unifies the studies of heredity, evolution and physiology. Progress in this field in recent years has been remarkable and a large amount of information in now available about how animal embryos develop. Despite the fact that the embryos differ tremendously in external character, we now know that the underlying molecular and cellular mechanisms are highly conserved. This course draws upon data from a disparate range of vertebrate and invertebrate model organisms to teach the fundamental principles of Developmental Biology, illustrating the power of the various model organism and the universal process that underpins biological diversity."*

Features and Goals of Our Revised Curriculum

What was maturing during this period was a teaching philosophy that would nurture principles through a process that was coined by one of us (VN) as the "cradle-to-grave Developmental Biology" approach. We had hoped to create an environment where students were exposed to developmental biology in first-year courses before beginning to specialize further in second- and third-year courses, which were progressively more dedicated to the discipline. Throughout these courses, students would be shown career paths involving traditional academic routes such as Honours, Ph.D., and then post-doctoral fellowships, as well as new opportunities in industry, medicine, food technology, agriculture and aquaculture that were spinning off from academia. We would emphasize the exciting new developments in tissue engineering for the production of artificial organs and tissues from living cells that had arisen from the basic principles of morphogenesis. The purpose of a new track in developmental biology was to teach students the key principles and concepts in development and to ensure that these are best understood in the context of the emerging technologies in genetics, biochemistry, physiology, anatomy and cell biology. *We would seek nothing less than a comprehensive understanding of the construction of multicellular life forms from the gene and molecule right up to the functioning organism.* By highlighting the urgent need for well-trained developmental biologists in both industry and academia, we had encouraged the University of Queensland administration to seize the opportunity to be a key provider of the next generation of these scientists. Previously, developmental biology was taught *ad hoc*, often under the umbrella of cell biology, embryology or zoology. For the first time, the University of Queensland took coordinated advantage of the largest concentration of developmental biologists in any Australian university to develop a highly coordinated, directed and streamed program in developmental biology, unavailable to students elsewhere.

Our goal was to produce graduates with the following key attributes:

- Core understanding of the establishment of body plan in various model organisms;
- In depth understanding of the cell and molecular mechanisms underlying development;
- In depth knowledge of the major questions currently facing developmental biologists;
- Ability to plan experimental approaches to answering questions in developmental biology;
- Skills in oral and written communication.

Devising an Inter-Departmental Program and Oranizational Structure for our Developmental Biology Curriculum

We loosely defined our Program in Developmental Biology as a unified group with an interest and responsibility in teaching, research and extension in a particular focus area. The feature of the program that distinguishes it from existing departmental structures is that participation in the program creates opportunities not otherwise obtainable within existing organisational units. The program does not detract from existing structures, but rather creates a new, flexible structure. The unique attribute of a program is that participants join because they see some advantage in belonging, ensuring a motivated membership. Based on benchmarking, critical self-analysis, and student inputs we defined a Program in Developmental Biology as:

- Consisting of individual researchers drawn from across departmental and institutional borders;
- Primarily drawing on existing personnel;
- Primarily drawing on existing infrastructure;
- Creating research opportunities through internal collaboration and links with industry;
- Having a well-defined teaching track in the faculty including second and third level courses contributing to a B.Sc. in the field of developmental biology;
- Having a structured Ph.D. program that offers interactions and opportunities augmenting those available through departments or centres;
- Defining a clear career path from the Bachelor's degree and then on to either academia, or research institutes, or the biotechnology industry; and
- Sponsoring activities that enhance the international reputation and quality of the program.

The responsibility for establishing this program lay with an organisational structure composed of:

- A Chair who takes responsibility for activities of the program. The chair should have an international research reputation and excellent organisational skills;
- An Executive to maintain the program's momentum;
- Co-ordinators who take responsibility for specific actions under the categories: organisation and promotion; teaching and research.

General Features of Australian Undergraduate Curricula

In the Australian education system, students typically undergo primary and secondary school education between the ages of 5 or 6 years and 17 or 18 years of age. They can then enter the tertiary or higher education system to complete a standard three-year Bachelor's degree as an undergraduate student at a university. Each university year is typically divided into two semesters of 13 teaching weeks, 1 class-free week of revision, followed by 2 weeks of examination. In the science faculties, selected students may then choose to pursue a fourth-year Honours program, which usually involves an intense period of research training. In the biological sciences, the Honours year usually involves attending seminars, designing experiments and then orally defending a proposed research plan, writing a literature review, and considerable experimental work. The Honours year culminates in the writing of a research thesis. On the basis of their performance in the Honours program, students are then selected for entry into the postgraduate research-based 3- to 4-year Ph.D. program.

One of the biggest changes to the curriculum of a number of Australian universities (including the University of Queensland, the University of Sydney and Flinders University) has been a move within the last few years towards a U.S.A.-style post-graduate Medicine degree. Instead of 18- and 19-year olds going straight into a 5- or 6-year Medicine degree, a high proportion of whom have gained very high grades in school, many of the best students now enter into what has become essentially a "pre-med" science

course. For the first time, we now had "access" to the best pool of talented undergraduates we had ever experienced, before they were funneled away into other professions. It became imperative for our program to capture some of the very best undergraduates for our discipline, and thence to develop their graduate careers.

Description of the Three-Year Undergraduate Track in our "Program in Developmental Biology"

At the University of Queensland the Bachelor of Science degree is typically based on completing four courses each semester over three years. In the first and second years, each course has approximately six formal contact hours (consisting of both lectures and practical sessions) per week.

First Year

The first year is designed to be quite broad to ensure that students are exposed to multiple disciplines before they progressively specialize in the second and third years. Students must complete at least four first-year courses before they begin to take other level courses. In the biological sciences at the University of Queensland, there are six generic first-level courses: Genetics and Evolution; Animal Biology; Plant Biology and Biotechnology; Molecular and Microbial Biology; Human Biology; and Ecology and Environment. In common with other specialties, Developmental Biology provides introductory lectures in both the Human Biology and Animal Biology first-year tracks in order to alert students, first, to the fact that the course exists and, second, to its general focus and direction. Generally, we have found this to be an easy case to explain; the combination of recent genomic/molecular advances and the historically anatomical/visual basis of the course routinely generates spectacular graphics capable of capturing the imagination of undergraduates. We have assembled a bank of outstanding pictures and movies, many from our own labs, which we make available to all the lecturers in our track.

Second Year

It is in the second year that students have the opportunity to begin their specialization in developmental biology. There are two second-year courses that are available for students of development biology: "Cell and Developmental Biology" (coordinated by one of us, Victor Nurcombe) and "Human Histology and Embryology" (taught by one of us, Brian Key). These two core courses provide an opportunity for us to develop the critical principles of developmental biology and to ensure that students are exposed to cutting-edge technologies that have yielded insights into animal development, particularly in regard to biomedicine and agriculture.

Human Histology and Embryology provides a wonderful avenue for exposing the embryological bases of many human diseases and syndromes. While this course can at times be overwhelming with terminologies and classical descriptions of tissue lineages, when it is intermixed with the right balance of practical outcomes, it becomes highly stimulating. For instance, we use *in vitro* fertilization technologies as the framework to present the early stages of development. This is followed by the use of stem-cell technologies and animal cloning in order to maintain the student's scientific interest. At all times, we stress the significance of abnormal tissue interactions in disease. For instance, in neural crest migration we introduce Hirschprung's disease and the use of animal models such as the lethal spotted mouse. A subtle mix of classical embryology and contemporary developmental biology is used to stimulate critical reasoning of students – this is preferred rather than merely rote learning of tissue mechanics. We use lecture titles such "Building the most complex tissue in the universe" (i.e., brain) as a way of stimulating imaginative approaches by our lecturers. "Is it male of female?" is our way of introducing the reproductive systems. We make use of the powerful imaging techniques available to view the embryo *in utero*, as well as fetal sampling and surgery and genetic therapies to provide a practical "real-world" significance to the core principles of the histology and embryology of this system. At all times, we implement a strategy of providing a scientific base to the discipline; rather than merely recite the textbook descriptions, we introduce fundamental questions about underlying mechanisms. While we never truly digress from the underlying need to provide basic embryological data, we implant ideas about biological approaches used to address questions that arise from the embryology. This is further nurtured by examining embryology through the modern technologies that are currently driving reproductive and embryological medicine.

We ensured that the other second-year course, Cell and Developmental Biology (BIOL2008) provided the basic principles in these two related fields, so that students were adequately prepared for a major in either one. A sister stream, the Program in Cell Biology, was established at roughly the same time as ours, and the question as to how they were to dovetail together naturally came to the fore. We chose an interlocking system, where the first half of the second-year course (about 6 weeks) was dedicated to building on the fundamentals of first-year cell biology, taught by practicing cell biologists, and the second half to developmental biology. In theory, this course should make clear how the two disciplines mutually reinforce each other, and how the techniques they use often cross over to solve mutually interesting questions.

As a discipline, developmental biology tends to focus on a few, well-characterized model organisms, often in concert with genome analysis. Happily, most are represented in our program: for example, *Xenopus* and zebrafish (Brian Key), *Drosophila* and *Caenorhabditis elegans* (David Merritt, Department of Entomology), ascidians (Bernie Degnan, Department of Zoology), chick (Victor Nurcombe), and mouse (Peter Koopman, IMB; and Peter Noakes, Department of Physiology). For the second half of the course, major emphasis is placed on these model organisms as well as on creating a sense of excitement about how quickly the field of developmental biology is moving. In particular, we stress how it has consistently spun off new technologies and new ways of thinking about biological relationships. The major themes are:

- the principal patterns of animal development;
- that development of functional tissues and organs involves coordinated division, commitment, differentiation, migration, and death of cells;
- that these processes are orchestrated by networks of genes;
- that developmental biology is an experimental science that requires skills in embryo handling, culturing and manipulation from the molecular to the whole-organism level;
- that many human birth defects result from aberrations in these processes and mutations in developmental control genes;
- that developmental processes have shaped metazoan evolution.

Despite quite formidable administrative obstacles, we also run some advanced practicals, the first of which emphasizes the handling of cells in tissue culture, the second of which uses immunohistochemistry to examine the developing *Drosophila* body plan in relation to *Hox* gene expression, and the third of which explores the embryonic manipulation of young chicks (Fig. 1). These practicals have proved enormously successful. The third practical is arranged as a competition between practical groups with the aim being to determine who can produce the most altered embryonic body plan. Students experimentally manipulate chick development by placing cellulose beads (loaded with such morphogens as FGF-2 or retinoic acid) adjacent to developing structures such as brain and limb. These practicals recapitulate some of the most interesting experiments in the history of developmental biology and rank very high in student feedback evaluations.

Third Year - the First of Two Consecutive Courses

Two third-year courses complete the core courses in the Developmental Biology track at the University of Queensland. In first semester, one of us (BK) co-ordinates "Developmental Neurobiology," while in the second semester the other (VN) co-ordinates "Molecular Mechanisms of Development." While the latter course was designed and introduced for the first time in 2001 (described later, see below), "Developmental Neurobiology" grew out of a course first introduced by BK in 1993 at the University of Melbourne and is team-taught by both authors. This course saw it beginnings before the era of large class sizes. It began with a small, highly select group of about 15 students, many of whom were destined to undertake Honours and Ph.D. programs in our research laboratories. In 2002, we have seen our class size increased to 105 and the number of lecturers increased to 6! While maintaining the same theoretical framework of topics covered, we have naturally had to change the mode of delivery of the content to accommodate the increased class size as well as the different lecturing styles of the additional lecturers teaching this course. We have never had a dedicated practical component to this course, although initially it could be taken conjointly with a complementary practical course that rotated groups of 15 students through our research laboratories to undertake experimental work. However, as class sizes increased, this approach was no longer feasible. Even though there are continual requests from our students for dedicated laboratory classes, we are unable to accommodate them at present with our limited resources.

Cultivating Critical Thinking

When we first started our third-year course, we had a strong desire to introduce the students to a scientific way of thinking. It was our philosophy that we should use the course Developmental Neurobiology to introduce students to the use of critical reasoning. We had the perfect opportunity to mold the thinking habits of our students to be in accord with the scientific method. While realizing that each of us has unique ways of addressing problems (Sternberg, 1997), we wanted to ensure that our students knew what were the important questions to address in order to solve a problem. We found the best way to begin this process was to give some formal lectures in the scientific method (Gower, 1996; Giere, 1997). In this way the importance of observation, the concept of induction and deduction in formulating hypotheses, and the process of prediction

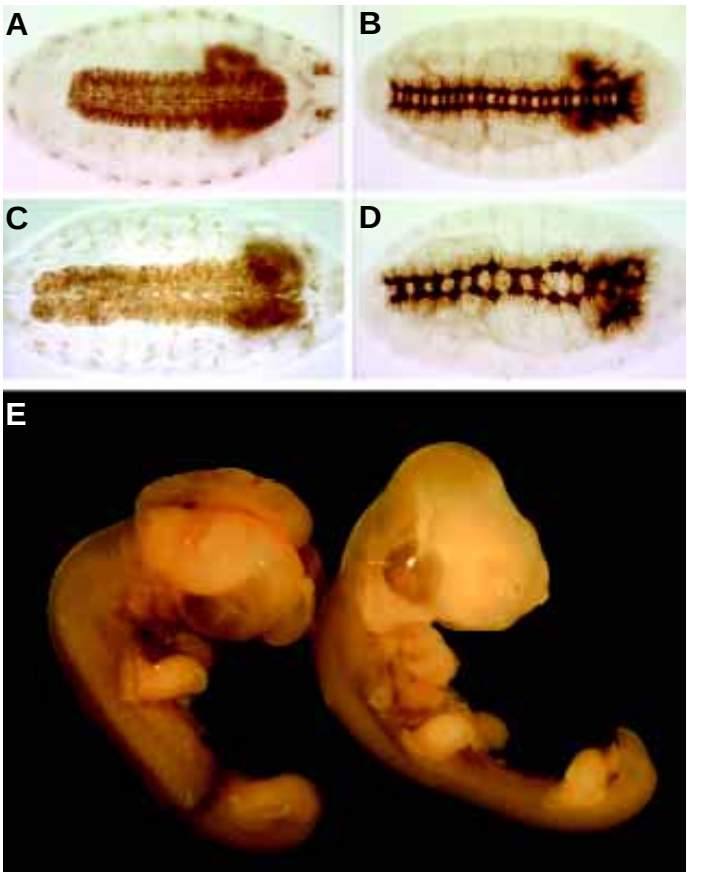

Fig. 1. Examples of experimental results obtained by undergraduate students enrolled in the third-year course "Mechanisms of Development" at the University of Queensland. (A-D) *Wholemounts of immunostained* Drosophila *embryos.* **(E)** *A control chick embryo (right-hand side) and a chick embryo with abnormal brain growth after exposure to beads coated in various growth factors.*

followed by the design of experiments to test these predictions were progressively introduced to the student. We were, however, always careful not to become slaves to the philosophy of science. In one lecture, I would introduce the students to the illusions of our thinking that can lead us astray (Piattelli-Palmarini, 1994; Newton, 1997). This lecture was peppered with games and real examples of how our common sense approach or uneducated intuition can be biased. At the same time, I stressed the importance of lateral thinking (typically involves searching for alternate ways of examining problems via unorthodox means) by using some classic approaches suggested by de Bono (1991 and 1995).

We were particularly interested in encouraging lateral thinking in such a way that would lead to creative ideas. Of course, we were cognizant of the fact that students need a sound base of theoretical knowledge so as to know the limitations of their creativity. These lectures were well received by the students and set the framework for many future interactions with data from scientific examples in the literature. Our philosophy was to engage the students in a dialogue. Rather than merely present information didactically, we presented problems and quizzed the students incessantly until a solution was forthcoming. This is, of course, very demanding on the lecturer because one has to allow the lecture to flow often in what

Fig. 2. The "growth cone game." *Students participate in a real-time demonstration of growth cone guidance and axon growth during a lecture in the third-year course "Developmental Neurobiology" at the University of Queensland.* **(A-C)** *A student is blindfolded and plays the part of a growth cone navigating across the surface of the neuroepithelium (front of the lecture theatre).* **(D)** *The lecturer (BK, in red shirt) constantly interrupts the journey to introduce guidance cues (other students).* **(E-F)** *The goal of the growth cone is to reach its preferred target (more students) which possesses cans of "air freshener" as chemotropic cues.* **(G)** *The growth cone finally reaches it preferred target "cue."*

would initially appear to be outside of the original topic of discussion. However, a skilled lecturer is able to maneuver the lecture to the appropriate end-point.

This interactive style of teaching worked very well with students, and we continued this approach as the class size approached 50 students — we found ourselves walking down the aisle and winding through the chairs and desks rather than remaining tethered to the podium. The primary literature played an important role in our approach — we had no assigned text but relied totally on review reports and recent state-of-the-art papers from only the highest impact journals. Each week, students were asked to read one assigned paper and come to class ready to participate in a detailed discussion. The previous two lectures in the week provided the background to the paper and gave the student the necessary working knowledge to begin to address in a meaningful way the questions posed by the paper.

Encouraging Student Engagement and Active Learning

As the class size has increased over the last few years from 50 to 105 and as the number of lecturers involved has expanded from two to six, we have had to change the mode of delivery. Each week, we now have three formal lectures followed by a one-hour self-directed learning module (SDL). The format of the SDL is variable, but is typically a problem-based exercise centred on a developmentally based neural syndrome or a set of experimental data which requires interpretation by the student. Emphasis on primary literature has decreased, as there is less direct staff-student interaction in the lecture as a result of the larger class size. While we still encourage such an exchange, its frequency is restricted to more general approaches. For instance, in a lecture on secondary neural induction involving the isthmus organizer, one of us (BK) will ask the class a question: "How would one test whether FGF-8 released by the

isthmus either directly or indirectly acts on the prosencephalic tissue to induce subsequent differentiation?" This is a relatively difficult question but one that will bring out a lot of important concepts. Initially, students have some difficulty coming to terms with the difference between "indirect" and "direct." The value of this inquisitive approach is to provoke students to answer the question for themselves. Eventually it is revealed that this can be achieved by transplanting a bead soaked in FGF-8 into the prosencephalon. With further quizzing, it is possible to introduce the idea of more stringent tests such as overexpressing dominant negative FGF receptors in the prosencephalon versus the isthmus via transgenesis.

The problem with this approach, of course, lies in ensuring that all students are actively involved in the process of answering the question and that the action is not restricted to a small number of students — it often helps to direct attention to certain students and to help them in their thinking. A student must not be left feeling inadequate in front of their peers; this is why this approach can be so difficult for the teacher but, conversely, can be such a rewarding experience for the student. This approach must not be overused in the larger class size, but when used appropriately can re-focus the attention of the students.

A Classroom Student-Participation Exercise

A very successful technique for engaging the students is to introduce activities that involve direct student participation. One particular example is the "growth cone game" that one of us (BK) uses to highlight the role of various guidance cues in the environment (Fig. 2). A student is chosen to be the "growth cone" and is blindfolded and tethered to a perikaryon (another student) by a string. The growth cone is spun several times so that it is disoriented and then instructed to find its targets (two students placed on opposite sides of the lecture theatre). Various students are placed as props between the growth cone and its targets. These props are introduced to the class at appropriate times as "cells" expressing either chemorepulsive cues or selective cell adhesion molecules. These "cells" are labelled on their foreheads as instructive versus permissive. The "growth cone" with hands stretched in front is encouraged to extend and retract them like filopodia. The role of tension in the axon provided by the "perikaryon" is also used to illustrate the role of microtubule-generated tension in axon elongation. Finally, when the "growth cone" reaches the vicinity of the target, the "target cells" are armed with cans of air freshener (as chemotropic ligands), and the "growth cone" has to terminate on the favoured odorant/target. The lecturer continually interrupts the activity to introduce new concepts and to explain the underlying biology.

Using a Textbook

As class size increased and the exposure to the primary literature became reduced, it became important to introduce a set text for the course. We chose the newly released "Development of the Nervous System" by Sanes *et al.* (2000). This text has been well received by the students because it is easy to read and has clear diagrams. Most of the key concepts are presented in chapters that fit nicely with our weekly lecture topics; those that do not are usually easily found in subsections that are not too widely dispersed in the book. In some respects, the use of the text has freed the lecturer to explore some of the topics more laterally and expose students to ongoing work in their own laboratories. The lecturers can do this knowing that the key principles are well presented in the text, and students can then more easily understand the relationship between the ongoing cutting-edge research and the more established dogmas in the field. This is an important concept that we pay particular attention to and one that is important for the students to appreciate: *that knowledge at the forefront of science is more often than not controversial and never clear-cut*. Students often find it difficult to appreciate that there is *so much conflict at the very leading edge of science* and *that knowledge takes some time to become accepted dogma*.

The other third-year course, "Molecular Mechanisms of Development" (DEVB3002), presented in the second semester, largely follows the ethos established in the first-semester course as outlined above. We mix a Socratic style of delivery, a number of guest lectures from distinguished faculty drawn from the State of Queensland on particular organ systems (kidney, skin, blood vessel), and an emphasis on how the knowledge gained in the laboratories has direct impact on biomedicine and biotechnology. The last third of the course is given over to stem-cell biology and how it is shaping ideas in the mushrooming field of tissue engineering. The latter has proved immensely popular, and all the readings and SDLs of the last part of the course are dedicated to its consideration.

Further Curriculum Development: Filling the Need for Practical Classes

The lack of practical classes for the third-year students has been of great concern to all of the faculty. There have been two partial attempts to bridge the gap. The program strongly supported a faculty initiative for a course entitled "Laboratory Project (BIOL3012)," where the best students are able to be attached to working labs for a semester while they prosecute small but real projects. Many of these projects are offered in the labs of the program Executive members. The second attempt is to start a summer school in developmental biology. Queensland's climate and location are attractive to developmental biologists and students both in Australia and internationally. We are capitalising on our location and reputation by offering summer schools at such locations such as the University of Queensland research stations on Heron Island and Stradbroke Island on the Great Barrier Reef, akin to schools offered at Wood's Hole and Cold Spring Harbor in the United States. Local and invited overseas authorities offer intensive training courses in their area of expertise, and industry funding defrays costs. This selection is being offered as a "bait" to our best students to come and do small research projects in the laboratories housed at these stations. It is "out-of-the-box" thinking such as this that we are hoping will maintain enthusiasm for the undergraduate courses and keep graduate applications high.

Course Enhancements: PowerPoint Presentations and Internet Sites

There has been a strong philosophy in the Department of Anatomy and Developmental Biology over a number of years to deliver all lectures via PowerPoint presentations. We have adopted the same approach for our courses in the Developmental Biology

stream. Initially, copies of these presentations were provided as handouts for the students; however, faculty-driven initiatives led to a single web-based interface for all biological science students (http://sbms.ilc.uq.edu.au/) (Fig. 3). We are now able to upload these handouts as PDF files so that students can download them and bring them to class. This web-based interface provides a convenient and time efficient means of communicating with students – there is a download page for all SDLs, lecture notes, additional readings and assignments. The timetable and updates to the courses are also accessed through an announcements page.

Course Profiles, Including Assignments and Exam Questions

Developmental Neurobiology (DEVB3001)

Course Profile

Student level Senior undergraduate
Course size 105 enrolled in 2002
Staff 6 lecturers, no technical assistance
Course context There are no formal pre-requisites for this course. However, it is expected that students will have sat for the second-year Cell and Developmental Biology course or the Human Histology and Embryology course. While this lack of formal requirements makes it difficult to evaluate the background knowledge of the students, it does allow access to the class of students with very different frames of reference, which can be stimulating during discussion.
Course placement This course is part of a stream for which students gain a major in "Developmental Biology." Students need to take four courses from a core of nine courses in order to obtain a major. Developmental Neurobiology is a compulsory course which must be completed for the major.
Course format The course consists of 36 one-hour lectures. There are 12 one-hour self-directed learning sessions which are accessed via the web page. All lectures are presented by PowerPoint and digital movies are frequently incorporated into the format.
Laboratory There are no dedicated laboratory sessions for the course. However, there are elective courses in which students can enrol to undertake laboratory-based experiments in individual research labs.

Course Structure

Detailed goals Academic - To appreciate and understand the major questions facing the field of developmental neurobiology especially in relation to biomedical science. A major focus will be on the approaches and strategies necessary to address these questions. Pedagogical - Students will gain skills necessary to

Fig. 3. Example of web pages that students use to obtain information (latest announcement), interact with their lecturers (course e-mail) and download lecture notes (resources) in the third-year Developmental Neurobiology course. *Each course in the Developmental Biology Program at the University of Queensland has its own home page and the same consistent format thanks to the vision and dedication of Dr. Alan Cody (School of Biomedical Sciences) who coordinates the Faculty Information Technology Program at the University of Queensland.*

read and understand the scientific literature and make informed decisions on the significance of research in the field of developmental neurobiology.

Course content Basic principles of development of nervous systems: induction, regional specification, neurogenesis, gliogenesis, differentiation, plasticity, cell death, axon growth and guidance. Significance of understanding development for facilitating regeneration and recovery of function following disease and injury is highlighted.

Week 1 Overview of brain development
Week 2 Making patterns in the brain
Week 3 Moving cells around in the brain
Week 4 Controlling the size of the brain
Week 5 Constructing a simple nervous system
Week 6 Wiring up complex nervous systems 1
Week 7 Wiring up complex nervous systems 2
Week 8 Making and breaking connections
Week 9 Refinement of synaptic connections
Week 10 Behavioural development
Week 11 Regeneration and repair of the nervous system
Week 12 How to build a brain

Examinations

There is a 1-hour mid-semester exam worth 20%, a 2-hour end-of-semester exam worth 60% and a written assignment worth 20%. The mid-semester exam consists of 30 short-answer questions and 15 false statements that have to be explained.

The aim of this mid-semester exam is to ensure that students keep up-to-date with their reading and to make sure that they know the working vocabulary appropriate for the developing nervous system.

Examples of Short-Answer Questions

1. What is the name of a protein that is involved in neural induction? _____
2. Mutations in genes affecting the notch-delta signalling pathway are called _____ mutations because they cause excess formation of neurones.
3. The proneural genes encode for proteins that bind to target genes and initiate neural _____.

Examples of False Statements to be Explained:

1. Consolidation of a growth cone during axon elongation ensures that the growth cone pulls the axon along.
2. Cellular differentiation within the nervous system has only ever been studied in the optic nerve, because this is the only place that growth and trophic factors have been observed.
3. The morphogenetic furrow in *Drosophila* defines the future optic nerve head in the eye

The end-of-semester exam is designed to test the student's ability to integrate their working knowledge of the developing nervous system so as to explain a novel set of data. It is more than the ability of a student to repeat textbook descriptions – students must be able to analyze and interpret data. The exam typically consists of four 30-minute questions.

Examples of End-of-Semester Exam Questions:

1. You have developed one of the following hypotheses:
   (a) Some identified sensory neurones are required for the development of proper locomotory behaviour of the newly hatched larval *Drosophila*.
   (b) That the axons from sensory axons on the adult wing do not take a normal pathway into the CNS if some critical embryonic sense organs are not present to guide the axons into the CNS.
   Pick one and outline some approaches you could use to demonstrate that this is the case.
2. Dr. Hunchback and his team of developmental biologists were intent on identifying the mechanisms underlying segmentation and segment identity in the rhombencephalon. They identified the regions in the early neural plate (before segmentation occurred) that gave rise to rhombomeres (R) 5/6 and R7/8. How did they do this? Next they heterotopically transplanted the presumptive R5/6 to the region of presumptive R8 in another embryo. They found that R5/6 now differentiated into R8. How did they do this? Next they took presumptive R8 and transplanted it rostrally to the level of the presumptive R5/6. This time, they found that the identity of the rhombomere did not change and remained as R8 in its ectopic position. What does this say about the commitment of cells in different regions of the hindbrain? Explain this result with what you know about morphogen action. Note that the most rostral rhombomeres develop first and that each rhombomere takes about an hour to become morphologically visible.

Examples of Assignment Questions

The aim of this assignment is to stimulate the student to delve into the literature with an idea of communication of findings to a broader audience. It is hoped that students with particular interests or skills are accommodated in one of the assignments. All assignments have an upper word limit of 1500 words, and students are encouraged to be creative. Nonetheless, all assignments must be appropriately referenced and scientifically sound.

1. Write an article in the style of the popular science magazine *New Scientist* on either (i) a new therapeutic approach for brain injury or disease; or (ii) a new exciting result from a scientific paper that has wide implications.
2. **(a)** Design a web page for a developmental brain defect to explain the defect. Provide pictures, diagrams, information on the basis of the defect and therapeutic approaches, e.g., neural tube defects – complications of spina bifida; lissencephaly; Bell's palsy; multiple sclerosis, ataxia-telangiectasia or other inherited cerebellar ataxias; amyotrophic lateral sclerosis; and its associated problems of Friedrich's ataxia; supranuclear palsy; syringomyelia; Pick's disease.
   (b) Design a web page based on the recent demonstration that new neurones are generated and form synaptic connections in adult hippocampus (van Praag *et al.,* 2002, Nature; 415:1030-1034). What are the implications of this research for our current model of cellular mechanisms underlying learning and memory in the adult?
3. Generate a computer animation or a program that demonstrates some aspect of developmental neurobiology. For example:
   (a) it could be an animation of development of the brain but based on experimental analysis or findings (the movie would need to be accompanied by a brief description and references) –
   (b) it could be an animation of movement and action of morphogens in neural issue complete with binding to receptors and the turning on of gene expression and subsequent morphological changes.
   (c) Computer animation about activity-dependent synaptic refinement, using LTP/LTD mechanisms
   (d) Interactions between sense organ precursor cells and their progeny during neurogenesis

Textbook for Assigned Readings

SANES, D.H., REH, T.A. and HARRIS, W.A. (2000). *Development of the Nervous System*. Academic Press, San Diego, CA.

Relevant Web Address for Supplementary Information

http://sbms.uq.edu.au/

Molecular Mechanisms of Development (DEVB3002)

Course Profile

Student level Senior undergraduate
Course size Approximately 105
Staff 6 lecturers and 2-3 guest lecturers
Course context As for DEVB3001 above
Course placement Essentially as for DEVB3001 above. BIOL2008 is the assumed prior learning standard; DEVB3001 is the direct third-year sister course. Students should have an understand-

ing of basic developmental mechanisms and time courses, the emergence of the body plan, basic cell-to-cell communication systems and signal transduction mechanisms as well as an integrated view of morphogenesis. An understanding of the basic mechanisms of genetic expression is also desirable.

Course format The course consists of 36 one-hour lectures. There are 12 one-hour self-directed learning sessions which are accessed via the web page. All lectures are presented by PowerPoint, including those given by the guest lecturers, and digital movies are frequently incorporated into the format.

Laboratory No formal practical classes; students are directed into the specialist BIOL3012 "Projects" stream, and members of the executive can select individuals – up to three – from the cohort. We are developing a session where selected students – up to 20 – will spend a week on one of the university research stations, prosecuting various embryonic manipulations using *Drosophila* and chick embryos.

Course Structure

Detailed goals Academic - To appreciate and understand the overall directions of developmental biology especially in relation to the biomedical and agricultural sciences. A major focus will be on the approaches and strategies necessary to address these questions. Pedagogical - Students will gain skills necessary to read and understand the scientific literature and make informed decisions on the significance of research which exploit the methods of developmental biology. The course will focus on how modes and varieties of molecular expression guide cell and tissue morphogenesis during the development of both invertebrates and vertebrates. As such, we aim to provide an overall context and definition to molecular and cellular biology. An overview of how this understanding is shaping modern medicine and animal husbandry will also be given; this in turn will illustrate just how fundamental developmental biology has been to the whole biotechnological revolution.

Skill acquisition Synthesis of knowledge, to be able to draw conclusions and propose explanations of biological phenomena; critical analysis and evaluation of published research; independent learning; and written scientific communication.

Topics will include Stem cells and tissue engineering; the relationship between development, genes and evolution and the modern genetic and cellular methods used to understand the mechanisms of development; the molecular and cellular mechanisms of sex determination; the role of epithelial-mesenchymal interaction and transition in differentiation and morphogenesis; the mechanisms of axis specification; organogenesis, including the central and peripheral nervous systems, skin, the kidneys and the gonads; and developmental biology and the biotechnological revolution

Course Content

Week 1 Evolution and Development I
Week 2 Evolution and Development II
Week 3 Strategies for Studying Development
Week 4 Mammalian Sex Determination
Week 5 Pattern Formation
Week 6 Epigenetic Mechanisms
Week 7 Myogenesis I
Week 8 Skin Development
Week 9 Kidney
Week 10 Stem Cells
Week 11 Tissue Engineering I
Week 12 Tissue Engineering II

Examinations

The mid-semester exam consists of 15 multi-choice, 10 short-answer, and 3 longer essay-style questions.

Examples of Mid-Semester Exam Questions

Multi-choice (1 mark each)

1. Which of the following statements is true:
   A. biological patterns are generated by an interplay of epigenetic and genetic mechanisms
   B. morphogens are genes that determine the rate of expression of other genes
   C. the form and shape of tissues is independent of hormone action
   D. all of the above
   E. none of the above
2. Complex shapes and patterns of tissues can arise:
   A. without the action of genes
   B. without complex genetic programming
   C. from emergent fields in excitable media
   D. all of the above
   E. none of the above

Short-Answer Section (5 marks each)

1. What is heterochrony? Provide an example of how the process of heterochrony can be responsible for the evolution of body plans.

Essay Section

1. Describe in point form the evidence that an inactivation centre exists on the mammalian X chromosome and that XIST is causally involved in X-chromosome inactivation.

Examples of End-of-Semester Exam Questions

Question 1 (Marks A=2, B=1, C=2, D=5)

A. What is the experimental evidence showing that the 'Lines of Blaschko' represent the migratory routes of epidermal precursor cells during embryonic development?
B. Where do epidermal stem cells reside in hairy skin?
C. What 'traits' distinguish a stem cell from a transit amplifying cell?
D. Give an example of an experiment that shows that the instructive signals for making a cutaneous appendage (such as a hair follicle of feather) comes from the dermis and not from the epidermis.

Question 2 (10 Marks)

Discuss the cell and molecular signalling events that lead to the formation of limb muscles from somites.

Example of Assignment Questions

1. "The biggest problem still outstanding for the therapeutic use of stem cells is understanding how to get naive cells to differentiate in a culture dish." Discuss.
2. A magic spell issues forth, and you suddenly find yourself quasi-omnipotent. Re-design an organ in the human body

along rational, as opposed to evolutionary, principles. Explain how you would improve on Nature.

Textbooks for Assigned Readings

GILBERT, S.F. and RAUNIO, A.M. (1997). *Embryology. Constructing the Organism*. Sinauer, Sunderland, Massachusetts, USA.

GILBERT, S.F. (2000). *Developmental Biology.* 6th Edition. Sinauer, Sunderland, Massachusetts, USA.

SLACK, J.M.W. (1991) *From Egg to Embryo. Regional Specification in Early Development*. 2nd Edition. Cambridge Univ. Press, Cambridge, UK.

WOLPERT, L., BEDDINGTON, R., BROCKES, J., JESSELL, T. and LAWRENCE, P., MEYEROWITZ, E. (1998). *Principles of Development.* Oxford University Press, Oxford, UK.

Relevant Web Address for Supplementary Information

http://sbms.uq.edu.au/

References

DE BONO, E. (1991). *The 5-day course in thinking*. Penguin Books, London, UK.

DE BONO, E. (1995). *Serious Creativity. Using the power of lateral thinking to create new ideas*. HarperCollins, London, UK.

GIERE, R.N. (1997). *Understanding Scientific reasoning.* The Dryden Press, Orlando, Florida, USA.

GOWER, B. (1996). *Scientific Method. An Historical and Philosophical Introduction.* Routledge, New York.

NEWTON, R.G. (1997). *The Truth of Science. Physical Theories and Reality.* Harvard University Press, Cambridge, Massachusetts, USA.

PIATTELLI-PALMARINI, M. (1994). *Inevitable Illusions. How Mistakes of Reason Rule Our Minds*. John Wiley & Sons, Hoboken, New Jersey, USA.

SANES, D.H., REH, T.A. and HARRIS, W.A. (2000). *Development of the Nervous System*. Academic Press, San Diego, California, USA.

STERNBERG, R.J. (1997). *Thinking Styles.* Cambridge University Press, Cambridge, UK.