Same Genes, Different Fates

An Inquiry-based Approach to Teaching Developmental Biology

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SUGGESTED PACING GUIDE

ACTIVITY	TIMING	MATERIALS
ENGAGEMENT Cell Signaling, Gene Expression, and Cell Differentiation Role-Play	20-25 minutes	8 sets of cell type cards. Each set includes: STEM, MESODERM/ECTODERM, HEART/NERVE, MUSCLE/CONDUCTION, and BRAIN/SPINAL CORD cards. 8 sets of binder clips. Each set includes: 1 clip w/ yellow label, 1 clip w/ red label, and 1 clip w/ blue label. 8 small plastic snack bags (to hold 3 binder clips each). 8 pieces of string or yarn (each 3 ft. long). 1 set of ribbons. Set includes: 1 blue ribbon (10 ft. long), 1 red ribbon (5 ft. long), and 1 yellow ribbon (5 ft. long).
EXPLORATION Specialized Cell Structure and Function Puzzle	15-20 minutes	1 set of puzzle cards (25 cards) per group of 4-6 students. Each set includes: illustration, subject, verb, object, and last-part-of-the-sentence cards for FAT, INTESTINAL, MACROPHAGE, MUSCLE, and NERVE cells. 1 "Specialized Cell Types" worksheet per group.
EXPLANATION "What Controls Gene Expression?" Concept Map	25-45 minutes	1 copy of selected concept map worksheet per student or group. "Figure 1: Gene Expression" transparency.
ELABORATION Prediction and Analysis of *Arabidopsis* Experiment Results	30-50 minutes	1 "*Arabidopsis* Experiment: Predicting Results" worksheet per student or group. 1 "*Arabidopsis* Experiment: Analyzing Results" worksheet per student or group. "Figure 2: How to Make a Transgenic Plant" transparency. "Figure 3: Analyzing Experiment Results" transparency. "Figure 4: Labeled *Arabidopsis* Seedling" transparency. "Figure 5: *Arabidopsis* Experiment Procedure" transparency. "Figure 6: *Arabidopsis* Experiment Results" transparency.
EVALUATION Express Yourself: Story-Telling about Differential Gene Expression	20-30 minutes for brainstorming. *Time to complete the project will vary.*	1 copy of project rubric per student or group. Art supplies (e.g., scrap paper, markers) for brainstorming session.

PURPOSE: Address the key question, "How does an organism use the same genetic blueprint to build different cell types?"

OBJECTIVES
- Learn key concepts related to differential gene expression.
- Understand how stem cells respond to chemical signals that initiate stages of development and differentiated gene expression.
- Identify various internal and external chemical signals that can influence gene expression.
- Consider structures and functions of several specialized cell types arising from genetically identical stem cells.
- Recognize the role of model organisms, including plants, in understanding human biology.
- Explore how molecular biologists can use biotechnology to study a gene or protein of interest.

NORTH CAROLINA ESSENTIAL STANDARDS

RECOMMENDED COURSES: Agriscience Applications, Biology, AP Biology, Biotechnology and Agriscience Research II

Same Genes, Different Fates addresses the following standards for biology and career and technical education courses at the high school level:

BIOLOGY

ESSENTIAL STANDARD

Bio.1.1. Understand the relationship between the structures and functions of cells and their organelles.

Clarifying Objective

Bio.1.1.3. Explain how instructions in DNA lead to cell differentiation and result in cells specialized to perform specific functions in multicellular organisms.

ESSENTIAL STANDARD

Bio.3.1. Explain how traits are determined by the structure and function of DNA.

Clarifying Objectives

Bio.3.1.2. Explain how DNA and RNA code for proteins and determine traits.

Bio.3.1.3. Explain how mutations in DNA that result from interactions with the environment (i.e., radiation and chemicals) or new combinations in existing genes lead to changes in function and phenotype.

ESSENTIAL STANDARD

Bio.3.2. Understand how the environment, and/or the interaction of alleles, influences the expression of genetic traits.

Clarifying Objective

Bio.3.2.3. Explain how the environment can influence the expression of genetic traits.

AGRISCIENCE APPLICATIONS

ESSENTIAL STANDARD

AG11.00. Explore concepts and safe practices as related to the use of biotechnology in the production of agricultural products.

AG11.02. Investigate recombinant DNA technology and related safety concerns found in the use of agricultural biotechnology.

BIOTECHNOLOGY AND AGRISCIENCE RESEARCH II

ESSENTIAL STANDARD

BB07.00. Outline the development of genetically modified organisms (GMO's).

Clarifying Objectives

BB07.01. Outline the stages in the development of genetically modified organisms.

BB07.04. Test genetically modified organisms for successful expression of engineered genes.

ESSENTIAL STANDARD

BB08.00. Examine the various methods of genetic manipulation in plant and animal cells.

Clarifying Objectives

BB08.01. Explain methods of inserting vectors containing recombinant DNA into plant cells.

BB08.03. Analyze the development of genetically modified plant and animal cells after insertion of recombinant DNA.

NEXT GENERATION SCIENCE STANDARDS

Same Genes, Different Fates addresses the following standards at the high school level:

LIFE SCIENCE: Structure and Function

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

LIFE SCIENCE: Inheritance and Variation of Traits

HS-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

COMMON CORE STATE STANDARDS CONNECTIONS: ELA/Literacy

RST.11-12.9. Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-LS3-1)

WHST.9-12.2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. (HS-LS1-1)

NATIONAL SCIENCE EDUCATION STANDARDS

Same Genes, Different Fates addresses the following content standards at the high school level:

STANDARD A (Science as Inquiry)

1. Abilities necessary to do scientific inquiry.
2. Understandings about scientific inquiry.

STANDARD C (Life Science)

1. The cell.
2. Molecular basis of heredity.

STANDARD E (Science and Technology)

2. Understandings about science and technology.

STANDARD F (Science in Personal and Social Perspectives)

6. Science and technology in local, national, and global challenges.

STANDARD G (History and Nature of Science)

1. Science as a human endeavor.
2. Nature of scientific knowledge.

INTRODUCTION

Same Genes, Different Fates provides step-by-step lesson plans, worksheets, visual aids, and manipulatives to help teachers incorporate the topics of differential gene expression, cell specialization, and applications of biotechnology into the high school curriculum. In particular, the activities provided are designed to meet the needs of teachers in Biology, AP Biology, and Career and Technology Education classrooms.

How *Same Genes, Different Fates* Uses the 5E Instructional Model To Teach about Gene Expression, Specialized Cells, and Biotechnology

The five activities in *Same Genes, Different Fates* have been developed within the framework of the Biological Sciences Curriculum Study's 5E Instructional Model. Designed to improve science education, the 5E Instructional Model is widely recognized as an effective method of facilitating and evaluating learning.

These, briefly, are the five main activities in the *Same Genes, Different Fates* curriculum module:

ENGAGEMENT. This phase of *Same Genes, Different Fates* engages students in understanding the process of differential gene expression. Students play the roles of stem cells in an organism responding to chemical signals that initiate stages of development. In this role-play, the stem cells give rise to specialized neurons and cardiac cells.

EXPLORATION. Students consider the structures and functions of five specialized cells (fat cell, intestinal cell, muscle cell, macrophage, nerve cell). They then generate ideas about how the functions of these cells and the process of gene expression could be employed to develop gene therapies.

EXPLANATION. In this concept-mapping activity, students use appropriate scientific vocabulary to develop and annotate a diagram showing the relationships among key concepts underlying gene expression.

ELABORATION. After gaining an understanding of how molecular biologists use biotechnology to study a gene or protein of interest, students first predict and then analyze the results of an experiment carried out with genetically engineered *Arabidopsis* plants.

EVALUATION. Students write and illustrate stories that can teach differential gene expression to an audience of learners younger than themselves. This summative activity provides a creative way for students to review, synthesize, and convey the knowledge they have gained in the previous phases of *Same Genes, Different Fates*.

Optional methods of extending each of the five main *Same Genes, Different Fates* activities to include additional content or experiences are provided within the lesson plans and at the end of each activity chapter in this curriculum guide.

How Organisms Use the Same Genetic Blueprint To Build Different Types of Cells

An organism's DNA is organized into thousands of genes, and most genes code for a specific protein. (Others code for RNA.) If a gene is transcribed and translated into a protein, then it is being "expressed" in that cell, a process referred to as **gene expression**. A cell will not express all of its genes and therefore not all of the proteins that it has the potential to make. Instead, cells make a set of proteins specific to their role in the organism through what is known as **differential gene expression**. For example, muscle cells make a different set of proteins than do skin cells. The set of proteins manufactured by the cell will generate specific structures with specialized functions.

There are approximately 200 different human cell types, all arising from the initial cell that was created at fertilization as a result of an egg cell fusing with a sperm cell. How does one cell give rise to the diversity of cell types that make up a multicellular organism?

An embryo contains **stem cells**, which are capable of giving rise to any cell type. **Development** can be defined as the coordination of the fates of individual cells arising from stem cells. The cells arising from stem cells are genetically identical **clones** and yet they assume the fate of specific cell types as the organism develops.

The fate of a cell is based on which cell it was derived from (its ancestry) and on the position of the cell within the developing embryo. Cells receive **signals** from the cell from which they were derived and from their neighboring cells. These signals are molecules, such as growth factors, that guide cell development by directing the actions of certain genes. Gene expression during development can also be influenced by environmental factors (e.g., the abundance of an essential nutrient). This is a reason that a cloned organism may exhibit different features than its parent.

Same Genes, Different Fates emphasizes gene expression during development. However, the same mechanisms for gene expression occur throughout the life of an organism.

How Scientists Use Biotechnology to Study Gene Expression

Biotechnology is possible because of scientists' knowledge about DNA, genes, and the molecules that interact with DNA. The universality of the genetic code makes biotechnology possible, because a gene from one organism can to be transferred to another species, where it can be transcribed into mRNA and translated into a protein. Scientists can use biotechnology as a tool to study gene expression and to characterize proteins.

To understand gene expression, it is helpful to first review the anatomy of a gene. Every eukaryotic gene has both a **promoter** region and a **coding region**. The promoter region is in front of the coding region and has a specific nucleotide sequence that **transcription factors** and **RNA polymerase** recognize and bind to prior to **transcription**.

In order for transcription to occur, the promoter must be "active," meaning that it is accessible to these transcription factors and to RNA polymerase. Transcription occurs in the **nucleus** and results in synthesis of an **mRNA** strand complementary to the coding region of the gene. mRNA will then be processed and relocated to the cytoplasm where it will direct assembly of a polypeptide on a ribosome during **translation**. Thus, the presence of a specific protein indicates that the mRNA that codes for this protein was also present. Therefore, we know that the promoter for its gene was active, allowing transcription to occur.

Scientists can make recombinant DNA molecules containing the promoter and the coding region of a gene of interest. These recombinant molecules can then be incorporated into an organism through the use of a **vector**, such as a **plasmid**, to create a genetically engineered (transgenic) organism. In order to visualize expression of that particular gene within this organism, molecular biologists utilize a **reporter gene** linked to the promoter of the gene of interest. A reporter gene encodes for an **enzyme** whose activity can be visualized and, therefore, easily monitored. When the gene of interest is being expressed, its promoter will be active and will also drive the expression of the reporter gene.

The Elaboration phase of *Same Genes, Different Fates* refers to the results of an experiment using genetically engineered *Arabidopsis thaliana* to study gene expression. A small flowering plant in the mustard family, *Arabadopsis* is a **model organism** widely used for the study of genetics and development. Gene expression in plants is controlled in the same fashion as gene expression in animals, and thus plants can serve as excellent models for understanding gene expression in eukaryotic organisms. Research into gene expression in plants therefore has important implications for advances in medicine as well as agriscience.

In summary, the *Same Genes, Different Fates* module helps students learn how the genes encoded in DNA are expressed within cells and organisms. This knowledge underpins scientific content ranging from the diversity of species to the causes of disease. It also provides critical understanding of the basis for genetic research, development of gene therapies, and applications of biotechnology in research and industry.

5E INSTRUCTIONAL MODEL:
THE TEACHER'S ROLE

These instructional activities are consistent with each phase of the 5E model:

ENGAGEMENT

- Create interest.
- Generate curiosity.
- Raise questions.
- Elicit responses that uncover what students know or think about the concept/subject.

EXPLORATION

- Encourage students to work together without direct instruction from teacher.
- Observe and listen to students as they interact.
- Ask probing questions to redirect students' investigations when necessary.
- Provide time for students to puzzle through problems.
- Act as a consultant for students.

EXPLANATION

- Encourage students to explain concepts and definitions in their own words.
- Ask for justification (evidence) and clarification from students.
- Formally provide definitions, explanations, and new labels.
- Use students' previous experiences as the basis for explaining concepts.

ELABORATION

- Expect students to use formal labels, definitions, and explanations provided previously.
- Encourage students to apply or extend concepts and skills in new situations.
- Remind students of alternative explanations.
- Refer students to existing data and evidence and ask "What do you already know?" "Why do you think…?"

EVALUATION

- Observe students as they apply new concepts and skills.
- Assess students' knowledge and/or skills.
- Look for evidence that students have changed their thinking or behaviors.
- Allow students to assess their own learning and group process skills.
- Ask open-ended questions, such as "Why do you think…?" "What evidence do you have?" "What do you know about x?" "How would you explain x?"

Adapted from Bybee, R., Taylor, J., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness, and applications*. Colorado Springs, CO: BSCS.

CELL SIGNALING, GENE EXPRESSION, AND CELL DIFFERENTIATION ROLE-PLAY

Overview

There are approximately 200 different human cell types (e.g., nerve cells, muscle cells, blood cells, skin cells), all arising from the initial cell that was created at fertilization. How does this one cell give rise to all the cell types that make up a human? The short answer to this question is "gene expression." The DNA within each cell is organized into thousands of genes, and each gene typically codes for a specific protein. (Some genes code for RNA.) If a gene is activated and therefore produces a specific protein, we say that this gene is being "expressed" in that cell. Successful activation of specific proteins results in the cell serving a specific function in the body.

Gene expression relies on chemical signals that are sent and received by cells. This exploration activity demonstrates how gene expression can occur during embryonic development, with varied cell signals resulting in differentiation of cells into more specialized types.

Teacher's Preparation

Before the class begins, the teacher should:

- Print and cut (or fold) eight sets of cell type cards. Each set should include one- or two-sided cards with all these labels: STEM, MESODERM/ECTODERM, HEART/NERVE, MUSCLE/ CONDUCTION, and BRAIN/ SPINAL CORD. (Each kind of card can be printed on a different color to make the differentiation steps more visible to the class.)

- Cut one piece of BLUE ribbon 10 feet in length. (A one-inch-wide plastic ribbon, or flagging tape, works well for this activity, as it is durable and can be seen clearly across the classroom. Some alternatives are paper streamers or gift ribbon.)
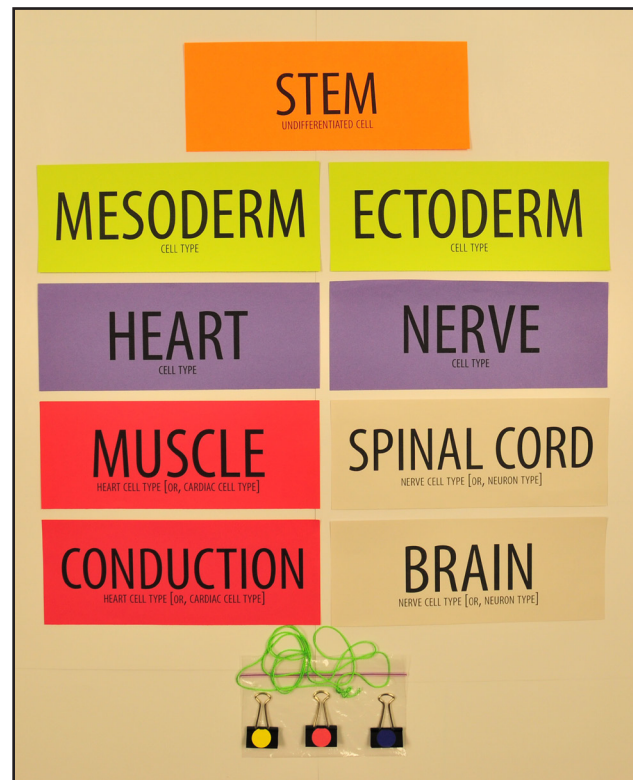
MATERIALS FOR EACH STUDENT ROLE-PLAYER: SET OF CELL TYPE CARDS, THREE COLOR-CODED BINDER CLIPS, ONE SMALL BAG WITH LONG LOOP OF STRING ATTACHED.

- Cut one piece of RED ribbon five feet in length.

- Cut one piece of YELLOW ribbon five feet in length.

- Place a red sticker on each of eight binder clips. (One-and-a-quarter-inch clips work well, as they are neither too big nor too small for the students to hold comfortably.)

- Place a blue sticker on each of eight binder clips.

- Place a yellow sticker on each of eight binder clips.

- Prepare eight small plastic bags (small snack bags work well), each containing a set of three binder clips (one red, one blue, one yellow). *Optional: Label each bag "Receptors." Also, number the bags (1, 2, etc.) to remind the class of the cells' initial positions in relation to the external environment. Ask volunteers to stand in numerical order before the role-play begins.*

- Cut eight pieces of string or yarn three feet in length.

- Punch or cut a small hole in each upper corner of the bags. Thread the string or yarn through the holes, then knot it. (Now each plastic bag filled with three binder clips can be worn by the student playing the role of a cell, leaving the student's hands free to hold the cell cards and manipulate the binder clips as needed.)

Extend the Engagement Activity (Optional)

REVIEW PRIOR KNOWLEDGE

Before Step 1, reinforce students' understanding of mitosis by beginning the role-play with only one stem cell, which will "divide" (i.e., another student volunteer will join the first student volunteer at the front of the room). Continue this process of cell division and exponential growth until there are eight stem cells (student role-players) at the front of the room. Give every student a bag of binder clips (receptors) and set of cell type cards, and point out to the class that every stem cell contains exactly the same set of genetic instructions (DNA) and potential to differentiate into any of the cell types needed by the organism of which it is a part.

During Step 3, draw upon students' knowledge of the cardiovascular and central nervous systems to describe the functions of the specialized cells that develop.

INTRODUCE THE CONCEPT OF GERM LAYERS

Before Step 1, ask students to imagine that they are all stem cells in a human embryo. Explain that their eventual "fates"— the types of specialized cells they will give rise to—will be determined by their locations within the embryo. Designate the rows of students nearest the classroom windows (i.e., nearest the environment outside the embryo) as "ectoderm" cells and explain that the prefix "ecto" means "external" or "outer." Then designate the students in the middle rows of the classroom as "mesoderm" cells and explain that "meso" means "middle." Finally, designate the rows of students farthest from the windows as "endoderm" cells and explain that "endo" means "within" or "inner." Now ask for four volunteers from the "ectoderm" section and four volunteers from the "mesoderm" section. These will be the eight volunteers needed for the engagement activity.

EXPLORE ALTERNATIVE OUTCOMES

After conducting the role-play activity as outlined in this guide, conduct the activity again with variations to further indicate how environment can influence gene expression and cell differentiation and development. Some suggested variations:

• Flicker the classroom lights on and off to indicate a harmful event. In this case, the developing organism lacks sufficient amounts of a nutrient needed for successful development of the brain and spinal cord. To reflect this event: after Step 2, ask one or more of the nerve cells to drop their remaining binder clips. The result will be seen in Step 3, when one or more nerve cells without receptors cannot bind to the signal that initiates gene expression and differentiation into brain or spinal cord cells. As an example, this can demonstrate the effects of folic acid deficiency, which may lead to spina bifida.

• Before the role-play begins, ask a student seated in the classroom (not one of the cell type role-players) to play the role of "harmful environmental event." The teacher can decide on what this event could be, or the class can discuss and together decide on the event. Examples: exposure to alcohol or other toxic substance, exposure to radiation, exposure to rubella (which can cause defects in the cardiac and central nervous systems), or nutrient deficiency. Instruct the student to come forward at some point during the role-play (this role-player will decide when the event will occur) and select one of the cell type role-players. The selected cell type role-player returns to her/his seat, leaving a gap in the line of cells at the front of the class. The role-play activity proceeds without this cell present to receive or transmit signals or to carry out its potential specialized function in the organism.

• Discuss the effect that an inherited genetic defect could have in the role-play scenario.

• Invite the students to consider how an understanding of the process they have witnessed in the role-play activity can be helpful in agriculture or medicine.

COVER ADDITIONAL CONTENT

More cell types. Ask students to imagine that they are all stem cells and that their classroom is an embryo. This could be a human embryo, or the class could decide together that they are another embryonic vertebrate. Based on where they usually sit in the classroom, where in the organism would each of them be developing: endoderm, mesoderm, ectoderm? Ask students to focus on specialized cells they did not see in the role-play activity. Given this positioning, what specialized cell type could each of them potentially develop into? Provide this as a homework assignment: each student will determine her/his specialized cell type based on seat position in the classroom, explain the reasoning behind this determination, research the cell type, make a simple drawing of the cell type, and describe this cell's function(s) in the organism.

Endoderm. The role-play activity provided in this guide focuses on the ectoderm and mesoderm. Divide students into groups of four to eight members. Ask each group to research the cell types that arise from stem cells located in the endoderm and develop a script and set of cell type cards so that they can demonstrate cell signalling, gene expression, and cell development in the endoderm.

Plant cells. The role-play activity provided in this guide focuses on animals. Divide the class into groups of four to eight students. Ask each group to research the cell types that can arise in plants. Each group then develops a script and set of cell type cards so that they can demonstrate cell signalling, gene expression, and cell development in a plant.

CELL DIFFERENTIATION AND SPECIALIZATION ROLE-PLAY: **STEP ONE**

| STEM | STEM | STEM | STEM | STEM | STEM | STEM | STEM |

INFORMATION FOR THE TEACHER

Genes turn on or off in response to chemical signals. Some of the genes required for cell differentiation respond to signals that are internal to the cell. For instance, early in embryonic development, stem cells respond to internal signals related to their positions within the organism, and this results in their differentiation into ectoderm, mesoderm, and endoderm cells.

The three steps of this role-play activity provide a simplified view into the highly complex processes of cell signalling, gene expression, and cell differentiation—indeed, processes that are still being explored in research laboratories.

At this step of the classroom scenario, which focuses on the mesoderm and ectoderm, the teacher tells the class that cells (student role-players) on one half of the line are near the outside of the organism (ectoderm) and that cells on the other half of the line are nearer the middle of the organism (mesoderm).

WHAT THE TEACHER DOES IN THE CLASSROOM

A. Invite 8 students to volunteer to come to the front of the class and play the role of stem cells. Provide each volunteer with a set of stem-cell cards and a snack bag filled with three color-coded binder clips (1 blue, 1 red, 1 yellow). Instruct these student role-players to display their "STEM" cards for the entire class to see.

B. Explain that the stem cells at the front of the classroom are exactly alike and bear the same genetic instructions (DNA). Stem cells are capable of cell division—mitosis—and thus creating "clones" (i.e., cells exactly like themselves). Most important to this demonstration is the fact that stem cells are undifferentiated cells and, depending on the genes they express, can give rise to any type of cell that could realistically be in the organism that is developing.

C. Explain that early in embryonic development, differentiation of stem cells into more specific cell types depends on the positions of the stem cells within the organism. A stem cell can react to internal chemical signals that relate to its position near the outside of the organism (ectoderm), its position in the middle of the organism (mesoderm), or its position in the center of the organism (endoderm).

D. **Indicate that half the line of stem cells (student role-players) is near the outside of the organism and the other half is in the middle of the organism.** Explain that they will, internally, be both emitting and receiving chemical signals because of their positions in the organism. They have internal receptors that enable them to bind to these signals, which cause specific genes to be expressed and lead to differentiation.

E. Instruct the stem cells to become mesoderm or ectoderm cells (each showing the class the appropriate "MESODERM" or "ECTODERM" card) depending upon where they are standing. Alternatively, involve the rest of the class by first asking them to tell you which types of cells the role-players will become based on their positions.

F. To illustrate that the cell types are acquiring different characteristics as they develop, **instruct the mesoderm cells to remove the blue binder clips from their bags and place these clips on the floor.** They will no longer have the ability to use these receptors.

| MESODERM | MESODERM | MESODERM | MESODERM | ECTODERM | ECTODERM | ECTODERM | ECTODERM |
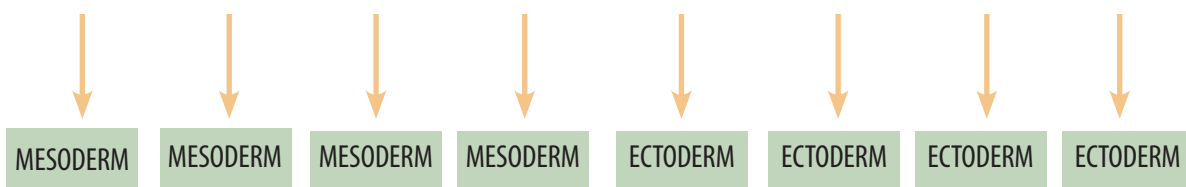
CELL DIFFERENTIATION AND SPECIALIZATION ROLE-PLAY: **STEP TWO**

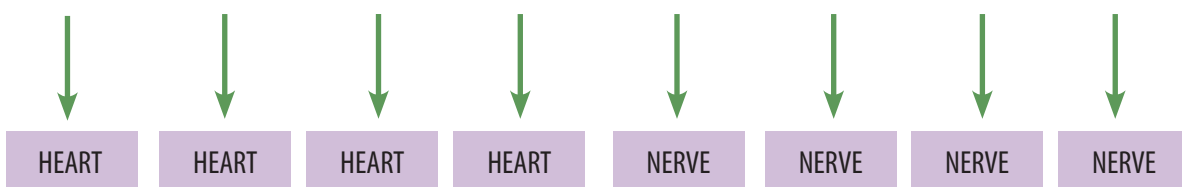| MESODERM	MESODERM	MESODERM	MESODERM	ECTODERM	ECTODERM	ECTODERM	ECTODERM

INFORMATION FOR THE TEACHER

While some of the chemical signals required for differentiation are internal to the cell, many others are transmitted from cell to cell.

In this classroom scenario, cells of the notochord (a column of cells on the back of an embryonic vertebrate) send signals that switch on genes in the ectoderm cells. These activated genes are needed for differentiation into nerve cells.
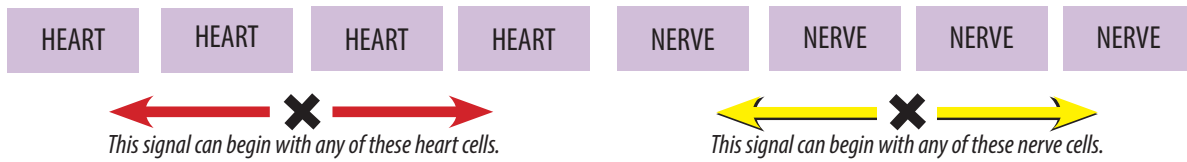
The teacher uses a blue ribbon to demonstrate this signal, while the ectoderm cell role-players use blue binder clips to mimic the cells' receptors binding to this signal. The mesoderm cells, which do not bind to this signal, differentiate into cardiac cells.

WHAT THE TEACHER DOES IN THE CLASSROOM

A. Invite the class to consider what the ectoderm and mesoderm cells might become through further differentiation. Can the students think of tissue types found on or near the outside of an animal, in this case a human (e.g., skin, spine, eye, hair, nail). What tissue types could we expect to find nearer the middle of the organism (e.g., heart, kidney, bone, connective tissue under the skin)? *The lungs, liver, and pancreatic are examples of tissue types arising from the endoderm (inner part).*

B. Explain that you (or a student volunteer) will play the role of molecules carrying chemical signals through the ectoderm. If it is appropriate to your lesson plan, discuss the notochord as the source of the signals in this example.

C. Explain that the binder clips represent receptors that are typically located on the cell membrane. These receptors enable cells to bind to chemical signals that can switch the genes on or off.

D. **Hold one end of the blue signal tape and distribute the rest as you walk along the line of ectoderm cells. Instruct the ectoderm cells to bind to the signal ribbon with their blue binder clips (receptors). All the ectoderm cells will bind to the signal ribbon, become nerve cells, and display their "NERVE" cards.**

E. The mesoderm cells, which now have no blue binder clips, cannot bind to the blue signal ribbon. Explain that their fate is to respond to different signals (which you will not act out today) and become cardiac cells. Instruct these students to display their "HEART" cards.

F. Discuss: Did the class mention the heart in their earlier discussion of the mesoderm cells' potential fates? Did they expect these cells to differentiate into cardiac cells? Did they expect the ectoderm cells to become nerve cells? Can the nerve cells become even more specialized? What does the class think the nerve cells can become?

HEART	HEART	HEART	HEART	NERVE	NERVE	NERVE	NERVE

CELL DIFFERENTIATION AND SPECIALIZATION ROLE-PLAY: **STEP THREE**

| HEART | HEART | HEART | HEART | NERVE | NERVE | NERVE | NERVE |

This signal can begin with any of these heart cells.   *This signal can begin with any of these nerve cells.*

INFORMATION FOR THE TEACHER

Cell-to-cell communication requires certain conditions in order to succeed in activating genes. For instance, some types of communication may be possible only among cells of the same type, among cells that are adjacent to or touching each other, or when a particular combination of signals is received.

In this classroom scenario, the heart cells that successfully receive one kind of signal become cardiac muscle cells, while the heart cells that do not receive this signal become cardiac conduction cells. Then, the neurons that successfully receive another kind of signal become spinal cord cells, while the remaining neurons become brain cells.

The types of cells arising at this step in the demonstration may vary, depending on the locations of the cells (student role-players) with respect to the signals.

WHAT THE TEACHER DOES IN THE CLASSROOM

A. Instruct the volunteers to stay in position throughout this step (i.e., they should not deliberately move closer to or farther away from their neighbors). **Give the entire red ribbon signal to one heart cell (student role-player).** Instruct that heart cell to bind to the signal with a red clip, become a cardiac conduction cell (displaying a "CONDUCTION" card), and send the signal (distribute the ribbon) to one or both of her/his neighbor cells that have any part of their clothing touching her/his clothing. These one or two cells bind to the red ribbon signal with their red clips, become cardiac conduction cells, and also display "CONDUCTION" cards. *This demonstrates contact-dependent cell signaling.*

B. In this classroom scenario, the remaining heart cells, which are not touching the signalling cell, become cardiac muscle cells. Instruct these students to display their "MUSCLE" cards.

C. Briefly discuss the functions of these specialized heart cells. If the students have previously studied the cardiovascular system, ask them to explain why the heart needs conduction and muscle cells.

D. **Give the entire yellow ribbon signal to one nerve cell (student role-player).** Instruct that nerve cell to bind to the ribbon signal with a yellow clip, become a spinal cord cell (displaying a "SPINAL CORD" card), and distribute the ribbon signal to the one or two nerve cells that are directly next to her/him. Those one or two cells bind to the yellow ribbon signal with their yellow clips, become spinal cord cells, and also display "SPINAL CORD" cards. *This demonstrates signaling among adjacent cells.*

E. In this classroom scenario, the remaining one or two nerve cells, which are not directly next to the signalling cell, become brain cells. Instruct these students to display their "BRAIN" cards.

F. Explain that there are approximately 200 different human cell types, all arising from the single cell created at fertilization.

| MUSCLE | MUSCLE | CONDUCTION | CONDUCTION | SPINAL CORD | SPINAL CORD | BRAIN | BRAIN |
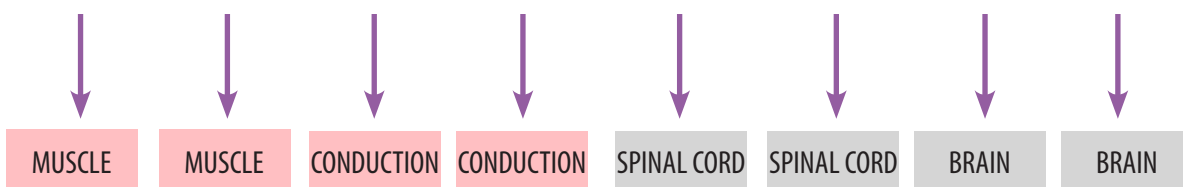
STEM

UNDIFFERENTIATED CELL

STEM

UNDIFFERENTIATED CELL

MESODERM

CELL TYPE

ECTODERM

CELL TYPE

HEART

CELL TYPE

NERVE

CELL TYPE

MUSCLE

HEART CELL TYPE [OR, CARDIAC CELL TYPE]

CONDUCTION

HEART CELL TYPE [OR, CARDIAC CELL TYPE]

BRAIN

NERVE CELL TYPE [OR, NEURON TYPE]

SPINAL CORD

NERVE CELL TYPE [OR, NEURON TYPE]

SPECIALIZED CELL STRUCTURE AND FUNCTION PUZZLE

Overview

During the Exploration phase of *Same Genes, Different Fates*, students learned that stem cells carrying the same genetic "instructions" can, through the process of gene expression, give rise to cells with different structures and different functions. Students now explore the structures and functions of specialized cells. They also discuss the role this information can play in scientific research and the development of solutions to real-world issues.

Teacher's Preparation

Before the class begins, the teacher should:

- Plan to divide the class into groups of four to six students. (Assigning tasks is one way to assure that all students will be involved in the activity. For groups of six students: one student can be in charge of completing the worksheet, while each of the other students can be in charge of making sure that all five puzzle cards for one cell type are matched.)

- Print and cut out one set of puzzle cards per group. Each set will include 25 different cards. There are five cards for each of the five cell types being discussed in this activity:

    » Illustrated card showing the cell's structure.

    » Label (subject) card telling the cell's name: fat cell, intestinal cell, macrophage, muscle cell, and nerve cell.

    » Verb card telling the cell's main action: stores, absorbs, devours, contracts, and receives & transmits.

    » Object card telling what the cell acts upon: energy, nutrients, pathogens, parts of the body, and impulses.

    » Description card giving more facts about the cell's structure, function, and/or nomenclature.

- Copy one worksheet for each group.

- Write one or more of these questions on the blackboard or whiteboard at the front of the class:

    » How could a researcher use knowledge about a specialized cell's function to develop a

therapy for a medical condition?

» How could a researcher use knowledge about gene expression and a specialized cell's function to develop a therapy for a medical condition?

» Focus on one cell type and, as a group, decide how gene expression and this cell type could be used to develop a therapy for a specific medical condition.

» When developing a gene therapy, would it be helpful to know if certain environmental factors (e.g., temperature, light, nutrition) affected gene expression?

What the Teacher Does in the Classroom

1. Distribute the five illustrated cards (fat cell, intestinal cell, macrophage, muscle cell, nerve cell) to each group. Hold the rest of the cards back, as they will be used later in this activity.

2. Instruct the students: "Within your group, observe the structures of the different human cell types illustrated on the cards. Taking into account the cell's shape and any other features presented, guess the cell's name and function in the human body."

3. Bring the class together to discuss the guesses that each group made about the illustrations of the five cell types. Ask them about their reasoning. Do not confirm whether the guesses are correct or incorrect.

4. Distribute the remaining cards. Each group should now have a complete set of 25 cards.

5. Instruct the students to work together within their groups to match the cards in order to identify the correct labels, descriptions, and illustrations for five cell types. Tell them that there are five cards specifically associated with each cell type.

6. Offer this hint to the students: "Use what you know about sentence structure. Find the subject, verb, and object to form a sentence about each cell type. When placed in the correct order, the cards should form short paragraphs about the cells."

7. As groups finish correctly matching their cards, they may complete their worksheets. They may also begin discussing, within their groups, the question or questions displayed on the board at the front of the class.

8. When all the groups are ready, bring the class together for a class discussion. Begin by asking, "How close to reality were your group's initial guesses about the illustrations' names and functions?"

9. Continue the class discussion by asking the students to share their ideas about the questions listed above.

Extend the Exploration Activity (Optional)

More animal cell types. Ask students, individually or in teams, to research and develop puzzle cards for additional animal cell types. For each cell type, they should prepare five cards: an illustrated card showing the cell's structure, a label (subject) card telling the cell's name, a verb card tell-

ing the cell's main action, an object card telling what the cell acts upon, and a final card giving more facts about the cell's structure and/or function. When placed in the correct order, the cards should form a short paragraph about the cell. When all the sets of new cards are complete and have been checked for accuracy, pass them around the classroom so that other students can put the sets together and learn about these cell types.
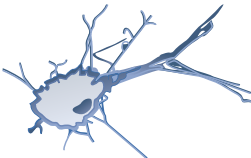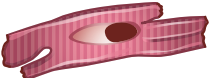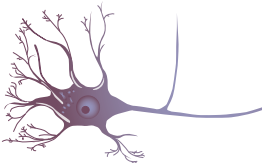
Plant cell types. Ask students to develop cards for cell types found in plants. Follow the same procedure as for the animal cell types.

Cell types in the context of systems. Ask students to identify the role that each specialized cell type plays in the relevant system or systems.

SPECIALIZED CELL TYPES

KEY

STRUCTURE	NAME	FUNCTION		MORE INFORMATION
Illustration	*Subject*	*Verb*	*Object*	*Last part of the sentence*
	A FAT cell	stores	energy	as triglycerides, a type of fat. Leftover calories from food are turned into triglycerides and stored for later use. Stored fat pushes the nucleus to the side of the cell. This cell is also called an <u>adipocyte</u>.
	An INTESTINAL cell	absorbs	nutrients	from food in the intestines. Small finger-shaped projections (microvilli) increase the cell's surface area. This cell is also called an <u>enterocyte</u>.
	A MACROPHAGE	devours	pathogens	(disease-causing organisms or viruses) that invade the body. This large cell also devours debris (e.g., dead or dying cells) resulting from the body's processes. Its name derives from the Greek words for <u>large</u> and <u>eat</u>.
	A MUSCLE cell	contracts	parts of the body	(e.g., the joints during an activity like walking, the uterus during childbirth, the heart during blood circulation). This cell is also called a <u>myocyte</u>.
	A NERVE cell	receives & transmits	impulses	in the nervous system. The structure of this cell includes a body, dendrites (branched extensions from the body that receive impulses), and an axon (that transmits impulses). This cell is also called a <u>neuron</u>.
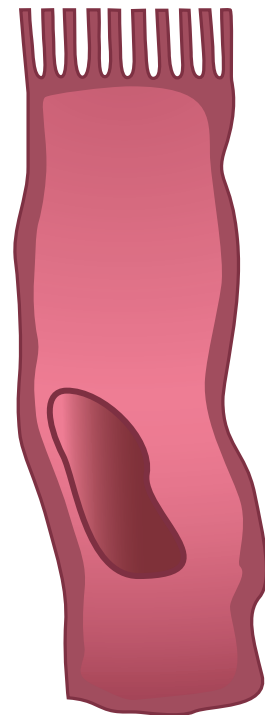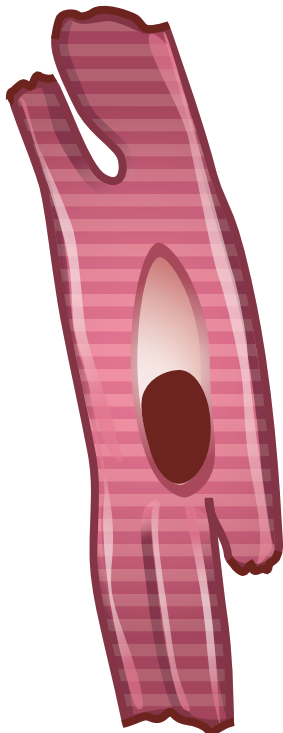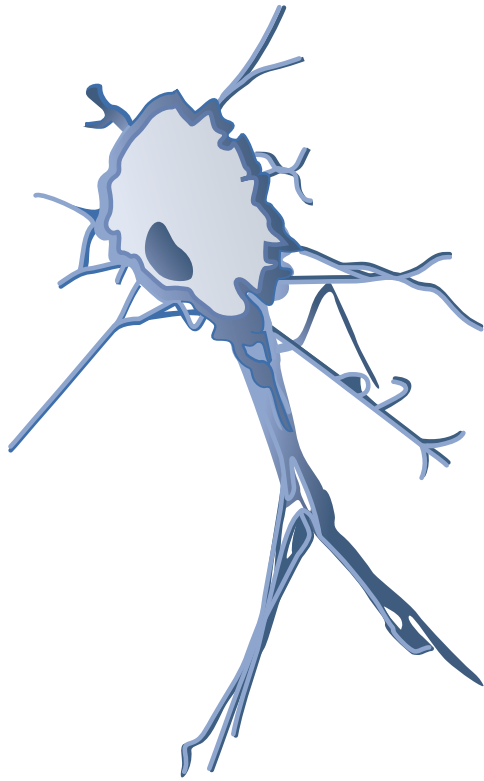
A **FAT** cell

An **INTESTINAL** cell

A **MACROPHAGE**

A **MUSCLE** cell

A **NERVE** cell

stores	energy
absorbs	nutrients
devours	pathogens
contracts	parts of the body
receives & transmits	impulses

as triglycerides, a type of fat. Leftover calories from food are turned into triglycerides and stored for later use. Stored fat pushes the nucleus to the side of the cell. This cell is also called an <u>adipocyte</u>.

from food in the intestines. Small finger-shaped projections (microvilli) increase the cell's surface area. This cell is also called an <u>enterocyte</u>.

(disease-causing organisms or viruses) that invade the body. This large cell also devours debris (e.g., dead or dying cells) resulting from the body's processes. Its name derives from the Greek words for <u>large</u> and <u>eat</u>.

(e.g., the joints during an activity like walking, the uterus during childbirth, the heart during blood circulation). This cell is also called a <u>myocyte</u>.

in the nervous system. The structure of this cell includes a body, dendrites (branched extensions from the body that receive impulses), and an axon (that transmits impulses). This cell is also called a <u>neuron</u>.

Name(s):

SPECIALIZED CELL TYPES

STRUCTURE	NAME	FUNCTION		MORE INFORMATION
Illustration	Subject	Verb	Object	Last part of the sentence

Use the back of this page if more room is needed.

"WHAT CONTROLS GENE EXPRESSION?" CONCEPT MAP

Overview

Concept maps are an ideal way to assess student understanding and encourage higher order thinking. In this module, concept mapping provides a way for students to organize graphically the key concepts underlying gene expression they are learning and explain them in their own words (linker statements).

Students will complete a concept map to address the question "What Controls Gene Expression?" They will focus on these key terms:

cell	mRNA	signals
DNA	nucleus	transcription
genes	promoters	translation
gene expression	proteins	

Three versions of the "What Controls Gene Expression?" concept map worksheet are provided for the teacher to choose from. The first worksheet provides the list of key terms and requires the student to create the nodes and linker statements. The second worksheet requires the student to fill in the nodes between given linker statements. The third worksheet requires the student to compose linker statements between given nodes.

What Is a Concept Map?

A concept map consists of nodes or cells (generally circles or boxes, each of which contains a concept, vocabulary term, or question) and labeled propositions (linker statements) that explain the relationship between the nodes. Nodes and their corresponding linker statements should read like sentences. Arrows on the links are used to indicate the direction in which the sentences should be read.

What to look for in a good concept map:

- Concepts are represented in a hierarchical fashion with the most general concepts at the top of the map and the more specific, less general concepts below.

- Nodes on the concept map are connected by propositions or cross-links. Forming these connections between different concepts or terms is a fundamental step in the learning process.
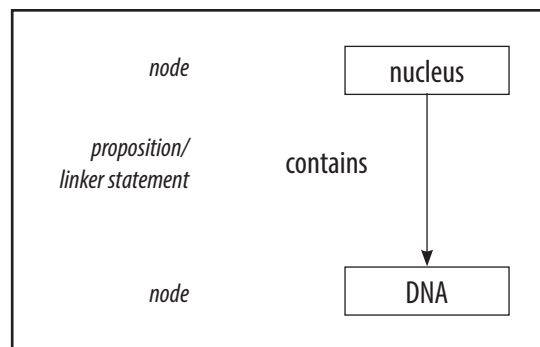
When learning how to make a concept map, it can be helpful to construct one using terms that are familiar. An example of a concept map is provided on a following page. This concept map was constructed to address the question "What items are found in the produce section at a grocery store?"

Teacher's Preparation

Before the class begins, the teacher should:

- Plan to have students work as individuals or divide the class into groups of two to four students.

- Make copies of the version of the "What Controls Gene Expression?" concept map worksheet that best fits the class's current level of understanding. Make one copy per student or group.

- Secure and test an overhead projector or document camera with which to display "Figure 1: Gene Expression."

- If carrying out optional Step 5, write the key terms on the blackboard or whiteboard at the front of the class so that students can refer to them as they work.

What the Teacher Does in the Classroom

1. (Optional) Divide the class into small groups of two to four students.

2. Distribute copies of a blank "What Controls Gene Expression?" concept map worksheet to individual students or to groups.

3. Explain how a concept map is constructed.

4. Explain to the students that they will be constructing a concept map to address the question "What Controls Gene Expression?" They must use all the key terms on their worksheets as a guide.

5. (Optional) Before explaining the key terms to them, ask the students to turn the worksheet over and, on the blank side, attempt to use the key terms (which have been written on the blackboard or whiteboard at the front of the class) to construct a concept map based on their current knowledge.

6. Ask the class if there are key terms that they need to know more about in order to feel confident about completing the concept map accurately. While explaining, refer to "Figure 1: Gene Expression" so that students can make visual connections among the concepts:

   Every gene has both a promoter region and a coding region. The promoter region is in front of the coding region and has a specific nucleotide sequence that transcription factors and RNA polymerase recognize and bind to prior to transcription. In order for transcription to occur, the promoter must be "active," meaning that it is accessible to these transcription factors and RNA polymerase.

   Transcription will result in synthesis of an mRNA strand complementary to the coding

region of the gene. mRNA will then be processed and relocated to the cytoplasm where it will direct assembly of a polypeptide on a ribosome. Thus, the presence of a specific protein indicates that the mRNA that codes for this protein was also present. Therefore, we know that the promoter for its gene was active, allowing for transcription to occur.

7. Focus the class on answering the question "What Controls Gene Expression?" Ask student volunteers to explain to the class how they would answer this question in their own words. Commend these volunteers and gently correct any misconceptions.

8. Ask the class to complete the concept map on their worksheets.

9. (Optional) Leave "Figure 1: Gene Expression" on display so that students may refer to it while they complete their concept maps.

10. Lead a class discussion of the students' concept mapping results. One way to do this: have the class work together to create one concept map on the blackboard or whiteboard at the front of the room. Groups or individual students can take turns placing key terms on the board and writing linking statements until the map is complete. The rest of the class can share different choices they made (e.g., in the wording of linking statements).

Bibliography

Novak, J. D., & Cañas, A. J. (2008, January). The theory underlying concept maps and how to construct and use them. Retrieved from http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf.

EUKARYOTIC
CELL

CYTOPLASM

GENE STRUCTURE

gene
(single strand)

DNA
(double helix)

Promoter

Coding region
(translated into mRNA)

NUCLEUS

DNA

TRANSCRIPTION

mRNA

NUCLEAR
PORES

CYTOPLASM

TRANSLATION
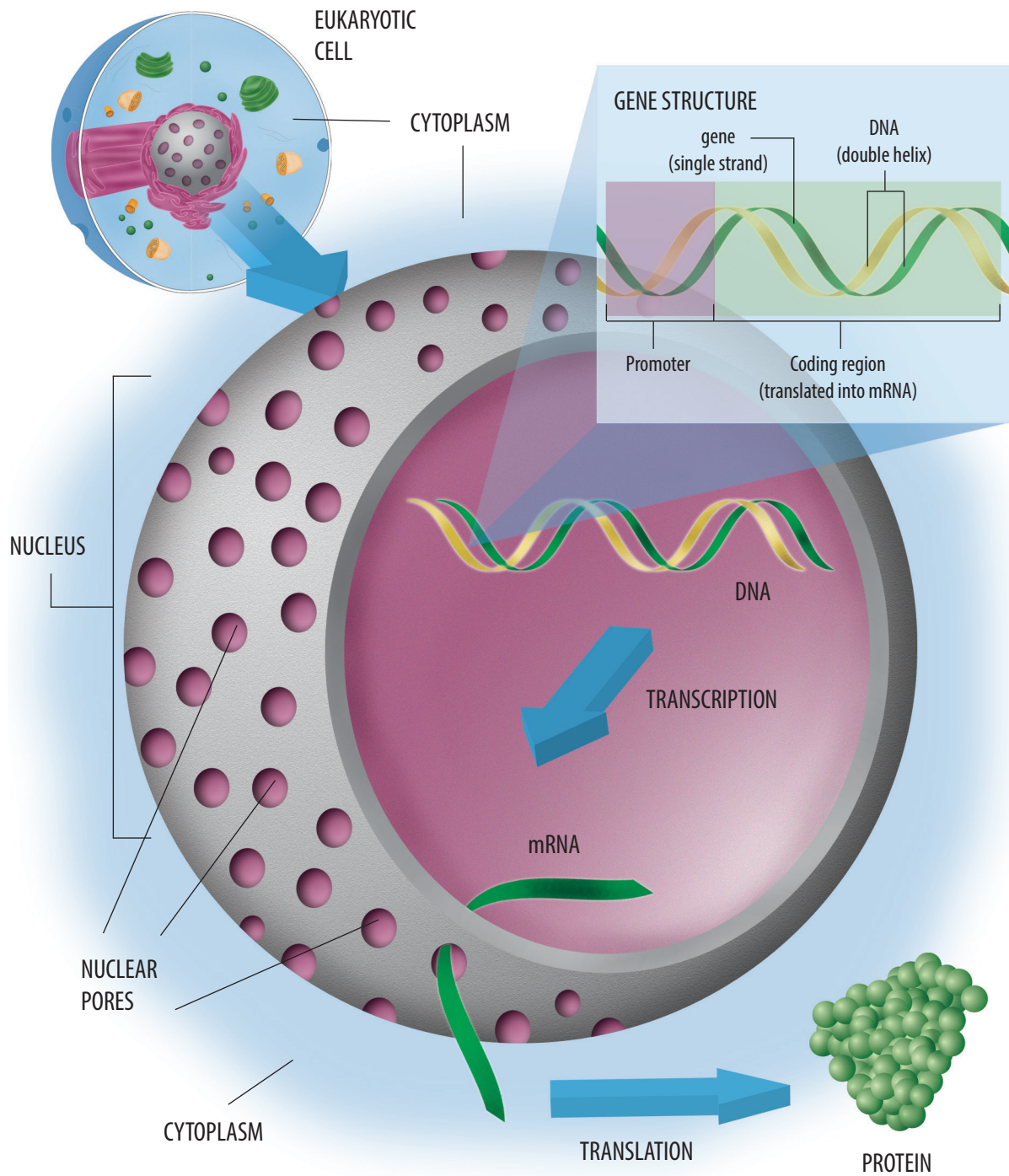
PROTEIN

Promoter X must be ACTIVE if gene X is going to be transcribed into mRNA and translated into protein.

Promoter X   gene X   Transcription   mRNA   Translation   protein X
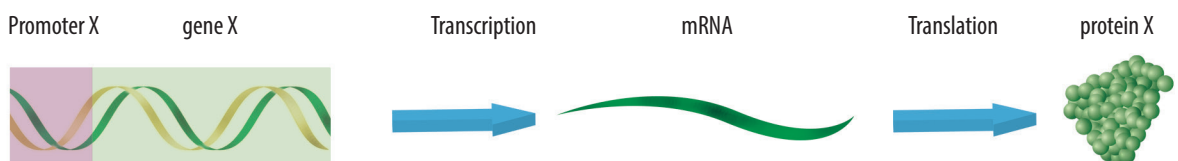
CONCEPT MAP EXAMPLE
WHAT ITEMS ARE FOUND IN THE PRODUCE SECTION AT A GROCERY STORE?

produce section — contains products that come from → plants

produce section — consists of → fruits

produce section — consists of → vegetables

fruits — contain one or more → seeds

fruits — may be → sweet

vegetables — do not contain → seeds

vegetables — can be → plant roots

plants — consist of → plant shoots

plants — consist of → whole plants

plant roots — include → carrots

plant shoots — include → broccoli

whole plants — include → bean sprouts

sweet — fruits include → berries
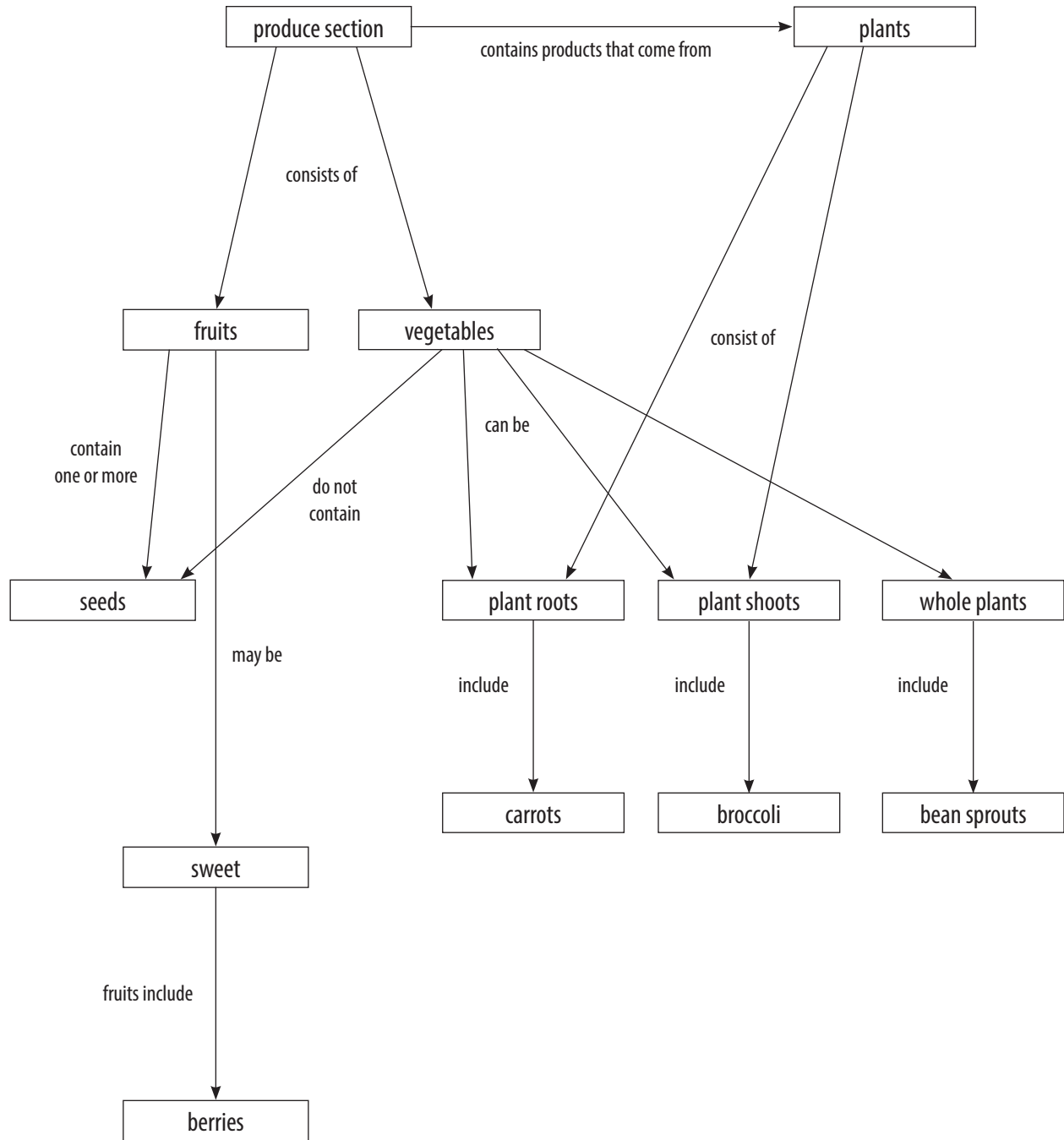
Name(s):

WHAT CONTROLS GENE EXPRESSION?

Use all the words below to construct a concept map.

cell
DNA
genes
gene expression
mRNA
nucleus
promoters
proteins
signals
transcription
translation

Name(s):

WHAT CONTROLS GENE EXPRESSION?

Use all the words below to construct a concept map.

contains
hereditary
information
called

is
organized
into

contains

can be turned
on/off in response to

provide
instructions
to make

contain special
DNA sequences
called

are the
product of

are
required
for

can be internal
or external
and can influence

cell
DNA
genes
gene expression
mRNA
nucleus
promoters
proteins
signals
transcription
translation

is a process
that copies
DNA into

requires

together
result in
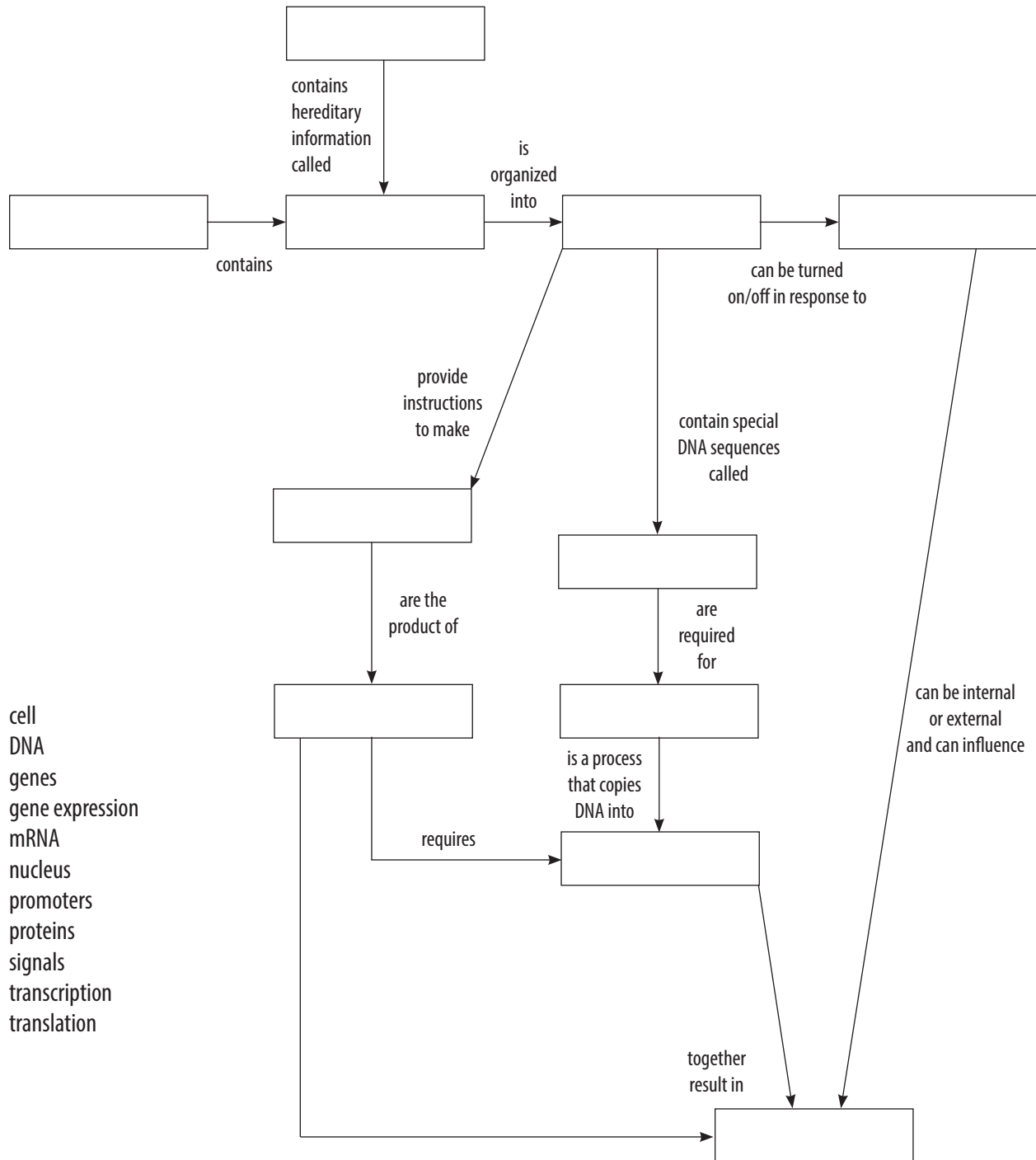
Name(s):

WHAT CONTROLS GENE EXPRESSION?

Complete this concept map by adding linker statements.
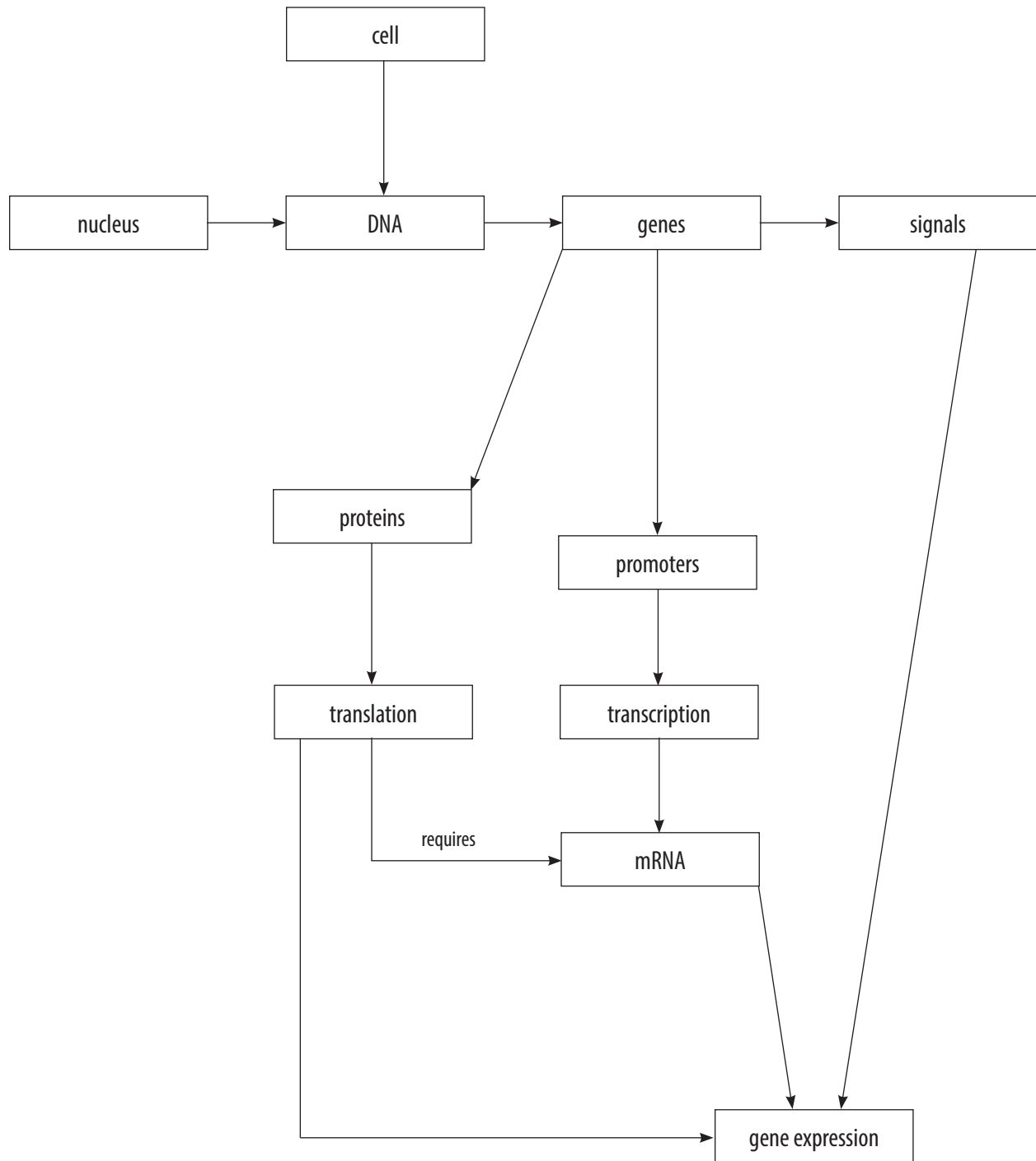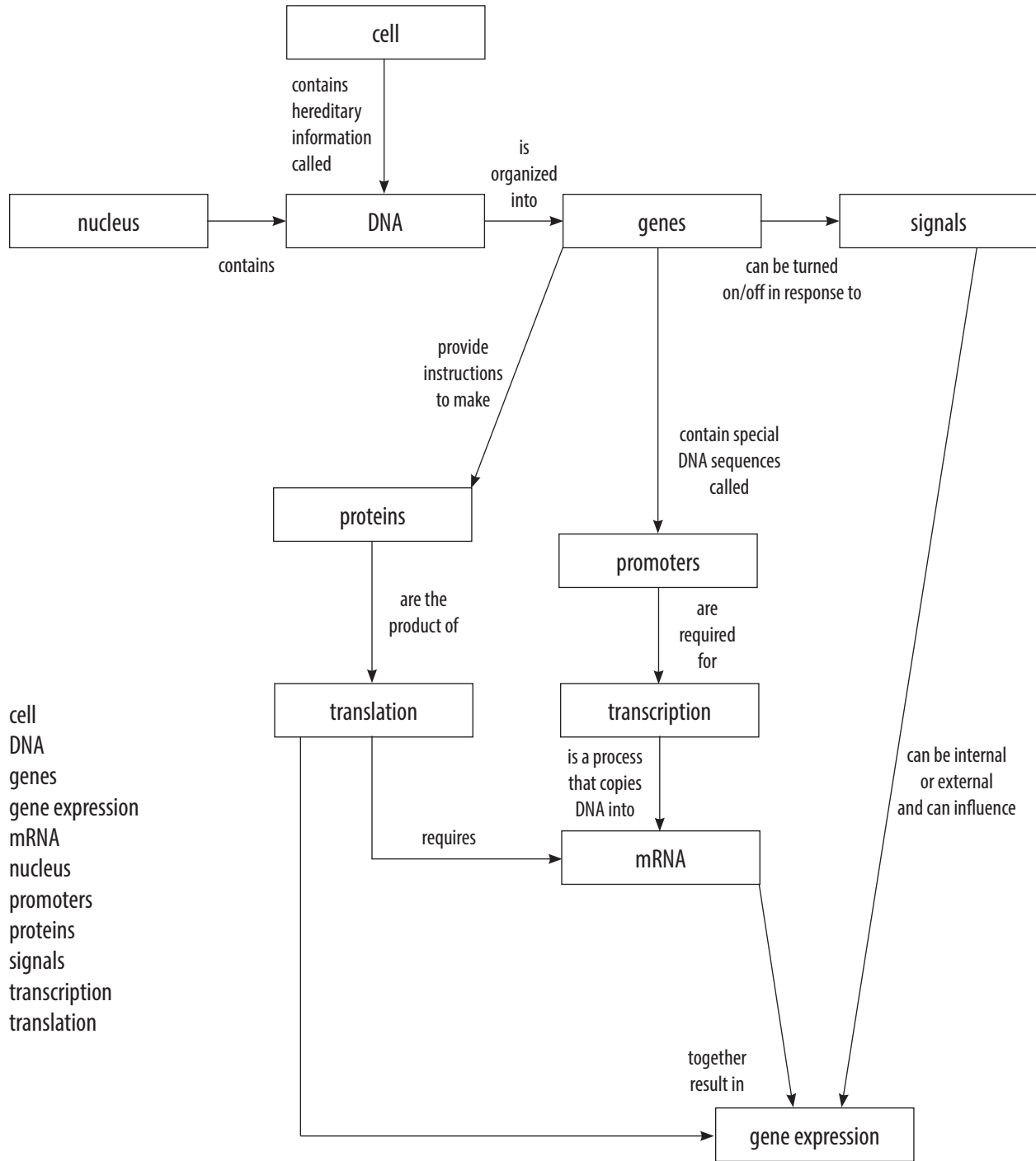
```
                        ┌──────────┐
                        │   cell   │
                        └──────────┘
                             │
                             ▼
┌──────────┐      ┌──────────┐      ┌──────────┐      ┌──────────┐
│ nucleus  │ ───▶ │   DNA    │ ───▶ │  genes   │ ───▶ │ signals  │
└──────────┘      └──────────┘      └──────────┘      └──────────┘
                                   ╱      │                    │
                                  ╱       │                    │
                                 ▼        ▼                    │
                          ┌──────────┐  ┌──────────┐           │
                          │ proteins │  │promoters │           │
                          └──────────┘  └──────────┘           │
                               │             │                 │
                               ▼             ▼                 │
                          ┌──────────┐  ┌──────────────┐       │
                          │translation│ │transcription │       │
                          └──────────┘  └──────────────┘       │
                             │    │          │                 │
                             │    │ requires ▼                 │
                             │    └───▶ ┌──────────┐            │
                             │          │  mRNA    │            │
                             │          └──────────┘            │
                             │               │                 │
                             ▼               ▼                 ▼
                          ┌──────────────────────────────────────┐
                          │           gene expression            │
                          └──────────────────────────────────────┘
```

WHAT CONTROLS GENE EXPRESSION?

cell

contains
hereditary
information
called

is
organized
into

nucleus → DNA → genes → signals

contains

can be turned
on/off in response to

provide
instructions
to make

contain special
DNA sequences
called

proteins

promoters

are the
product of

are
required
for

cell
DNA
genes
gene expression
mRNA
nucleus
promoters
proteins
signals
transcription
translation

translation

transcription

is a process
that copies
DNA into

requires

mRNA

can be internal
or external
and can influence

together
result in

gene expression

PREDICTION AND ANALYSIS OF *ARABIDOPSIS* EXPERIMENT RESULTS

Overview

One aspect of understanding a gene's function is to learn where within an organism a gene is expressed. During this Elaboration activity, students will be predicting and analyzing results of an experiment involving two different genes that appear to be important in plant growth and development.

Molecular biologists have proposed possible functions for these two genes:

> **gene *9A*** encodes a protein that is thought to be involved in chlorophyll production.

> **gene *4C*** encodes a protein that is thought to be involved in root cell division.

A second aspect to understanding a gene's function is determining if environmental signals alter gene expression and, if so, in which tissues. In this activity, students will also have the opportunity to investigate expression of gene *4C* in environments with contrasting levels of nitrogen (NO_3^-), an important building block that plants use to make molecules such as nucleic acids, amino acids, and chlorophyll.

Derived from research in plant molecular biology led by Dr. Alan M. Jones at UNC-Chapel Hill, this activity involves differential GUS expression in intact *Arabidopsis* plants. GUS (β-glucuronidase) is an enzyme derived from bacteria whose expression can be observed by the conversion of a colorless, chromogenic substrate into a blue-colored product. The gene encoding for GUS is commonly used as a reporter gene in recombinant DNA technology applications. Cells that are expressing GUS are simultaneously expressing the gene of interest.

Teacher's Preparation

Before the class begins, the teacher should:

- Plan to have students work as individuals or in groups of two to four students.

- Make one copy of both worksheets ("*Arabidopsis* Experiment: Predicting Results" and "*Arabidopsis* Experiment: Analyzing Results") per student or group.

- Secure and test an overhead projector or document camera with which to display "Figure 1: Gene Expression" (optional, included in the Explanation activity), "Figure 2: How to Make a Transgenic Plant" (optional), "Figure 3: Analyzing Experiment Results," "Figure 4: Labeled *Arabidopsis* Seedling," "Figure 5: *Arabidopsis* Experiment Procedure," and "Figure 6: *Arabidopsis* Experiment Results."

What the Teacher Does in the Classroom

1. (Optional) To help students understand how biotechnology can be used to study gene expression, it will be helpful to first review with them the anatomy of a gene. Refer to "Figure 1: Gene Expression" (included in the Explanation activity) while reviewing this process.

2. Explain that the students will be first predicting and then analyzing results of an experiment designed to understand two genes that appear to be important in plant growth and development. The students will be considering where these genes are expressed within an organism. Molecular biologists have proposed possible functions for these genes:

   gene *9A* encodes a protein that is thought to be involved in chlorophyll production.

   gene *4C* encodes a protein that is thought to be involved in root cell division.

3. A second aspect to understanding a gene's function is determining if environmental signals alter gene expression and, if so, in which tissues. Explain that the students will also be investigating expression of gene *4C* in environments with contrasting levels of nitrogen (NO_3^-), an important building block that plants use to make molecules such as nucleic acids, amino acids, and chlorophyll.

4. Explain that the students will be first predicting and then analyzing results of an experiment carried out with genetically engineered (transgenic) *Arabidopsis* plants. Gene expression in plants is controlled in the same fashion as gene expression in animals, and thus plants can serve as excellent models for understanding gene regulation in eukaryotic organisms. *Arabidopsis thaliana* is a model organism for the study of genetics and development for a variety of reasons. *Arabidopsis* has small plant size, six-week generation time, high seed production, and the ability to self-pollinate. Additionally, foreign DNA can easily be introduced into its genome, a number of mutants are available for study, and its genome has been sequenced.

5. (Optional) Refer to "Figure 2: How to Make a Transgenic Plant" while explaining how a plant can be genetically engineered and used to study gene expression:

   A promoter:gus construct is a recombinant DNA molecule that can be used to study gene expression. Molecular biologists must first incorporate this molecule into the plant. The most common way to introduce recombinant DNA to a plant is through *Agrobacterium*-mediated gene transfer. *Agrobacterium tumefaciens* is a species of soil bacteria that naturally infects plants and results in the formation of crown gall tumors in many species.

   This species of bacteria harbors a circular piece of DNA called a "Ti plasmid." The plasmid contains genes involved in the formation of the crown gall tumor. These genes are found within a portion of the plasmid known as the TDNA (for transferred DNA). This TDNA incorporates into the plant's own DNA and drives the synthesis of proteins involved in tumor formation. Scientists have modified the TDNA sequence so that it still integrates into the plant's genome but no longer causes tumor formation. This modification has allowed scientists to insert recombinant DNA sequences into the TDNA for integration into the plant genome.

   In addition to inserting a gene of interest (along with a promoter to drive gene expression), scientists also insert a selectable marker gene that allows for selection of successfully transformed plants. Every cell of the transformed plant, along with the seeds it produces, will carry the gene of interest and the selectable marker gene.

6. Refer to "Figure 3: Analyzing Experiment Results," "Figure 4: Labeled *Arabidopsis* Seedling," and "Figure 5: *Arabidopsis* Experiment Procedure" while explaining the experiment:

These plants have been modified to contain a reporter gene (*gusA*) that encodes for the enzyme β-glucuronidase (GUS) linked to the promoter of interest. This combination molecule known as the promoter:gus construct is an example of a recombinant DNA molecule. A plasmid vector was used to introduce this recombinant molecule into the plant, and the recombinant molecule is now present in every cell of the plant.

If the promoter is active, both the gene of interest and the *gusA* gene will be transcribed. GUS expression can then be observed by the addition of a colorless, chromogenic substrate, X-gluc (5-bromo-4-chloro-3-indolyl β-D-glucuronic acid), to the intact plant. The X-gluc will bind with the GUS protein, which results in the production of a blue-colored product only in cells that are expressing GUS.

For better visualization of the blue-colored product, 70% ethanol can be added to the stained plants to bleach the chlorophyll from the tissues.

7. Ask the students to complete the "*Arabidopsis* Experiment: Predicting Results" worksheet. They should use their knowledge of gene expression and base their responses on what they know about the *Arabidopsis* experiment.

8. Facilitate a class discussion of the students' predictions. Acknowledge appropriate hypotheses and address any misconceptions about the scientific concepts, but do not yet reveal what the outcomes of the experiment will be.

9. Ask the students to complete the "*Arabidopsis* Experiment: Analyzing Results" worksheet. Allow them to look at their answers to the "*Arabidopsis* Experiment: Predicting Results" worksheet so they can compare their predictions with the actual results.

10. Refer to "Figure 6: *Arabidopsis* Experiment Results" while leading a class discussion of the students' analyses of the results of the experiment.

Extend the Elaboration Activity (Optional)

Conduct an online virtual lab. *DNA Microarray Virtual Lab* <http://learn.genetics.utah.edu/content/labs/microarray> is recommended. Prepare for this activity by testing the website to confirm that your school's computers have up-to-date versions of any software needed.

Conduct an experiment. A wet lab using genetically modified *Arabidopsis* seeds and GUS substrate supplied by Arabidopsis Biological Resource Center is included at the end of this section of the *Same Genes, Different Fates* curriculum guide. Alternatively, *Temperature-Dependent Gene Expression Kit* (Carolina BioKits Item #154769) or *Introduction to Gene Regulation: The lac Operon* (Carolina BioKits Item #171027) by Carolina Biological is recommended.

Make connections to other DESTINY modules. The *BioBusiness* module explores how businesses use recombinant DNA technology to develop products. The *BioBusiness* wet-lab involves transformation of bacterial cells with a recombinant plasmid containing the reporter gene for green fluorescent protein (GFP). Like GUS, GFP is a protein product that can be easily visualized within cells and organisms. GFP is also used in the wet-lab included in the *Weigh to Go!* module. This experiment involves purification of a genetically engineered designer protein from transformed bacterial cells. A focus of the *Weigh to Go!* module is the adipocyte-secreted hormone leptin.

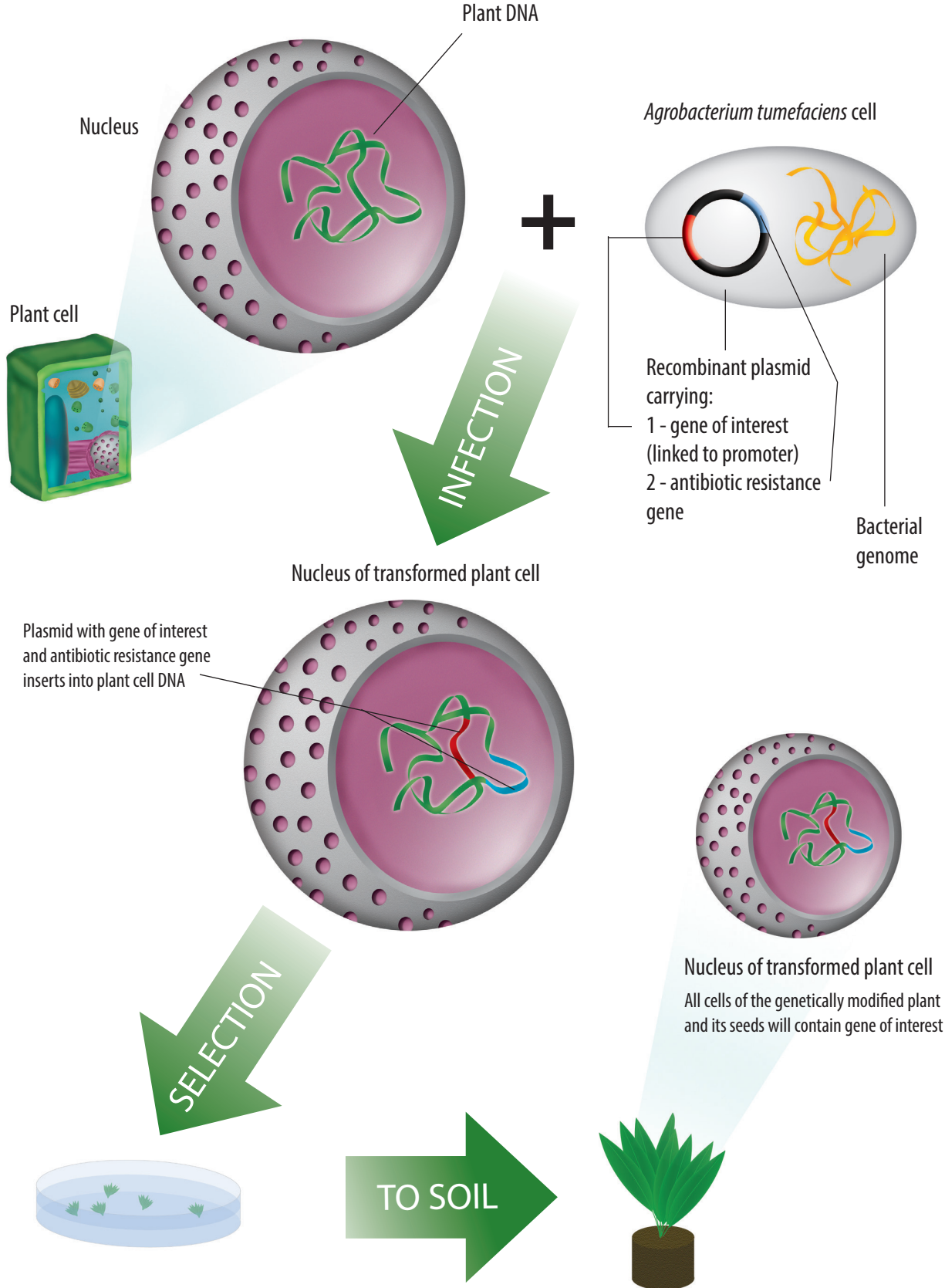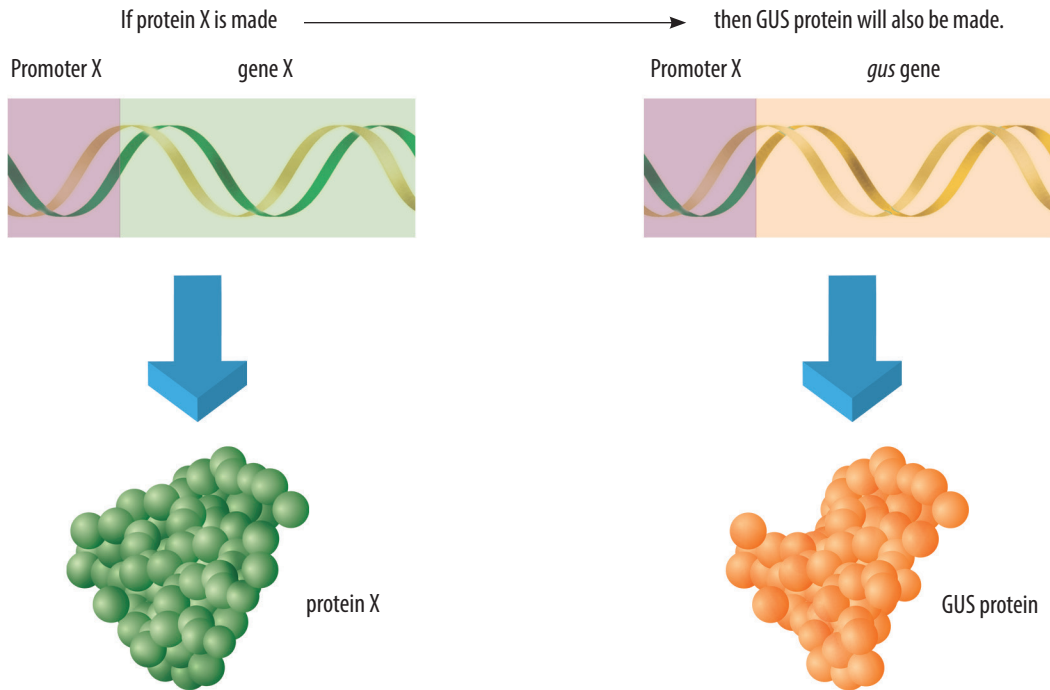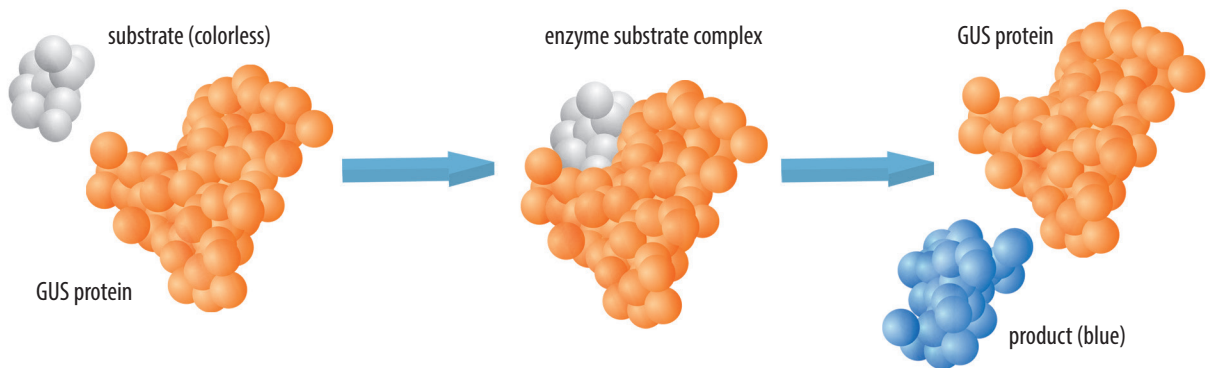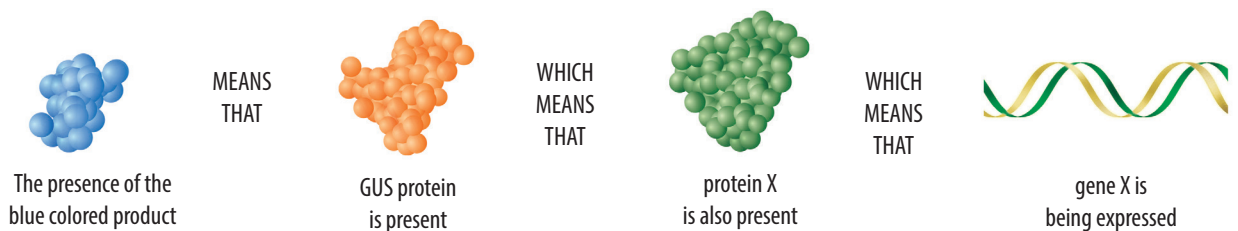# FIGURE 2: HOW TO MAKE A TRANSGENIC PLANT

Plant DNA

Nucleus

Plant cell

Agrobacterium tumefaciens cell

+

INFECTION

Recombinant plasmid carrying:
1 - gene of interest (linked to promoter)
2 - antibiotic resistance gene

Bacterial genome

Nucleus of transformed plant cell

Plasmid with gene of interest and antibiotic resistance gene inserts into plant cell DNA

Nucleus of transformed plant cell

All cells of the genetically modified plant and its seeds will contain gene of interest

SELECTION

TO SOIL

FIGURE 3: ANALYZING EXPERIMENT RESULTS

If the promoter is active, both the gene of interest and the *gusA* gene will be transcribed.

If protein X is made ⟶ then GUS protein will also be made.

Promoter X	gene X		Promoter X	*gus* gene

protein X

GUS protein

GUS expression can then be observed by the addition of a colorless, chromogenic substrate that results in the production of a blue-colored product only in cells that are expressing GUS.

substrate (colorless)

GUS protein

enzyme substrate complex

GUS protein

GUS protein

product (blue)

Cells that are expressing GUS are simultaneously expressing the gene of interest.

The presence of the blue colored product — MEANS THAT — GUS protein is present — WHICH MEANS THAT — protein X is also present — WHICH MEANS THAT — gene X is being expressed
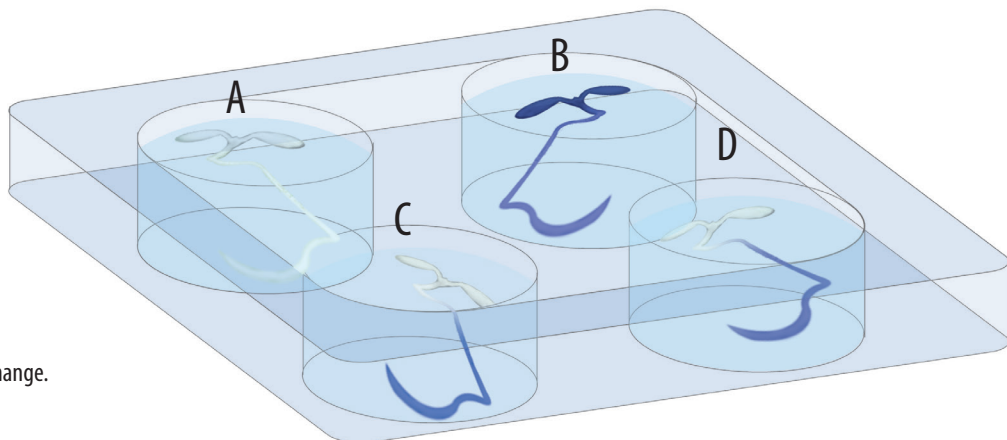
Cotyledons

Stem

Root hairs

Root
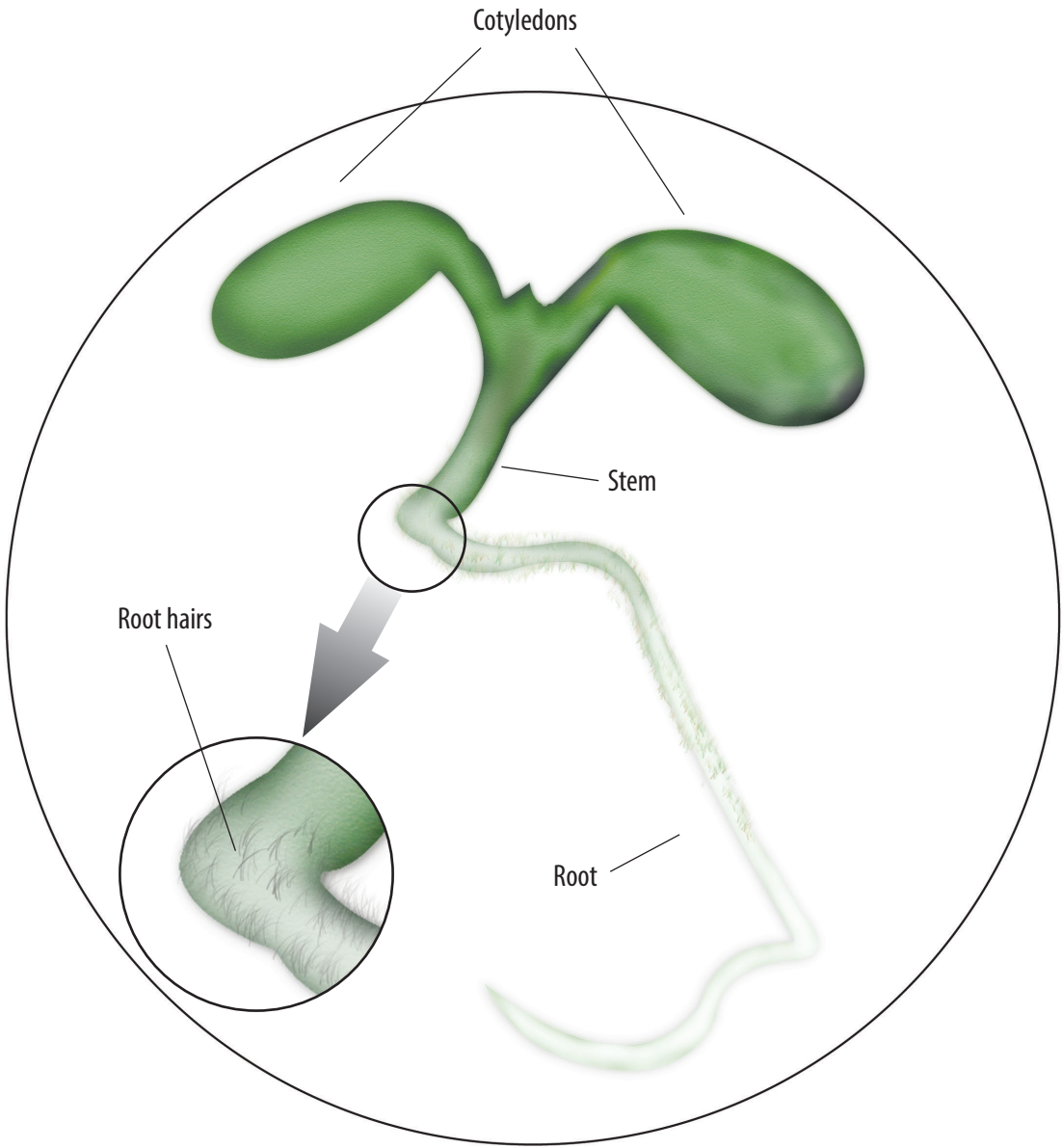
FIGURE 5: *ARABIDOPSIS* EXPERIMENT PROCEDURE
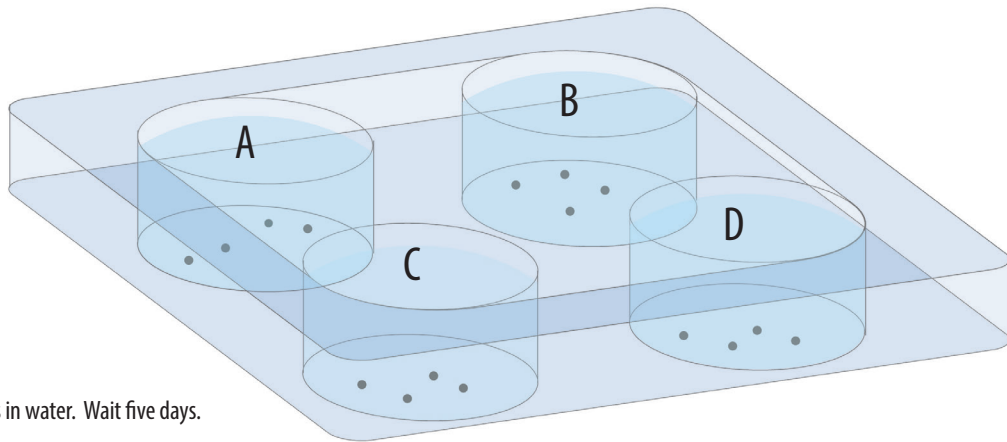
1. Germinate seeds in water. Wait five days.
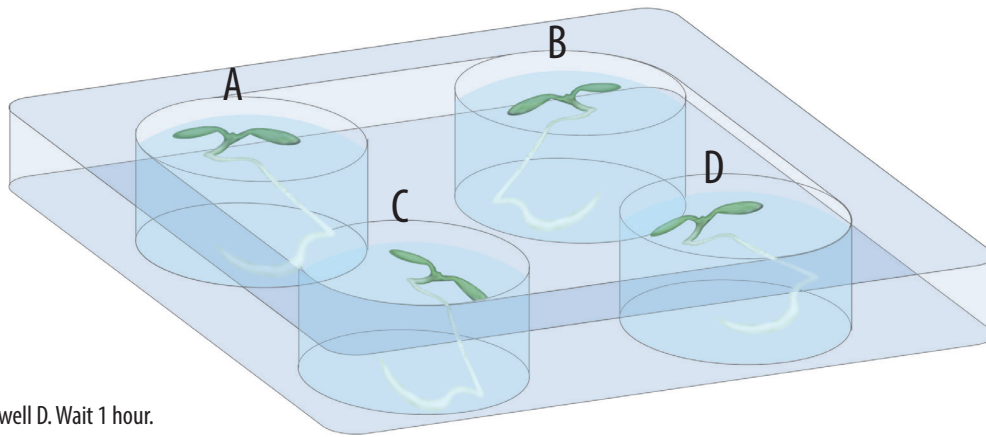
2. Add nitrogen to well D. Wait 1 hour.
3. Remove liquid from all wells.
4. Add substrate to all wells. Wait 24 hours (if at room temp).
5. Remove substrate from all wells.
6. Add 70% ethanol. Wait 4-5 hours or until chlorophyll has disappeared.
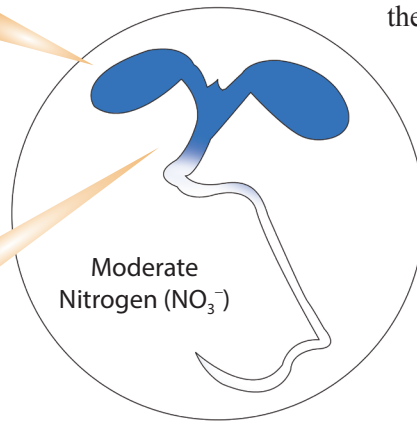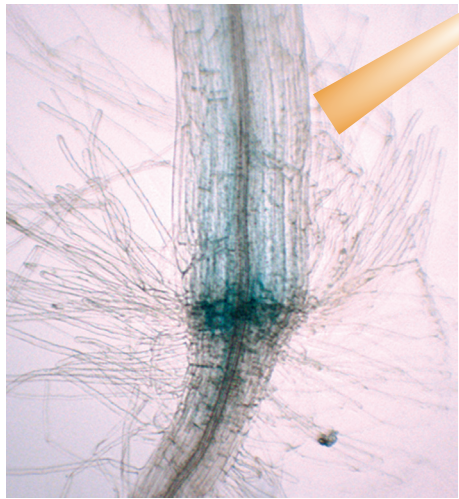

7. Observe color change.

Promoter9A:gus three-day-old seedling. GUS expression (and thus the protein encoded for by gene *9A*) is faint and is observed at the root-shoot junction and at the tips of the cotyledons.
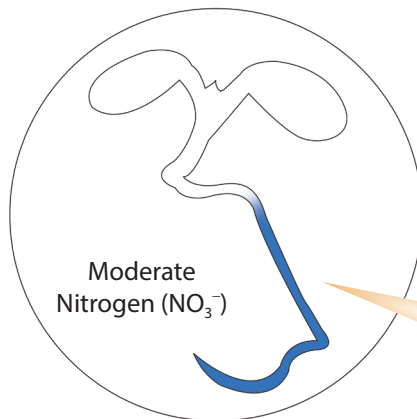
Moderate Nitrogen (NO_3^-)

B. Plant with *9A* promoter linked to *gus*

Promoter4C:gus three-day-old seedling. GUS expression (and thus the protein encoded for by gene *4C*) is prevalent in the plant root and heaviest at the root tip.

Moderate Nitrogen (NO_3^-)

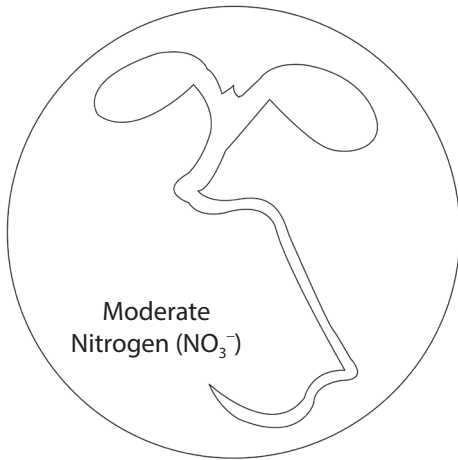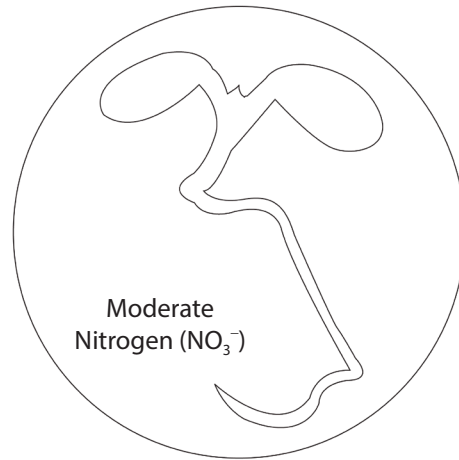C. Plant with *4C* promoter linked to *gus*

Name(s):

ARABIDOPSIS EXPERIMENT: PREDICTING RESULTS

Base your responses on the experiment performed with *Arabidopsis thaliana* and GUS substrate.
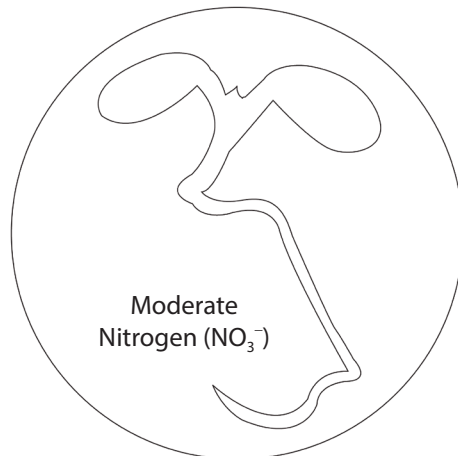
1. Shade in the diagrams (A, B, C, D) to show where you think a blue color will appear in each plant.

Moderate
Nitrogen (NO_3^-)

Moderate
Nitrogen (NO_3^-)

A. Non-genetically engineered plant

B. Plant with *9A* promoter linked to *gus*

Moderate
Nitrogen (NO_3^-)

High
Nitrogen (NO_3^-)

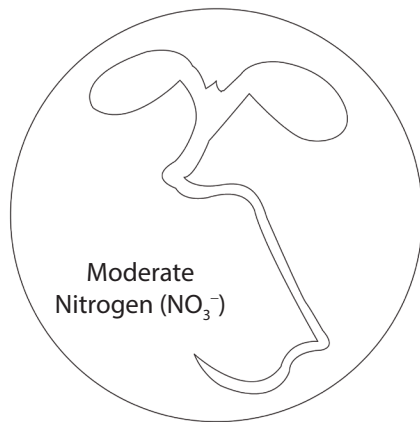C. Plant with *4C* promoter linked to *gus*

D. Plant with *4C* promoter linked to *gus*

2. What will the presence of a blue color indicate?

3. Explain what a control in an experiment is. Which plant (A, B, C, or D) is the control in this experiment?

4. Explain your answer to Question 1. Your answer should refer to genes *9A* and *4C*, nitrogen, the promoter, and the control.
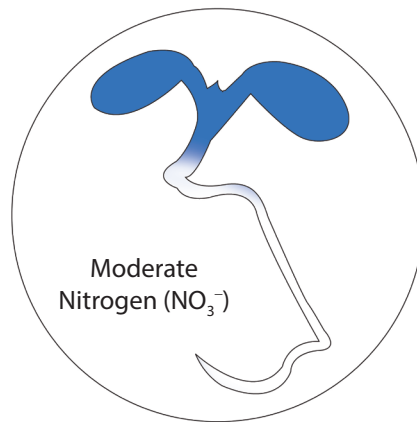
Name(s):

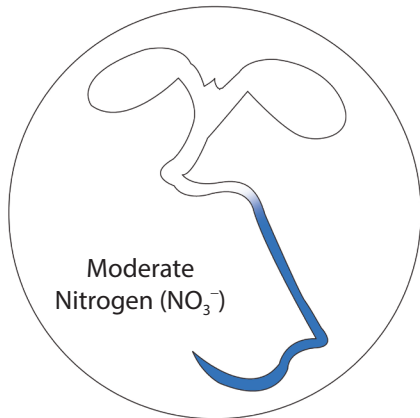# *ARABIDOPSIS* EXPERIMENT: ANALYZING RESULTS

Base your responses on your analysis of these results of the experiment performed with *Arabidopsis thaliana* and GUS substrate. *Shaded areas indicate presence of blue color.*
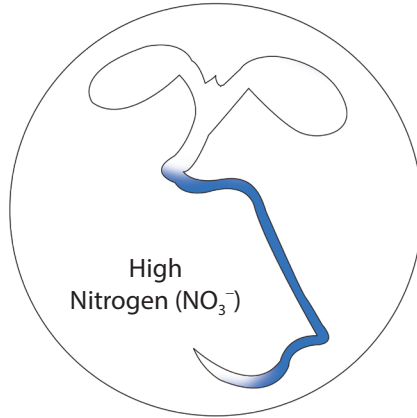

A. Non-genetically engineered plant

Moderate Nitrogen (NO_3^-)

B. Plant with *9A* promoter linked to *gus*

Moderate Nitrogen (NO_3^-)

C. Plant with *4C* promoter linked to *gus*

Moderate Nitrogen (NO_3^-)

D. Plant with *4C* promoter linked to *gus*

High Nitrogen (NO_3^-)

1. Compare your predicted results to the actual results. Describe how they are the same and how they are different.

2. Do the Plant B results support the idea that gene *9A* codes for a protein involved in chlorophyll production? Explain your answer.

3. Do the Plant C results support the idea that gene *4C* codes for a protein involved in root cell division? Explain your answer.

4. High nitrogen is known to slow root growth. Does this experiment appear to confirm that finding? Explain your answer.

ARABIDOPSIS EXPERIMENT: PREDICTING RESULTS

1. Shade in the diagrams (A, B, C, D) to show where you think a blue color will appear in each plant.

Answers will vary. Acknowledge appropriate hypotheses (e.g., blue color appearing in the parts of the plants where the genes of interest are likely to be expressed) and address any misconceptions about the scientific concepts, but do not yet reveal what the outcomes of the experiment will be.

2. What will the presence of a blue color indicate?

The promoter and gene being investigated were expressed in the cells and tissues in the area where the blue color appears.

3. Explain what a control in an experiment is. Which plant (A, B, C, or D) is the control in this experiment?

A control in an experiment is not exposed to the variable (e.g., nutrient amount, genetic modification) being investigated. The control indicates what happens without the presence of the experimental variable, and it can be compared to other results of the experiment. Plant A is the control in this experiment.

4. Explain your answer to Question 1. Your answer should refer to genes *9A* and *4C*, nitrogen, the promoter, and the control.

Answers will vary. Again, acknowledge appropriate hypotheses and address any misconceptions about the scientific concepts, but do not yet reveal what the outcomes of the experiment will be. Check that answers sufficiently address all elements of this question (nitrogen, promoter, control, and both genes of interest). Take the class's current level of understanding of these topics into account when assessing responses.

ARABIDOPSIS EXPERIMENT: ANALYZING RESULTS

1. Compare your predicted results to the actual results. Describe how they are the same and how they are different.

Answers will vary.

2. Do the Plant B results support the idea that gene *9A* codes for a protein involved in chlorophyll production? Explain your answer.

Students should notice the GUS staining in the cotyledons and stem (hypocotyls). The presence of blue color indicates that GUS is present, which means that the *9A* promoter driving GUS expression was active. This result indicates that the gene thought to be involved in chlorophyll production was also active and producing its protein. This staining pattern indicates that the promoter and gene being investigated were indeed expressed in the cells and tissues producing chlorophyll.

3. Do the Plant C results support the idea that gene *4C* codes for a protein involved in root cell division? Explain your answer.

Students should notice blue color in the root tip and extending away from the root tip (toward the root-shoot junction). The presence of blue color indicates that GUS is present, which means that the *4C* promoter driving GUS expression was active. This result indicates that the gene thought to be involved in root-specific cell division was also active and producing its protein. This staining pattern indicates that the promoter and gene being investigated were indeed expressed in the cells and tissues associated with cell division.

4. High nitrogen is known to slow root growth. Does this experiment appear to confirm that finding? Explain your answer.

By comparing the Plant C and Plant D results, students can observe that a high nitrogen level alters gene expression. This is noticeable at the root tips. They can use this information to address the question. *Information that the teacher can provide to explain the Plant C and Plant D results: High nitrogen has been shown to slow root growth. Thus, GUS expression at the root tip should diminish. Instead, GUS expression may be enhanced at the root-shoot junction as the plant can now put more energy into shoot growth.*

Arabidopsis Wet Lab (Optional)

This wet-lab protocol is similar to the *Arabidopsis* experiment that students encounter during the paper-and-pencil Elaboration activity. It has been simplified to exclude the nitrogen variable.

Many steps in this protocol can be carried out by the teacher, with students taking responsibility for the final steps. This will reduce class time spent on the project. However, it may be appropriate, as well as more engaging, for students to carry out many of the steps themselves. Depending upon the extent of the students' involvement, this project can take place in portions of one to four class periods.

Worksheets

Worksheets for recording predictions and analyses of the wet-lab results are provided in the following pages ("*Arabidopsis* Wet Lab: Predicting Results" and "*Arabidopsis* Wet Lab: Analyzing Results").

Materials

Plan for students to work in small groups of up to four students: Each group will need:

- A 4-well plate. (Or 3 paint pots 0.5″-0.75″ in diameter—see "Alternative Materials" below.)
- A clear cover for the plate. (Or clear plastic wrap—see "Alternative Materials" below.)
- 2 tubes. (1 tube for the substrate and 1 tube for the 70% ethanol or rubbing alcohol.)
- 3 transfer pipettes.
- 3ml of tap water.
- Small piece of foil. (Used to keep light out of the top and sides of the plate or paint pots.)
- 1.5ml of 70% ethanol or rubbing alcohol.
- 1.5ml of GUS substrate from ABRC.
- 10-30 seeds of each genotype (MLO9, MLO4, and nontransformed control) from ABRC.
- Access to hand lenses or a microscope.
- Access to an incubator (optional).

Teachers may obtain the seeds and substrate at no charge from the Arabidopsis Biological Resource Center (ABRC). Order the *Same Genes, Different Fates* Education Kit (stock number CS19983) online at http://abrcoutreach.osu.edu. Each kit serves 24 students working in groups of four. For reconstituting the substrate, which ABRC will send in a dry form, the teacher will require small amounts of tap water and rubbing alcohol.

Alternative Materials

Artists' supplies can provide an inexpensive alternative to four-well plates. The clear plastic pots used for mixing and storing small quantities of paint are recommended. These typically come in strips of six to eight pots that can be cut apart with scissors.

Choose paint pots that are a half-inch to three-quarters of an inch in diameter. The 4.9ml paint pots, a common size, are three-quarters of an inch in diameter. To remove any factory residues, rinse the paint pots in tap water before use.
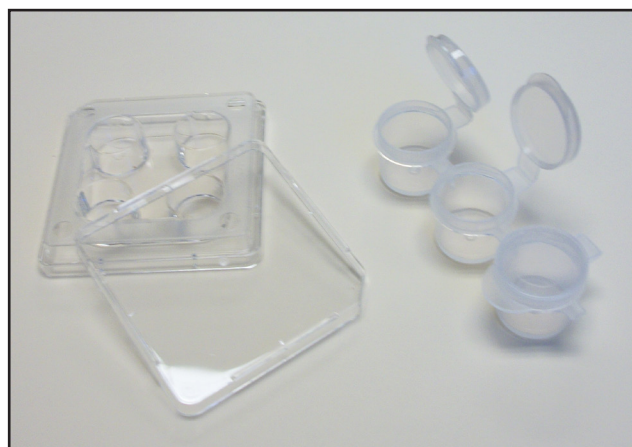
FOUR-WELL PLATE AND COVER (LEFT) AND SMALL PAINT POTS (RIGHT).
INEXPENSIVE PAINT POTS CAN BE USED INSTEAD OF PLATES.

Most plastic paint pots have attached, clear lids. If the covers are opaque, cut them off and instead use Saran wrap or a similar clear plastic wrap as a cover.

ARABIDOPSIS WET-LAB PROTOCOL

Day One

[30-45 minutes—Class period 1]

Allow time for the seeds to germinate and grow into seedlings. This takes five to seven days.

1. Label pipettes: **"Water," "GUS,"** and **"Alcohol."**

2. Label wells: **"A. Control," "B. 9A,"** and **"C. 4C."**

3. Use the pipette labeled **"Water"** for this step. Add 1ml of tap water to each well.

4. Sprinkle 10-30 seeds of the appropriate genotype into each labeled well.

5. To prevent evaporation, place the clear cover over the wells.

6. Place the plate in a well-lit area, but do not expose to full sun. The seeds will germinate and grow at room temperature. They do not need any special attention while growing, but will need to be monitored to make sure there is ample water in each well.

7. Predict results.

Day Five to Seven: Teacher's Preparation

1. Prepare the GUS substrate by adding 10 drops of rubbing alcohol to the tube, mixing vigorously, and filling the tube to the 10ml mark with tap water.

2. Aliquot 1.5ml of 1X GUS substrate into 1 tube per group of students. Store these tubes and any remaining substrate in a freezer until needed. *Substrate stored in a freezer remains usable for up to a year. Please note that light kills the substrate.*

3. Aliquot 1.5ml of 70% ethanol solution or rubbing alcohol into 1 tube per group of students.

Day Five to Seven

[20-30 minutes—Class period 2]

1. Remove the clear cover from the plate.

2. Use the pipette labeled **"Water"** for this step. Placing the tip of this pipette at the edge of each well, remove the water from each well. Take care not to suck up any of the seedlings into the pipette. *Quickly move to Step 3 to prevent the seedlings from drying out.*

3. Obtain a tube of 1X GUS substrate solution and a piece of foil from the teacher.

4. Use the pipette labeled **"GUS"** for this step. Using this pipette, add enough 1X GUS substrate solution to each well to completely cover the seedlings. (This should be about 0.5ml of substrate per well.) Make sure all the seedlings are completely covered with solution.

5. Place the clear cover back on the plate, cover with foil to prevent light from entering, and allow the seedlings to incubate at 37°C or room temperature. At 37°C, incubate the seedlings for 70 minutes. At room temperature, the staining will become apparent in a few hours. *Students can return to view results the next day.*

[20-30 minutes—Class period 3]

1. Obtain a tube of 70% ethanol or rubbing alcohol solution from the teacher.

2. Remove the foil and the clear cover from the plate.

3. Use the pipette labeled **"GUS"** for this step. Placing the tip of this pipette at the edge of each well, remove the 1X GUS substrate solution from each well. Take care not to suck up any of the seedlings into the pipette.

4. Use the pipette labeled **"Alcohol"** for this step. Immediately add 0.5ml of 70% ethanol (or rubbing alcohol) to each of the wells. This solution will bleach the chlorophyll from the green tissues and enable better visualization of the blue-colored product. *For best results, allow 4-5 hours for the chlorophyll to be bleached from the cotyledons.*

5. Place the clear cover back on the plate.

[20-30 minutes—Class period 4]

1. Remove the clear cover from the plate.

2. Use a microscope or hand lens to observe the seedlings in each well. Determine which plant tissues contain a blue-colored product.

3. Record and analyze results.

Stratification

Seeds shipped from ABRC may have been freshly harvested and therefore exhibit more pronounced dormancy. To break the dormancy, a three-day period of stratification is recommended. By breaking dormancy, stratification will improve the rate and synchrony of germination.

1. After Step 5 on Day One, wrap the plate in foil and keep at 4°C for three days.

2. Remove the plate from the cold environment.

3. Unwrap the plate.

4. Proceed with Day One's Step 6 and the rest of the experiment as described.

(Note that this cold treatment is required only for freshly harvested seeds.)
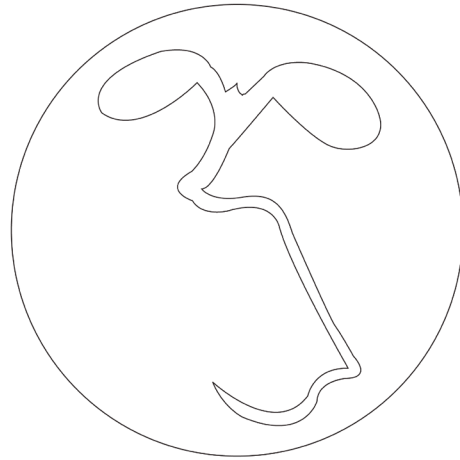
ARABIDOPSIS WET LAB: PREDICTING RESULTS

Base your responses on the experiment performed with *Arabidopsis thaliana* and GUS substrate.

1. Shade in the diagrams (A, B, C) to show where you think a blue color will appear in each plant.
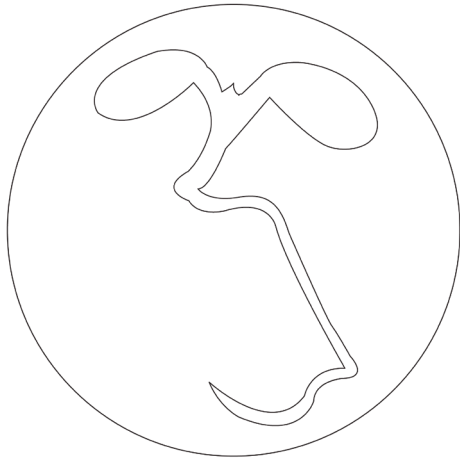
A. Non-genetically engineered plant

B. Plant with *9A* promoter linked to *gus*

C. Plant with *4C* promoter linked to *gus*

2. What will the presence of a blue color indicate?

3. Explain what a control in an experiment is. Which plant (A, B, or C) is the control in this experiment?

4. Explain your answer to Question 1. Your answer should refer to genes *9A* and *4C*, the promoter, and the control.

ARABIDOPSIS WET LAB: RECORDING AND ANALYZING RESULTS

Base your responses on the results of the experiment you performed with *Arabidopsis thaliana* and GUS substrate.
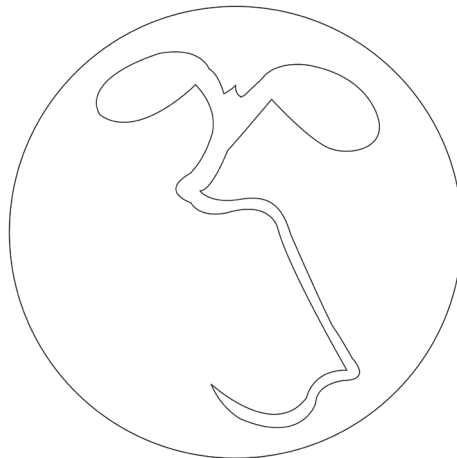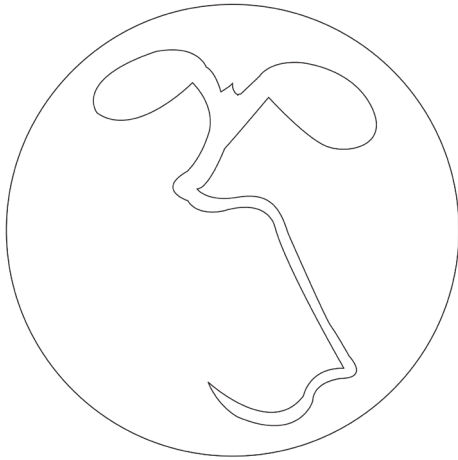
1. Shade in the diagrams (A, B, C) to show where the blue color appeared in each plant.

A. Non-genetically engineered plant
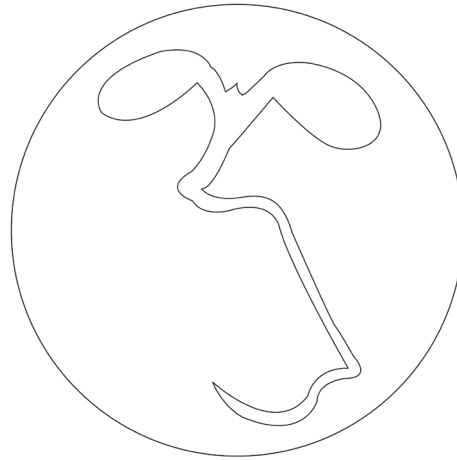
B. Plant with *9A* promoter linked to *gus*
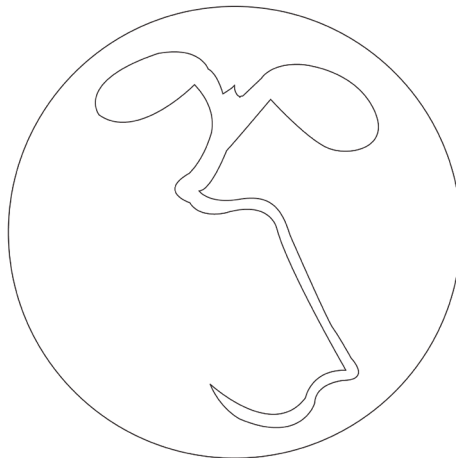
C. Plant with *4C* promoter linked to *gus*

2. Compare your predicted results to the actual results. Describe how they are the same and how they are different.

3. Do the results support the idea that gene *9A* codes for a protein involved in chlorophyll production? Explain your answer.

4. Do the results support the idea that gene *4C* codes for a protein involved in root cell division? Explain your answer.

ARABIDOPSIS WET LAB: PREDICTING RESULTS

1. Shade in the diagrams (A, B, C) to show where you think a blue color will appear in each plant.

Answers will vary. Acknowledge appropriate hypotheses (e.g., blue color appearing in the parts of the plants where the genes of interest are likely to be expressed) and address any misconceptions about the scientific concepts, but do not yet reveal what the outcomes of the experiment will be.

2. What will the presence of a blue color indicate?

The promoter and gene being investigated were expressed in the cells and tissues in the area where the blue color appears.

3. Explain what a control in an experiment is. Which plant (A, B, C, or D) is the control in this experiment?

A control in an experiment is not exposed to the variable (e.g., nutrient amount, genetic modification) being investigated. The control indicates what happens without the presence of the experimental variable, and it can be compared to other results of the experiment. Plant A is the control in this experiment.

**4. Explain your answer to Question 1. Your answer should refer to genes *9A* and *4C*, the promoter, and the control.**

Answers will vary. Again, acknowledge appropriate hypotheses and address any misconceptions about the scientific concepts, but do not yet reveal what the outcomes of the experiment will be. Check that answers sufficiently address all elements of this question (promoter, control, and both genes of interest). Take the class's current level of understanding of these topics into account when assessing responses.

ARABIDOPSIS WET LAB: ANALYZING RESULTS

1. Shade in the diagrams (A, B, C) to show where the blue color appeared in each plant.

2. Compare your predicted results to the actual results. Describe how they are the same and how they are different.

Answers will vary.

3. Do the Plant B results support the idea that gene *9A* codes for a protein involved in chlorophyll production? Explain your answer.

Students should notice the GUS staining in the cotyledons and stem (hypocotyls). The presence of blue color indicates that GUS is present, which means that the *9A* promoter driving GUS expression was active. This result indicates that the gene thought to be involved in chlorophyll production was also active and producing its protein. This staining pattern indicates that the promoter and gene being investigated were indeed expressed in the cells and tissues producing chlorophyll.

4. Do the Plant C results support the idea that gene *4C* codes for a protein involved in root cell division? Explain your answer.

Students should notice blue color in the root tip and extending away from the root tip (toward the root-shoot junction). The presence of blue color indicates that GUS is present, which means that the *4C* promoter driving GUS expression was active. This result indicates that the gene thought to be involved in root-specific cell division was also active and producing its protein. This staining pattern indicates that the promoter and gene being investigated were indeed expressed in the cells and tissues associated with cell division.

EXPRESS YOURSELF: STORY-TELLING ABOUT DIFFERENTIAL GENE EXPRESSION

Overview

Students role-play a scenario in which they have been hired as product developers for an educational supply company. The company is introducing a new line of children's educational products in different areas of biology. The students' task is to create products that will provide accurate information about differential gene expression in an accessible story for children (about 10 years of age). This task enables students to use a range of skills (including linguistic, artistic, and collaborative skills) to review, organize, and convey scientific knowledge they have gained during the previous phases of the *Same Genes, Different Fates* module.

Teacher's Preparation

Before the class begins, the teacher should:

1. Plan to have students work as individuals or in groups of two to four students.

2. Make copies of the rubric for each student or group.

3. Gather art supplies (e.g., scrap paper, markers) for a brainstorming and product-development session at the start of the activity.

4. (Optional) Gather children's books, comic books, and similar materials to serve as models for the students as they brainstorm and begin to develop their educational products.

What the Teacher Does in the Classroom

1. Inform the students that they have been hired as product developers for an educational supply company. The company is introducing a new line of children's educational products in different areas of biology. The students' task is to create products that will teach children (about 10 years of age) about differential gene expression.

2. The completed products can be picture books, alphabet books, comic books, stories, or movie scripts (with storyboards). The teacher may provide all these options to the students or select one type of product that everyone will make.

3. Each product must include at least three illustrations of scientific concepts. In planning and preparing these illustrations, each student or team may choose among the scientific concepts listed on the rubric.

4. Emphasize that this is an educational product for kids (about 10 years old), so it should be entertaining and have a story to it, while also providing an easy-to-understand introduction to stem cells and how they give rise to different cell types in a multicellular organism.

5. Provide copies of the rubric to all the students or groups. As they work, the rubric will remind them of information they need to include in their products and the high level of accuracy and clarity that is expected.

6. Remind the students that their work will be based upon what they have learned in class, so they can consult their notes and assigned textbook to confirm the accuracy of their products. (Be clear to the students that consulting the textbook does not mean *copying* from the textbook. The students are creating original work, using their own words and illustrations to explain differential gene expression to children.)

7. Discuss the rubric with the class so that students have a shared understanding of the evaluation terms. Discuss "included" and "correct." Discuss "minor error" (e.g., students display an overall understanding of a concept but misspell a word, mislabel a step, or omit a feature from an illustration).

8. (Optional) Discuss the term "creative." Because this is not an art class, artistic ability is not being assessed. However, science, too, requires creativity. In addition to needing to think of new ways to approach research questions, scientists and others who work in science-related fields (which could range from research to marketing to legislating to teaching) also often need to devise clear, appealing (and nonetheless accurate) ways to explain scientific concepts. This is how people, including the very young, become interested in scientific topics and come to understand and possibly even benefit from them. Ask the students how they define creativity and come to a common understanding about what "creative" will mean in terms of this assignment.

9. Give the students time and materials in the classroom to brainstorm their products. As they work, check to be certain they understand the assignment and are planning products that will meet the goals set out in the rubric.

Extend the Evaluation Activity (Optional)

After developing and completing their educational products, students may wish to present the results of their hard work in the classroom and beyond. Some options are:

- Schedule a mini education symposium in the classroom and ask the students to present their work. (If possible, invite a special guest—a scientist who works locally, the principal, another science teacher—to attend.)

- Arrange for the students to visit a science class at an elementary or middle school and present their work.

- Place the students' products in a display area at the school or school district central office. (If the products are displayed outside the school, arrange for photographs to be taken and shown to the students.)

NAME(S) OF PRODUCT DEVELOPER(S)	

TITLE OF EDUCATIONAL PRODUCT	

TYPE OF PRODUCT (CIRCLE ONE)

Alphabet book   Comic book   Picture book   Story book   Movie script & storyboard

SCIENTIFIC CONCEPTS
Included & correct = 5 pts. • Included but with one minor error = 4 pts. • Included but with two minor errors = 3 pts.
Included but with three minor errors = 2 pts. • Included but incorrect = 1 pt. • Absent = 0 pts.

DNA → RNA → Protein		Neuron	
Differential gene expression		Myocyte	
Stem cell		Adipocyte	
Endoderm, mesoderm, ectoderm		Enterocyte	
Internal signal		Macrophage	
External signal		Model organism	
Environmental factor		Gene therapy	

TECHNICAL PRESENTATION
No errors = 5 pts. • One error = 4 pts. • Two errors = 3 pts. • Three errors = 2 pts.
Four errors = 1 pt. • Five or more errors = 0 pts.

Spelling of non-scientific words		Grammar	

OVERALL PRESENTATION
Complete & very clear = 5 pts. • Complete & generally clear = 4 pts. • One missing or unsatisfactory key element = 3 pts.
Two missing or unsatisfactory key elements = 2 pts. • Many missing or unsatisfactory key elements = 1 pt. • Absent = 0 pts.

Story (plot, sequence of information)		Designed to appeal to a young audience	
3 illustrations of scientific concepts		Addresses overall assignment	

TOTAL POINTS	

KEY TERMS

Arabidopsis thaliana (mouse-ear cress). A member of the mustard (*Brassicaceae*) family, this self-pollinating plant is widely used by molecular biologists as a model organism for the study of genetics and development.

biotechnology. Any process that uses cells, organelles, macromolecules, biochemicals, or biochemical pathways to create a product. Fermentation is an ancient biotechnology; gene therapy is a more recent one.

clones. Genetically identical cells or organisms that are derived from the same parent cell/organism through cell division.

coding region. The region of a gene that is actively transcribed into mRNA.

development. The coordination of the fates of individual cells arising from stem cells within an embryo. The cells arising from stem cells are genetically identical (clones) and yet they assume the fate of specific cell types as the organism develops.

differential gene expression. The use of distinct information in a gene to produce certain sets of proteins specific to the cell's role in the organism. A cell will not express all of its genes and therefore not all of the proteins that it has the potential to make. The proteins it does produce determine the structure and function of the cell.

DNA (deoxyribonucleic acid). The organic molecule that directs a cell's activities and serves as the carrier of genetic information from one generation to the next.

enzyme. A protein that acts as a biological catalyst, thereby speeding up chemical reactions.

eukaryotic. Pertaining to a cell that contains membrane bound organelles, including a nucleus that houses the cell's DNA.

gene. A sequence of DNA that codes for a particular protein.

gene expression. The full use of information in a gene that occurs when a gene is transcribed into mRNA and translated into a protein.

gene regulation. A cell's ability to control when and to what extent a gene is transcribed into mRNA and translated into protein.

genetically engineered (transgenic) organism. A single-celled or multicellular organism that contains recombinant DNA.

genome. All of the genes present within a cell. The human genome is estimated to contain approximately 20,000 genes.

GUS (β-glucuronidase). An enzyme derived from bacteria whose expression can be observed by the conversion of a colorless, chromogenic substrate into a blue-colored product. The gene encoding for GUS is commonly used as a reporter gene in recombinant DNA technology applications.

Human Genome Project. A 13-year effort, coordinated by the U.S. Department of Energy and the National Institutes of Health, to identify all genes in human DNA and accomplish related projects. Scientists mapped approximately 20,000 genes and finished in 2003.

model organisms. Organisms that help scientists better understand biological processes. Examples of model organisms include invertebrates such as *Drosophila* (fruit fly), *Caenorhabditis elegans* (roundworm), and vertebrates such as zebra fish, frogs, and mice. *Arabidopsis* (a plant) and yeast (a fungus) are also model organisms.

mRNA (messenger ribonucleic acid). An organic molecule assembled during transcription by RNA polymerase that synthesizes an RNA copy of the gene.

multicellular. Containing two or more cells; all multicellular organisms contain eukaryotic cells.

nucleus. The double membrane-bound organelle that houses a cell's DNA; found within eukaryotic cells.

plasmid. A circular piece of DNA naturally found in bacterial cells that is capable of self-replication and typically contains one or more antibiotic resistance genes. Plasmids can be manipulated by restriction enzymes in order to incorporate foreign DNA fragments, thereby generating recombinant DNA molecules.

promoter. A region of DNA located in front (upstream) of the coding region that has a specific nucleotide sequence which RNA polymerase recognizes and binds to prior to transcription.

protein. An organic molecule synthesized by cells that consists of one or more polypeptide chains (polymers of amino acids).

proteome. The complete collection of proteins produced by a cell/organism at a given time.

recombinant DNA. DNA generated in the laboratory that contains genetic information from more than one species.

reporter gene. A gene that encodes for an enzyme whose activity can be visualized and therefore easily monitored within a transgenic organism. In this activity the reporter gene encodes for the enzyme β-glucuronidase (GUS).

restriction enzymes (restriction endonucleases). Enzymes that act as "molecular scissors" to cut DNA at specific nucleotide sequences. Restriction enzymes are useful in generating recombinant DNA molecules.

RNA polymerase. The enzyme that acts during transcription to synthesize an RNA strand with a nucleotide sequence complementary to the template DNA strand being transcribed.

signal. A chemical message (neurotransmitter or a hormone) or an external stimulus (light, gravity, etc.) perceived by cells that induces a change in function or behavior, usually through changes in gene expression.

stem cell. An undifferentiated cell that is capable of cell division and can give rise to any cell type in an adult organism.

transcription. The synthesis of an mRNA strand complementary to the coding region of a gene.

transcription factors. Proteins that help to regulate transcription by facilitating the binding of RNA polymerase to the promoter region of a gene.

transgenic organism. See **genetically engineered organism.**

translation. mRNA directs the assembly of a polypeptide on a ribosome in the cytoplasm of a cell.

vector. In genetic engineering, a plasmid or virus that carries recombinant DNA into the organism of study.