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PATHWAYS

The Regeneration Issue

What researchers are learning from animals

Science jobs of the future

What Do You and These Zebrafish Have in Common?

Hint: It's more than you think!

National Institute of General Medical Sciences

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Regeneration Is

This tiny hydra does awesome things.

Some animals can regrow an amputated limb—or even a severed head! Scientists are studying these incredible creatures to help treat human diseases.

If you've ever accidentally cut yourself, you probably didn't think much about the scab or new skin that formed. The process of healing, repairing, and replacing damaged tissue is what scientists call regeneration.

In the case of a scraped knee, it's mostly just skin that's regrowing. But all around us, living things demonstrate mind-blowing abilities to regenerate entire limbs, internal organs, even a full-grown body from a bit of tissue.

"Scientists in the field of regenerative medicine look at animals that can naturally regenerate and heal types of wounds that humans can't," explains **Thomas Lozito, Ph.D.**, assistant professor at the University of Southern California in Los Angeles, who was fascinated by reptiles and amphibians as a child. "We try to map out a blueprint for getting humans to do the same thing," says Dr. Lozito. (Today he runs a lab with over 1,000 lizards!)

Take the **axolotl**, a salamander that can lose its entire tail—and grow it back. Or organisms known as **hemichordates**, which can lose their heads and then create new ones! Or the **hydra**, a freshwater creature that regenerates its cells every 20 days.

Scientists study these research organisms to learn how their regenerative processes work. Their goal: to use their understanding to develop treatments for human health issues like spinal cord injuries, Alzheimer's disease, the loss of an arm or a leg, and much more.

Photo © Science Photo Library/Media Bakery

AMAZING

(Find Out Why!)

An axolotl can regrow its tail...and its legs, jaws, spinal cord, brain, and more!

Celina Juliano, Ph.D., assistant professor at the University of California, Davis, was also an animal lover as a kid. Today she studies the hydra—one of the first animals in which regeneration was discovered, way back in the 1700s. A hydra is a minuscule freshwater creature that's related to jellyfish, sea anemones, and coral. It's basically a tube with tentacles on the top and a sticky disk on the bottom, but it can do amazing things. "A hydra can be cut into little pieces, and each piece will grow back into a full hydra," Dr. Juliano says. "You can even separate a hydra into single cells, form those cells up into a ball, and they'll rearrange themselves back into a hydra. And a hydra continually renews itself, replacing all of its cells with new cells."

Helping others motivates **Voot P. Yin, Ph.D.**, director of scientific services at MDI Biological Laboratory in Maine. Dr. Yin works with zebrafish, salamanders, and mice. "We have found that zebrafish can fully regenerate a missing or damaged muscle, even in their heart," he says. Many of the genes in zebrafish are closely related to those in humans. One of the major goals of regenerative medicine is discovering how to decode the genetic circuitry that allows regeneration to occur. "Then we need to reactivate those circuits in humans, so that if you have an injury like a heart attack, we can use the body's own genetic programming to allow regeneration to happen," Dr. Yin explains. This type of research can lead to important discoveries in regenerative medicine that can be applied to almost any organ system.

The quest to make people's lives better will continue to ignite scientists' imaginations. And maybe it will also lead you on a journey into the exciting field of regenerative medicine!

Regenerative medicine is a field of science that focuses on restoring or healing damaged body parts so that they function normally. The long-term goal is to stimulate tissue and organs to heal themselves.

EARLY-CAREER SCIENTISTS IN THE SPOTLIGHT

Lamont R. Jones, M.D., M.B.A., vice chair, Department of Otolaryngology, Head and Neck Surgery, Henry Ford Health System, Detroit, Michigan

What kind of research are you doing? My current project is focused on better understanding why patients are at risk of developing keloids, which are noncancerous skin growths.

How did your interest in science develop? As a Detroit Public High School student, I was involved in a summer program performing research, in a basic science lab. Along with my parents and teachers, the lab experience and exposure fueled my interest in science and helped influence me to go to medical school.

What made you want to be a physician-scientist? The value of research discoveries is that you're able to magnify your impact. Being a researcher and physician lets me take a problem and work on discoveries that can improve the lives of many patients.

Mansi Srivastava, Ph.D., assistant professor of Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts

Did you always dream of becoming a scientist? Growing up in India, I never imagined that I'd someday be a Harvard professor. But my mother was a high school biology teacher, and my best friend's mom was a botany professor. I give these women full credit for getting me engaged in science.

What organism do you study? I look at *Hofstenia miamia*, also known as **three-banded panther worms**. They're called panther worms because they're active predators: They hunt for little swimming brine shrimp that we include in their tanks in our lab.

What is your advice to students who want to be scientists? It's very important to be able to work with other people. Also, ask questions! There is no such thing as a dumb question.

Axolotl photo © GlobalP/iStockPhoto.com

October 21, 2019 THE SCIENCE CAREER NEWS ISSUE 2

HELP WANTED

Job alert! A new regeneration lab is opening in your town and needs to fill the positions listed here. Think about which job you'd most like to do. Then write or share with your class the skills you could bring to the position, and what you hope to discover in your role. Good luck!

PRINCIPAL INVESTIGATOR

RESPONSIBILITIES: Serve as a "coach" leading a team of scientists who work on groundbreaking discoveries. Come up with goals and empower other scientists to conduct research in support of these goals. Mentor other scientists. Write research papers and give presentations about your progress and discoveries to share with scientists around the world.

RESEARCH ASSISTANT

RESPONSIBILITIES: Assist the principal investigator in managing and executing experiments. Plan, conduct, and analyze cutting-edge independent research in the lab. Supervise junior team members and further develop research-related activities to support the goals of the lab.

LAB MANAGER

RESPONSIBILITIES: Oversee instruments, computers, and devices in the lab. Know how to operate all machinery and teach other team members as needed. Keep lab animals healthy and happy. Maintain a log of what materials need to be replenished. Manage the budget for lab equipment and supplies.

DATA SCIENTIST

RESPONSIBILITIES: Develop computer programs to help scientists manage and understand huge amounts of data. Come up with unique ways to map, present, and share findings. Teach others new methods to compile statistics and questions to ask along the way.

EMPLOYER'S NOTE *All jobs require curiosity, teamwork, passion, and a willingness to learn from your mistakes. A good sense of humor will go a long way too!*

Science All-Star Alejandro Sánchez Alvarado

Alejandro Sánchez Alvarado, Ph.D., is a true pioneer. As the scientific director of the Stowers Institute for Medical Research in Kansas City, Missouri, Dr. Sánchez Alvarado oversees major regenerative research projects in his lab at the institute. The star of his research is the planarian flatworm, which he says looks like a cartoon character! "A planarian can be cut into a number of pieces, and each and every one of those fragments will go on to regenerate a complete planarian," he explains excitedly. "And we want to understand how they can do this."

Dr. Sánchez Alvarado has always loved scientific mysteries. Growing up in Caracas, Venezuela, he spent his summers on his grandfather's farm where he relished studying the creatures around him.

These days he goes on expeditions to find organisms in oceans as far away as French Polynesia; analyzes billions of pieces of information about organisms' cells and genes using computers; double-checks the computers' data by observing the organisms under microscopes; and much more.

Just what keeps Dr. Sánchez Alvarado so captivated? His answer is poetic: "I have a fascination for these very small and unheralded things. I'm certain they contain a large number of secrets waiting to be uncovered."

From top: Dr. Sánchez Alvarado as a child holding a green anaconda; three representations of planarian flatworm anatomy.

Photos: background image, Lemberg Vector studio/Shutterstock; adult and young Sánchez Alvarado, courtesy Alejandro Sánchez Alvarado; flatworm anatomy, © Sarah Elliott – Stowers Institute for Medical Research (on the cover: Arco Images GmbH/Alamy)

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SCHOLASTIC

GRADES 6–12

PATHWAYS

TEACHING GUIDE

Science Activities About Regeneration and Research Careers

Visit **scholastic.com/pathways** for additional lessons, videos, and more.

Dear Teacher,

In this guide you'll find:

- ✓ Lesson on regeneration, with tips for reading scientific texts
- ✓ Scaffolded activity sheets for research
- ✓ Class set of student magazines

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NIH National Institute of General Medical Sciences

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Exploring Regenerative Medicine

Help your students imagine the real-world applications of cellular regeneration through experimental design.

Objective

Students will be able to use specific strategies while reading a scientific text in order to demonstrate an understanding of regeneration.

Standards

NGSS Crosscutting Concepts; Structure and Function 6–12
CCSS Reading Standards for Literacy in Science and Technical Subjects 6–12

Time

60–90 minutes

Materials

- *Pathways* magazine
- **Grs. 6–8:** Research the Curious World of Regeneration activity sheet
- **Grs. 9–12:** From Curiosity to Hypothesis activity sheet
- Vocabulary list at scholastic.com /pathways

Directions

1 **Ask** students: *What happens when you get a paper cut? Do you know what happens when a salamander loses its tail?* Help students arrive at a definition of *regeneration* (the process of forming new tissue). Then, have students imagine a world where nothing regenerates. Prompt them to consider what in our world does and does not regenerate, and to what extent (think about buildings, plants, rocks, animals, etc.). Ask: *Is there anything humans can learn from a worm? Why do scientists research regeneration? How could it change lives, or even society?*

2 **Hand out** the student magazine and review tips and tricks for reading informational text as needed.

- If you don't know a word, mark it. If you can't figure out its meaning using context clues, look it up, then reread.
- Use the informational text features (headings, bolded words, captions, sidebars) to help you.
- Annotate: Draw arrows and write your questions/reflections in the margins.
- Challenge yourself to find the main idea and several examples to support it.
- For extra support, break down the passage: Read the first paragraph and annotate the main idea; read the next paragraph and do the same.

3 **Read** the magazine individually or as a class. Discuss, including students' questions and annotations. Ask: *How are mammals similar to organisms like axolotls?* (Like mammals, axolotls have skin, muscles, cartilage, and bones. They also have digestive, circulatory, and nervous systems.) And then ask: *Why can axolotls regrow lost legs and internal organs and we can't?* (Human tissue is much more complex. Scientists are studying axolotls, planarians, and hydras to learn which cell types and genes are essential to regeneration.)

4 **Distribute** the activity sheet. Support students in designing their own experiment, challenging them to draw on the magazine and their grade-level knowledge of experimental design.

5 **Wrap up** by using regeneration as a springboard to discuss the wonders of science. Tell students there are science/lab jobs that can immerse them in fascinating research every day. Encourage them to nurture their curiosity and keep a record of their questions. They just might get to uncover the answers one day!

Supporting All Learners

To increase the challenge
- Have students come up with discussion questions that use each of the vocabulary words.
- Have them research other organisms that regenerate and compare and contrast what these organisms can/can't do.

To decrease the challenge
- Have students work (or read) in groups of varying abilities.
- For experimental design, review terms like dependent and independent variables, constant, control group, and repeated trials.

To support English language learners
- Emphasize the Latin roots of scientific terms. Examples: "re" (again or back), "gener" (create), "ation" (noun suffix).
- Assign a color to word types (e.g., action words = circle in red).

Name _____

Research the Curious World of Regeneration

Find out what we know so far about regeneration, then think like a scientist and come up with your own research questions.

Planarian

Type of organism: Flatworm
Regenerative abilities: It can regrow its entire body—including its head—from a tiny bit of tissue. If one planarian is cut into 20 pieces, in three weeks you'll have 20 planarians. Cells called neoblasts are activated and re-create missing tissue, including nerves, guts, and muscles.

Axolotl

Type of organism: Aquatic salamander
Regenerative abilities: It can regenerate its tail, limbs, heart, spinal cord, pancreas, and kidney. The cells near the damaged spot transform to stem cells, which then form bones, skin, and tissue. Researchers study axolotls to investigate whether humans can one day regenerate in similar ways.

Human

Type of organism: Mammal
Regenerative abilities: Humans have limited regenerative capabilities. We can usually regrow lost hair. Our skin, bone marrow, liver, and the insides of our intestines can grow back when they're damaged, but our limbs can't. Researchers have helped develop ways to grow back fingertips.

Idea Starters for Research Questions

Brainstorm good investigative questions by asking yourself:

How does...

What would happen if...

What is the difference between...

What conditions would cause...

Now Build Your Own Questions

Brainstorm a research question you want to ask about each organism.

1. Planarian

_____

_____

2. Axolotl

_____

_____

3. Human

_____

_____

_____

Extra Credit

BUILD YOUR EXPERIMENT Choose one of your research questions and design an experiment to find out more. (You may have to narrow your question's focus when you form and test your hypothesis.) As you summarize your experiment on the back of this sheet, be sure to isolate your variable (what will you change? will you have a control?) and explain how you will measure and collect data.

Name _____

From Curiosity to Hypothesis

Go out on a limb to develop a research hypothesis about regeneration, animal behavior, disease, or something else you're curious about!

CREATING A HYPOTHESIS

1 On separate paper, brainstorm or research a few organisms that regenerate (or some other topic that you are interested in knowing more about). Circle the one you are most curious about.

2 Imagine you are going to conduct research on this organism/topic. Consider what you already know vs. what you want to know. Write down ideas for narrowing your focus. Circle your favorite.

3 Set a main objective for your research. Then write it as a hypothesis you can test:

I hypothesize that if _____

_____,

then _____

_____.

REFLECTING & REVISING

- Could my hypothesis help me learn something I didn't know before?
- Is it testable? Consider independent and dependent variables. Will I be able to observe and measure a change?
- Am I using math to measure my outcomes? (Example: percent of change over time, how many _____, by how much did _____ change?)

4 Based on the reflections above, revise your hypothesis to:

I hypothesize that if _____

_____,

then _____

_____.

CHALLENGE ZONE

On separate paper, develop a summary of the steps needed to test your hypothesis. Be sure to consider:

- independent and dependent variables
- constant(s)
- control group
- repeated trials
- experimental conditions/setting
- data collection

Predict the outcomes: Imagine your hypothesis was disproved. What happened, and what could you learn from that? If you made observations consistent with your hypothesis, what would you expect to find out?

What's another question you could study to go further, after you have found out the results of your initial hypothesis?

VOCABULARY LIST

Despite its self-healing qualities, the **axolotl** is an endangered species.

Look! No wrinkles! **Hydras** don't get old!

The **three-banded panther worm** can regrow its head!

The acorn worm is a **hemichordate**.

axolotl *(noun)*: a type of salamander that lives in the mountain lakes of Mexico and the western U.S. Axolotls are commonly 9 to 12 inches long and can regrow limbs.

blueprint *(noun)*: a detailed plan of how to do something.

cartilage *(noun)*: a tough but flexible tissue that covers the ends of long bones at a joint and gives shape and support to other parts of the body, such as ears, nose, and windpipe.

circulatory system *(noun)*: a network consisting of blood, blood vessels, and the heart. Among its various roles, this network delivers nutrients to every cell in the body.

digestive system *(noun)*: the body system that breaks down food, absorbs nutrients, and gets rid of solid food waste.

DNA *(noun)*: the molecule found in cells that carries instructions for cell structure and processes in the body. DNA contains genes that are passed on from parents to offspring and gives living things their inherited characteristics. The letters DNA stand for deoxyribonucleic acid.

gene *(noun)*: a small section of DNA that contains the instructions for making a specific protein. Proteins control the processes that occur in the body's cells.

hydra *(noun)*: a small invertebrate organism about one inch long that lives in fresh water. Its body is a hollow cylinder with a mouth and tentacles at the top. Hydras do not appear to age and have an amazing ability to regrow their bodies.

hemichordate *(noun)*: a small wormlike invertebrate found along the shores of the Caribbean and other warm waters. It can regrow a body part within a few days of amputation.

keloid *(noun)*: a thick scar resulting from excessive growth of scar tissue.

nervous system *(noun)*: a network which transmits signals between the brain and the rest of the body, including internal organs. The nervous system's activity controls the ability to move, breathe, see, think, and more.

planarian *(noun)*: a type of flatworm common to many parts of the world, living in both saltwater and freshwater ponds and rivers. Planarians can regrow any part of their bodies after amputation.

regeneration *(noun)*: regrowth after being lost or damaged (particularly forming new animal or plant tissue).

statistics *(noun)*: a field of study that concerns the collection, organization, displaying, analysis, interpretation, and presentation of data.

three-banded panther worm *(noun)*: a small organism that can regrow any missing body part and named for its three stripes and its carnivorous appetite for live prey.

EXPERIMENT CORNER

EXPERIMENT VOCABULARY

independent variable *(noun)*: the variable that is changed or controlled in a scientific experiment. It represents the cause or reason for an outcome.

dependent variable *(noun)*: the variable in an experiment that is being measured or tested. The dependent variable responds to the independent variable.

control group *(noun)*: the group in an experiment that doesn't experience the independent variable. Scientists can compare the control group to the experiment group to see the independent variable's effects.

VOCABULARY IN ACTION: SAMPLE RESEARCH QUESTION

How do air temperatures cooler than room temperature impact plant growth (height) during germination?

For this experiment, scientists will adjust the independent variable of air temperature to see what effect it has on the dependent variable of plant height. They will create three experimental groups allowing planted seeds to germinate at 20°F, 40°F, and 60°F. The scientists will also create a control group where seeds are allowed to germinate at standard room temperature (72°F). The control group helps scientists to measure experiment results and determine whether the air temperature (independent variable) does indeed impact plant height (dependent variable).