CHAPTER 11

The Control of Gene Expression

Objectives

Introduction Describe and compare reproductive cloning and therapeutic cloning.

Gene Regulation in Prokaryotes

11.1 Describe and compare the regulatory mechanisms of the *lac* operon, the *trp* operon, and operons using activators.

Cellular Differentiation and the Cloning of Eukaryotes

11.2 Explain how selective gene expression yields a variety of cell types in multicellular eukaryotes.
11.3 Describe the experiments in the 1950s that used carrots and frogs to demonstrate that nuclei from differentiated cells can retain their full genetic potential.
11.4 Describe the potential uses of reproductive cloning of nonhuman mammals.
11.5 Compare the sources and properties of embryonic stem cells and adult stem cells.

Gene Regulation in Eukaryotes

11.6 Explain how DNA is packaged into chromosomes.
11.7 Explain the cause of the tortoiseshell pattern of a cat.
11.8 Explain how eukaryotic gene expression is controlled and note how it is different from gene control in prokaryotes.
11.9 Describe the process and significance of alternative DNA splicing.
11.10 Explain how mRNA breakdown, initiation of translation, protein activation, and protein breakdown can each regulate gene expression.
11.11 Explain how the control of gene expression in eukaryotic cells is analogous to the control of water moving through the series of pipes that carry water from your local water supply to a faucet in your home.

The Genetic Control of Embryonic Development

11.12 Describe generally the cascade of events that occur during fruit fly development. In particular, note the role of homeotic genes.
11.13 Describe the roles of cell-to-cell signaling and signal-transduction pathways in development.
11.14 Explain why the early versions of homeobox genes appear to have arisen very early in the history of life.

The Genetic Basis of Cancer

11.15, 11.16 Explain how viruses, proto-oncogenes, and tumor-suppressor genes can each contribute to cancer.
11.17 Describe the main events in the development of colon cancer.
11.18 Describe the recent discoveries associated with the genetic basis of breast cancer.
11.19 Describe behaviors that can increase and decrease your risk of developing cancer.

Key Terms

reproductive cloning
embryonic stem cells (ES cells)
therapeutic cloning
gene expression
promoter
operator
operon
repressor
regulatory gene
activator
differentiation
clone
regeneration
nuclear transplantation
adult stem cells
nucleosome
X chromosome inactivation
transcription factor
enhancer
silencer
alternative RNA splicing
homeotic gene
signal-transduction pathway
homeobox
oncogene
proto-oncogene
tumor-suppressor gene
carcinogen

Word Roots

trans- = across (*signal-transduction pathway:* the process by which a signal on a cell's surface is converted into a specific cellular response inside the cell)

Lecture Outline

Introduction *Human Cloning?*

A. The process of developing a human clone is fraught with problems. Technical difficulties stand in the way as well as moral and ethical concerns. But imagine that a damaged heart could be repaired with new muscle tissue and with no concern about tissue rejection. That is the goal of the company (Advanced Cell Technology or ACT) that reported the first successful human clone. ACT is in the business of making **embryonic stem cells** that can be used therapeutically and help people with irreversible tissue damage such as a spinal cord injury.

B. Two approaches are used to study development.
   1. *Preview:* Recombinant DNA techniques are used to study the parts of gene regulation (Chapter 12).
   2. Trace the genetic causes of abnormal development as clues to how genes control normal development. This is how *D. melanogaster* mutants are studied.

C. This chapter describes the control of gene expression in prokaryotes and eukaryotes, embryonic development, cell differentiation and cloning, and the genetic basis of cancer.

I. Gene Regulation in Prokaryotes

Module 11.1 Proteins interacting with DNA turn prokaryotic genes on or off in response to environmental changes.

A. The flow of information from gene to protein is called **gene expression.**

B. This model of gene control was first proposed as a hypothesis in 1961 by Jacob and Monod, for the control of lactose utilization enzymes in *E. coli.*
NOTE: Much experimental evidence has since confirmed the existence of this and other operons in many bacteria.

C. Important features of the model: An **operon** consists of several DNA sequences coding for different enzymes, all involved in the same cellular process. Expression of the operon is controlled as a unit. Other DNA sequences in and near the operon control the operon's expression. The presence or absence of the enzyme's substrate turns on or off the controls.

D. Operon expression normally starts with RNA polymerase binding at the **promoter** region (the first nongene region of the operon) and moving along and transcribing each gene in the operon.

E. When the *lac* operon is "turned off," a **regulatory gene** is transcribed and translated into a **repressor** protein. The repressor protein binds with the operator region of the operon, repressing the transcription of the genes further along the operon (Figure 11.1B).

F. When the *lac* operon is "turned on," the regulatory gene continues to be transcribed and translated into repressor, but the presence of substrate (lactose) interferes with the binding of the repressor to the **operator.** This permits the expression of the remainder of the operon. Expression continues until the substrate is used up. Then the repressor is free to repress the operator, and the operon turns off as above (Figure 11.1B).

G. The *lac* operon is repressed when lactose is absent and transcribed when lactose is present.

H. Another operon, the *trp* operon, is transcribed when tryptophan is absent and repressed when tryptophan is present. The enzymes expressed by *trp* help synthesize tryptophan (Figure 11.1C).

I. A third type of operon uses activators rather than repressors. **Activators** are proteins produced by the regulatory genes that make it easier for RNA polymerase to bind to the promoter region of an operon.

II. Cellular Differentiation and the Cloning of Eukaryotes

Module 11.2 Differentiation yields a variety of cell types, each expressing a different combination of genes.

A. Producing eukaryotic organelles and regulating their functions require a much more complex network of gene control.

B. In multicellular eukaryotes, there is the added complexity of regulating what kinds of cells are produced when and where.

C. Muscle, pancreas, and blood cells (and other cell types) of a single animal all are derived by repeated cell divisions from the zygote.

D. The structure of each cell type is visibly different, reflecting its function (Figure 11.2A–C).

E. The table showing patterns of gene expression for several cell types illustrates the role gene expression has in the structure and function of cells. All cells listed have the enzymes for glycolysis, but only red blood cells have hemoglobin.

Module 11.3 Differentiated cells may retain all of their genetic potential.

A. Experimental evidence supports the retention of all of a multicellular organism's DNA in each of its differentiated cells, in most cases.

B. F. C. Steward and his students were the first to demonstrate that fully differentiated plant cells retained the information to grow an entirely new plant (Figure 11.3A).

C. In the 1950s, Briggs and King transplanted nuclei from differentiated cells lining a frog tadpole's intestine to unfertilized, enucleated frog eggs. Many such treated eggs developed into normal tadpoles (Figure 11.3B). This group was the first to demonstrate that a vertebrate nucleus from a fully differentiated cell retained its full genetic potential.

D. In 1997, Dolly the sheep was born (Figure 11.3C). This was the first successful **cloning** of a mammal from a dedifferentiated nucleus. This dedifferentiated nucleus was transplanted into the enucleate egg of another sheep and implanted into the uterus of a third sheep.
NOTE: Since the egg contains mitochondria and mitochondria contain DNA, Dolly actually has two genetic parents, both female.
NOTE: This cloning of entire organisms is how many, if not most, of your students will view cloning. There is much to discuss here with regard to morality and ethics; before doing so, remind your students that, though cloning such as this is what gets much media attention, they need to consider the application of this technology in terms of cloning organs for autologous transplants.

Module 11.4 Connection: Reproductive cloning of nonhuman mammals has applications in basic research, agriculture, and medicine.

A. Cloning mammals presents an advantage that previously was not available to researchers. Now geneticists can investigate the effects of a single gene or a group of genes. However, the success rate of cloning mammals must rise to make this practice practical.

B. Scientists in the agriculture industry are using cloning technology to breed stock with desired traits. The pharmaceutical industry is experimenting with animals that could produce drugs that can be used in treating a variety of diseases—for example, cystic fibrosis.

C. Figure 11.4 shows piglets that were cloned as a source of organ transplants. Severe tissue rejection and diseases from viruses must be eliminated prior to this becoming standard medical practice.

Module 11.5 Connection: Because stem cells can both perpetuate themselves and give rise to differentiated cells, they have great therapeutic potential.

A. Embryonic stem cells (ES cells) can divide indefinitely under the right laboratory conditions and when stimulated give rise to a wide variety of cell types (Figure 11.5). The hope of medical scientists is to some day be able to grow any tissue and even organs in the lab that can be used to treat patients in need of such therapy.

B. An alternative with less controversy surrounding the research is the use of **adult stem cells.** Many adult tissues have stem cells that can give rise to selected cell types. This avenue of research has promise and is currently under investigation.

III. Gene Regulation in Eukaryotes

Module 11.6 DNA packing in eukaryotic chromosomes helps regulate gene expression.

A. The total DNA in a human cell's 46 chromosomes would stretch 3 meters.
NOTE: This amount of DNA is packed in cell nuclei as small as 5 mm in diameter, a reduction factor of almost 1 million!

B. All the DNA fits because of elaborate packing: wrapping around histones and other proteins into **nucleosomes,** coiling, supercoiling, and additional folding into chromosomes (Figure 11.6).

NOTE: During interphase, chromosomes of most cells are more loosely packed than the metaphase chromosome shown in Figure 11.6.

C. DNA packing prevents gene expression, most likely by preventing transcription.

Module 11.7 In female mammals, one *X* chromosome is inactive in each cell.

A. An interesting known example of the role of DNA packing in the control of expression is ***X* chromosome inactivation** in the cells of female animals. Certain cell lines have one or the other *X* chromosome (inherited from the individual's mother or father) inactivated; thus, there can be a random mosaic of expression of these two *X* chromosomes, as is seen in tortoiseshell cats (Figure 11.7).

Module 11.8 Complex assemblies of proteins control eukaryotic transcription.

A. In both prokaryotes and eukaryotes, gene regulation is based on the regulation of transcription. However, whereas prokaryotes combine several regulated genes into one operon, eukaryotes apparently tend to regulate individual genes. Thus, in eukaryotes there are many more regulatory proteins involved and a greater degree of complex interactions than in prokaryotes.

B. Activation appears to be of greater importance in the regulation of eukaryotic gene expression than is repression. **Transcription factors** (of which activators are an example) interact with enhancer sites (a DNA sequence) in regulating the binding of RNA polymerase to a gene's promoter (Figure 11.8).

C. The binding of activators to **enhancers** initiates transcription. Unlike prokaryotes, in eukaryotes enhancers are usually some distance away from the gene they regulate.

D. Repressor protein interaction with **silencer** sites on DNA inhibits the start of transcription.

E. Eukaryotes do not have operons and related genes are often found scattered about the genome. Regulation of functionally related genes seems to be dependent on their association with a specific enhancer(s).

Module 11.9 Eukaryotic RNA may be spliced in more than one way.

A. Introns have been shown to function in gene regulation. RNA splicing may regulate the movement of mRNA from the nucleus to the cytoplasm. **Alternative RNA splicing** provides a cell with several possible products from one gene region (Figure 11.9). A good example of this is the sex determination of the fruit fly. The pattern of RNA spicing of the same gene determines the sex of the fly. Approximately 100 examples of alternative splicing have been identified in the human genome.

B. Finally, it has been suggested that introns make genes longer, thereby increasing the possibility of crossovers between exons, and providing another mechanism for increasing genetic diversity.
Review: Crossing over (Module 8.18).

Module 11.10 Translation and later stages of gene expression are also subject to regulation.

A. In addition to the regulation of transcription and posttranscriptional modification, gene expression can also be regulated at the level of mRNA degradation, translation initiation, protein activation, and protein breakdown.

B. Breakdown of mRNA: The lifetime of mRNA molecules varies, controlling the amount of protein translated from a single transcription and posttranscriptional processing event. In nonmammalian vertebrates, red blood cells lose their nuclei, but not their ribosomes and mRNAs, which can continue to translate into hemoglobin for a month or more.

C. Initiation of translation: Some inhibitory control of the process of translation is known, such as the inhibitory action of a protein found in red blood cells when heme subunits are not available.

D. Protein activation: Posttranslational control mechanisms in eukaryotes often involve cutting polypeptides into smaller, active final products (Figure 11.10).

E. Protein breakdown: Another posttranslational control affects how fast protein products are degraded.

Module 11.11 *Review:* Multiple mechanisms regulate gene expression in eukaryotes.

A. In multicellular eukaryotes, cells influence each other's gene expression (as will be seen in the following modules) (Figure 11.11).

IV. The Genetic Control of Embryonic Development

Module 11.12 Cascades of gene expression and cell-to-cell signaling direct the development of an animal.

NOTE: An example of these cascades can be seen in the determination of which end of a fruit-fly egg cell will become the head and which end will become the tail. These events occur within the ovaries of the mother fly and involve the following series of events (Figure 11.12B):

A. Early studies by T. H. Morgan on fruit flies led to the work of Lewis, Nusslein-Volhard, and Wieschaus that revolutionized the concepts of development and gene expression. Figure 11.12A illustrates how improper cell-to-cell signaling can cause mutations in an organism.

B. The egg cell produces (by gene activation) a protein that signals the adjacent follicle cells.

C. These follicle cells are stimulated (in gene activation) to produce proteins that provide feedback to the egg cell.

D. As a result, microtubules within the egg cell are oriented along what will become the new fly's head-to-tail axis, with different types of mRNA located at the two different ends.

E. After fertilization, repeated mitosis results in the development of the embryo from the zygote. Translation of the head mRNA results in the production of a protein concentration gradient from head to tail. This protein concentration gradient corresponds to a gradient of gene expression.

F. This gradient of gene expression results in the development of the fly's body segments.

G. The cascade continues as this gradient of gene expression results in further differentiation and specialization of the body segments.

H. The genes that regulate these major features of the body plan (body segments and the body parts that develop at each segment) are called homeotic genes.

I. **Homeotic genes** are master controls that function during embryonic development in animals to determine the developmental fates of different groups of cells destined to become different tissues.

Preview: Embryonic development is discussed in detail in Modules 27.9–27.15.

J. Their improper functioning can lead to bizarre changes in morphology (Figure 11.12A).

Module 11.13 Signal-transduction pathways convert messages received at the cell surface into responses within the cell.

A. As shown in Module 11.12, the gene expression of one cell can affect the gene expression of other cells. This is the result of **signal-transduction pathways.**
Review: Signal transduction plays a major role in the regulation of the cell cycle (Module 8.9).
Preview: The importance of signal-transduction pathways is also shown in the discussions of cancer (Module 11.16) and control systems (Chapters 26 and 28).

B. The main components of a signal-transduction pathway are shown in Figure 11.13 and are listed below:
1. The signaling cell secretes signal molecules.
2. The signal molecules bind to receptors on the target cell's plasma membrane.
3. This results in a cascade of events.
4. That leads to the activation of a specific transcription factor.
5. The transcription factor activates a specific gene.
6. This results in the expression of the protein for which the gene codes.

Module 11.14 Key developmental genes are very ancient.

A. Virtually every homeotic gene found in fruit flies contains a common 180-nucleotide sequence. Very similar sequences have been found in virtually all eukaryotic organisms studied.

B. These organisms range from unicellular organisms such as yeast to plants, earthworms, frogs, chickens, mice, and humans.
NOTE: This is evidence for the common origin of life and is relevant to the material in Module 1.5 (Unity in Diversity) and Unit III (Concepts of Evolution).

C. These nucleotide sequences, called **homeoboxes,** translate into a small polypeptide sequence that binds to specific DNA sequences and thereby regulates their expression. See Figure 11.14 for a comparison of the fruit-fly and mouse homeotic genes.

V. The Genetic Basis of Cancer

Module 11.15 Cancer results from mutations in genes that control cell division.

Preview: Table 11.19 lists the incidence of several types of cancer.

A. In all its forms, cancer is a disease of gene expression.
Preview: Diet influences cancer risk (Module 21.20).

B. Viruses can cause cancer by inserting cancer-causing genes **(oncogenes)** into the host genome.
Review: Modules 10.17–10.19 and 10.21 discuss how viruses insert genes into a host's genome.

C. A normal gene with the potential to become an oncogene is called a **proto-oncogene.** Proto-oncogenes usually code for proteins that stimulate cell division or affect growth-factor synthesis or function. A mutation that results in a failure to regulate the production of these proteins will result in the conversion of a proto-oncogene into an oncogene (Figure 11.15A).

D. Most cancers occur in somatic cells, thus they are not inherited.

E. Mutations in **tumor-suppressor genes,** genes whose products inhibit cell division, also contribute to uncontrolled cell division and tumor formation (Figure 11.15B).

Module 11.16 Oncogene proteins and faulty tumor-suppressor proteins can interfere with normal signal-transduction pathways.

Review: Regulation of the cell cycle (Module 8.10) and signal-transduction pathways (Module 11.13).

A. In response to a growth factor, a signal-transduction pathway can act to stimulate cell division (Figure 11.16A). In response to a growth-inhibiting factor, a signal-transduction pathway can act to inhibit cell division (Figure 11.16B)

B. A mutation in a proto-oncogene may produce an oncogene that may produce a hyperactive version of a protein that stimulates cell division, even in the absence of growth factor. Moreover, abnormal amounts or versions of growth factor, transcription factor, and so on, could all result in the abnormal excess production of proteins that stimulate cell division.

C. Faulty tumor-suppressor genes produce faulty tumor-suppressor proteins that may fail to inhibit cell division.

D. Figure 11.14A and B illustrates two different types of mutations (*ras* and *p53*) that have been implicated in many cancers.

Module 11.17 Multiple genetic changes underlie the development of cancer.

A. More than one somatic mutation is required to produce a significant cancer (Figure 11.17B). An example of this is the development of colon cancer.

B. Colon cancer first appears as an unusually high rate of cell division occurring in apparently normal cells. Next, a benign tumor (polyp) appears, followed by the development of this benign tumor into a malignant tumor (Figure 11.17A).

C. Underlying these changes are changes at the DNA level (that are passed on to daughter cells: cell cycle) to proto-oncogenes and tumor-suppressor genes (including tumor-suppressor genes that code for proteins involved in the repair of damaged DNA). That several mutations are required explains why some cancers can take a long time to develop.

Module 11.18 Talking About Science: Mary-Claire King discusses mutations that cause breast cancer.

A. Dr. King, currently a professor at the University of Washington, has spent 25 years studying the genetic basis of breast cancer (Figure 11.18).

B. Breast cancer strikes 1 out of every 10 American women in her lifetime.
NOTE: At the populational level, the risk of cardiovascular disease is greater. However, an individual's risk will vary with genetics and lifestyle (Module 11.17).

C. Most breast cancer does not appear to have a heritable basis.

D. However, the study of familial cases of breast cancer may provide insight into the underpinnings of nonhereditary breast cancer.

E. King and her colleagues have succeeded in identifying a gene on chromosome 17, *BRCA1,* that is mutated in many families with a history of familial breast cancer.

F. The presence of a mutated *BRCA1* gene greatly increases a woman's risk of developing breast and ovarian cancer.

G. There is evidence that the normal version of *BRCA1* is a tumor-supressor gene that codes for DNA repair proteins.

H. In addition to *BRCA1,* another gene, *BRCA2,* has also been linked to an increased risk of familial breast cancer.

I. The discovery of these genes allows for genetic testing of woman to determine their risk for breast and ovarian cancer. Unfortunately, current treatment for the prevention of these cancers is radical. There is also the question of how insurance companies will deal with people with known genetic predisposition.

Module 11.19 Connection: Avoiding carcinogens can reduce the risk of cancer.

NOTE: There is much evidence that the tendency to get certain cancers is hereditary (Module 11.18).
Review: The cellular basis of cancer is discussed earlier in this chapter and in Module 8.23.

A. Cancer-causing agents other than viruses are called **carcinogens.**

B. Mutagenic chemicals cause mutations. In general, mutagens are carcinogens. Two significant mutagens are X-rays and UV radiation.
NOTE: Almost inevitably there will be a student in the class who goes to a tanning salon. Damage to the skin by exposure to UV radiation results in a tan. UV radiation is a mutagen that greatly increases the risk of skin cancer, and the younger the age at which the exposure occurs, the greater the risk. Depletion of the ozone layer increases the amount of UV radiation that reaches the Earth's surface.

C. The largest group of carcinogens are mutagenic chemical compounds. Substances from tobacco are known to cause more cases and types of cancer than any other single agent (Table 11.19).
NOTE: Studies have shown that beta-carotene does not reduce the risk of lung cancer and death from lung cancer in nonsmokers and actually increases these risks in smokers.

D. Exposure to carcinogens is additive, so long-term exposure to these agents is more likely to cause cancer.

E. Tissues in which cells have a high rate of cell division are more likely to become cancerous.

F. Many factors that expose a person to cancer-causing agents involve voluntary behaviors. But other voluntary behaviors, such as choosing to include more fiber, certain vitamins, and certain phytochemicals (compounds found in plants) in one's diet, can lower the risk.
Preview: Diet can influence cancer risk (Module 21.20).

Class Activities

1. Link gene regulation to the students' development from a single undifferentiated cell (the zygote) through all the stages of their lives; relate this to embryonic development (Chapter 27).
2. This is a good time to remind your students that science does not operate in a vacuum, that scientists need to be aware of the social impact of their work. The Bush administration has placed limits on stem cell research. This is the time to initiate a discussion of whether the government has the right to do so, of the ethics of stem cell research, and the ethics of using stem cells for the treatment of diseases.
3. When discussing changes in lifestyle to reduce the risk of cancer (i.e., stop smoking, stop using tanning beds), you may also want to take this opportunity to link this topic to the environmental concepts discussed in Chapter 38 by discussing the effect of ozone depletion (Module 7.14) on skin cancer rates.

Transparency Acetates

Chapter 11 Introduction: Reproductive cloning versus therapeutic cloning

Figure 11.1B	The *lac* operon: operon turned off (lactose absent)
Figure 11.1B	The *lac* operon: operon turned on (lactose inactivates repressor)
Figure 11.1C	Two types of repressor-controlled operons
Table 11.2	Patterns of gene expression in five types of cells
Figure 11.3A	Growth of a carrot plant from a differentiated root cell
Figure 11.3B	A nuclear transplantation experiment using the frog
Figure 11.5	Differentiation of embryonic stem cells in culture
Figure 11.6	DNA packing in a eukaryotic chromosome
Figure 11.7	Tortoiseshell pattern on a cat, a result of X chromosome inactivation
Figure 11.8	A model for the turning on of a eukaryotic gene
Figure 11.9	Production of two different mRNAs from the same gene
Figure 11.10	Protein activation: The role of polypeptide cleavage in producing the active insulin protein
Figure 11.11	The gene expression "pipeline" in a eukaryotic cell
Figure 11.12B	Key steps in the early development of head-tail polarity in a fruit fly
Figure 11.13	A signal-transduction pathway that turns on a gene (Layer 1)
Figure 11.13	A signal-transduction pathway that turns on a gene (Layer 2)
Figure 11.13	A signal-transduction pathway that turns on a gene (Layer 3)
Figure 11.13	A signal-transduction pathway that turns on a gene (Layer 4)
Figure 11.14	Comparison of fruit fly and mouse homeotic genes
Figure 11.15A	Alternative ways to make oncogenes from a proto-oncogene (all leading to excessive cell growth)
Figure 11.15B	The effect of mutating a tumor-suppressor gene
Figure 11.16A	A stimulatory signal-transduction pathway and the effect of an oncogene protein
Figure 11.16B	An inhibitory signal-transduction pathway and the effect of a faulty tumor-suppressor protein
Figure 11.17A	Stepwise development of a typical colon cancer
Figure 11.17B	Accumulation of mutations in the development of a cancer cell
Table 11.19	Cancer in the United States

Media

See the beginning of this book for a complete description of all media available for instructors and students. Animations and videos are available in the Campbell Image Presentation Library. Media Activities and Thinking as a Scientist investigations are available on the student CD-ROM and web site.

Animations and Videos	File Name
DNA Packing Animation	11-06-DNApackingAnim.mov
Turning on a Gene Animation	11-08-TurningOnAGeneAnim.mov
Control of Translation Animation	11-10-ControlOfTransltnAnim.mov
Protein Processing Animation	11-10-ProteinProcessingAnim.mov
Head-Tail Axis Fruit Fly Animation	11-12B-HeadTailFruitFlyAnim.mov
Cell Signaling Animation	11-13-CellSignalingAnim.mov
Signal-Transduction Pathway Animation	11-13-SignalTransducAnim.mov

Activities and Thinking as a Scientist	Module Number
Web/CD Activity 11A: *The* lac *operon in* E. coli	11.1
Web/CD Activity 11B: *Gene Regulation in Eukaryotes*	11.10
Web/CD Activity 11C: *Review: Gene Regulation in Eukaryotes*	11.11
Web/CD Activity 11D: *Development of Head-Tail Polarity*	11.12
Web/CD Activity 11E: *Signal-Transduction Pathway*	11.13
Web/CD Activity 11F: *Connection: Causes of Cancer*	11.19
Web/CD Thinking as a Scientist: *How Do You Design a Gene Expression System?*	11.8
Web/CD Thinking as a Scientist: *How Can the "Head" Gene Be Regulated to Alter Development?*	11.12