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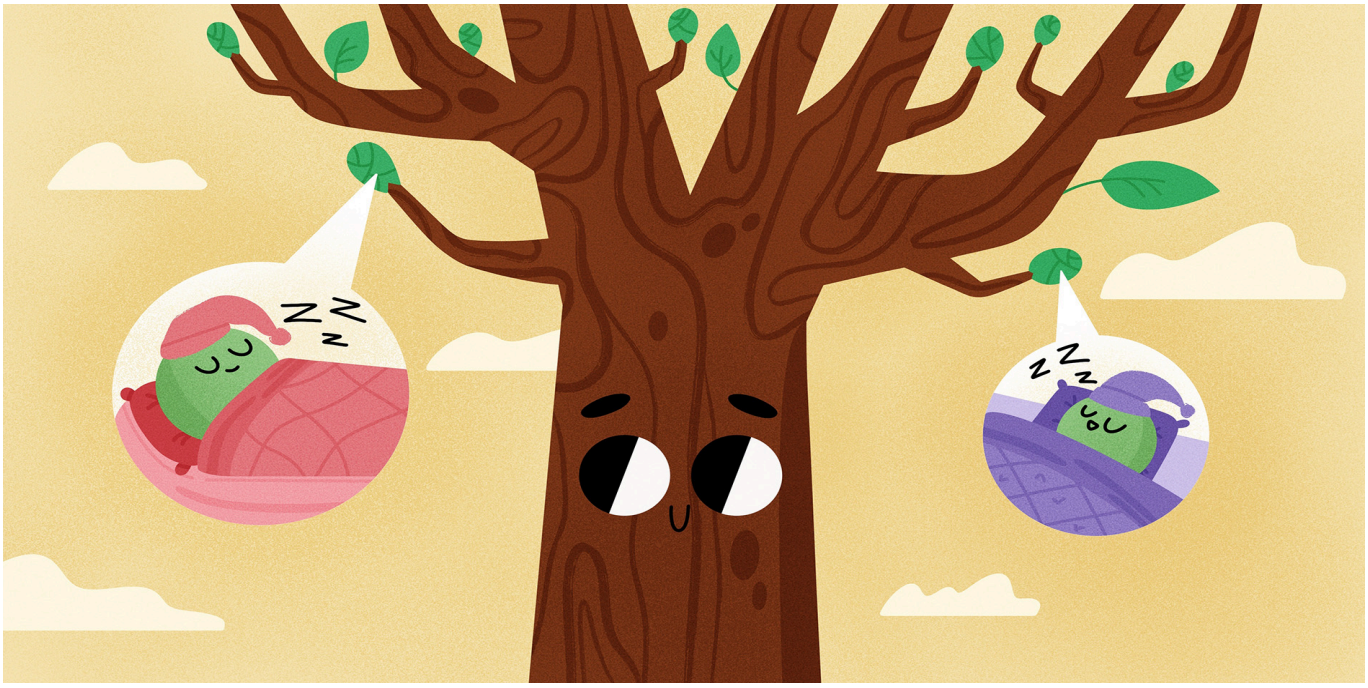
Published: 17 April 2023
doi: 10.3389/frym.2023.965617



THE SHOOT APICAL MERISTEM: A TREE'S BEST BUD

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YOUNG REVIEWERS:

JOSEPHINE
AGE: 11

OLIVE
AGE: 12

Every spring, something seemingly miraculous happens in the woods in certain parts of the world—thousands of leaves burst from buds on bare tree branches, transforming the landscape from the browns and grays of winter to the bright greens of spring and summer. Although this process is most obvious in regions with drastic seasonal changes, seed plants all over the world regularly produce and lose leaves as they grow. How does this happen? Where do these leaves come from? The cells that make up these leaves are produced by a tiny cluster of cells called the shoot apical meristem. The cells in the shoot apical meristem have the potential to develop into various kinds of cells. Through cell division, meristem cells eventually produce all the above-ground parts of a plant, including leaves. In this article, we explain how meristems function and highlight how these tiny clusters of cells impact our day-to-day lives. We will also provide suggestions for observing meristems at work.

Imagine lying down on a patch of grass, enjoying a warm summer day. Above you, layers of green leaves shield you from the sun's rays,

and you hear them rustle as a gentle breeze drifts by. The leaves are bright green and vibrant now, but if you live in a temperate part of the world where the seasons change dramatically, you know that they will soon turn shades of red, yellow, or brown—a trademark of trees that lose their leaves each year. When the magnificent show of colors comes to an end, only bare trunks and branches will remain during the cold winter. When spring arrives, you notice buds on the trees, which eventually burst open to reveal leaves (Figure 1, Videos 1, 2)—and then the cycle starts again. How can trees regrow their leaves year after year? The answer to this question can be found within the bud, in a cluster of cells called the shoot apical meristem.

VIDEO 1

Timelapse video of a winter bud from *Forsythia* opening.

VIDEO 2

Timelapse video of a winter bud from a linden tree opening.

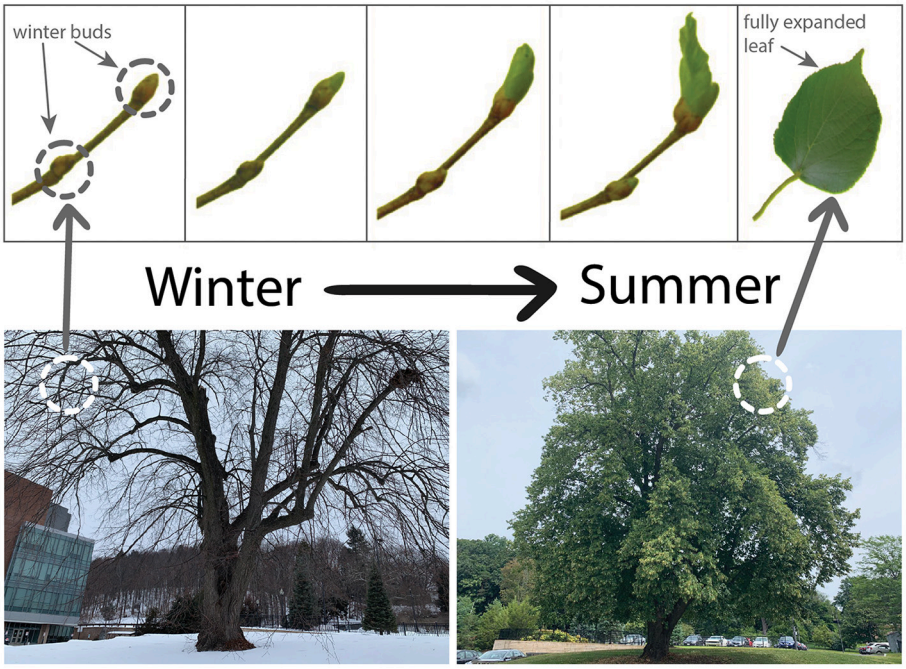

Figure 1

In the winter, buds protect the tiny leaves that will expand in the spring. In the **(Top)** panel, you can see sequential images of a bud becoming a leaf in the spring. The **(Bottom)** panel shows the same tree in the winter and the summer.

WHAT IS A MERISTEM?

SHOOT APICAL MERISTEMS (SAMS)

Clusters of stem cells at the tips of shoots and branches that give rise to the above-ground parts of a plant.

STEM CELL

An undifferentiated cell that can divide to generate more undifferentiated cells or specific cell types.

Leaves are formed by clusters of cells called **shoot apical meristems (SAMs)**. A meristem contains a cluster of cells known as **stem cells**. These stem cells can develop into many of the specialized cell types in the plant [1]. For example, a leaf cell and a petal cell on the same tree are different in structure and function, but they both come from meristem cells. While there are different types of meristems in plants (for example, the root apical meristem produces roots), this article will focus on SAMs, which are found at the tips of branches and stems. In many plants, this cluster of cells is typically 50–100 micrometers wide, 10 times smaller than the head of a pin. Meristem cells are always dividing, which is how a cluster of cells can turn into a big tree.

DECIDUOUS

A plant that sheds its leaves annually.

TEMPERATE REGIONS

Regions of the earth between the Tropic of Cancer and the arctic circle or between the Tropic of Capricorn and the antarctic circle.

In the opening scene, you imagined a **deciduous** tree, a plant that annually sheds its leaves. Deciduous trees have winter buds, and the shoot apical meristem is in the center of these buds, surrounded by tiny leaves produced by the meristem (Figure 2). Come spring, these leaves will grow and emerge from the bud [2]. This cycle of meristem development, synchronized with the seasons, happens only in the **temperate regions** of the world, but the above-ground parts of *all* seed plants anywhere in the world are also produced by shoot apical meristems [3]. When stem cells in meristems divide, they can generate not just leaf cells or other specialized cells, but also more stem cells. This ensures there are always stem cells in meristems to make new leaves, year after year.

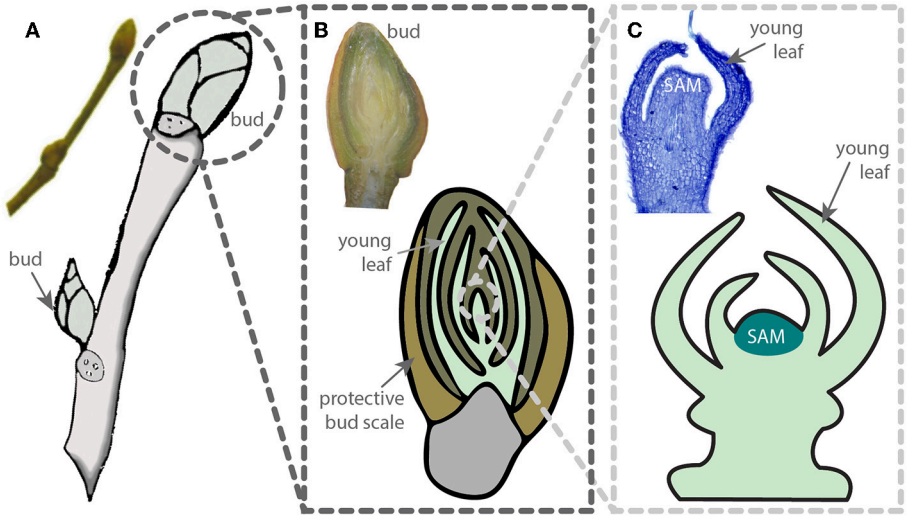

Figure 2

Winter buds enclose a shoot apical meristem and leaves that will emerge in the spring. **(A)** Winter buds from the linden tree. **(B)** Leaves are packed inside the bud, protected by bud scales. **(C)** Shoot apical meristem (SAM) is found in the very center of the bud.

STEM CELLS CAN PRODUCE MANY CELL TYPES

UNDIFFERENTIATED CELLS

Cells like stem cells that do not have specialized functions and that can differentiate into many specific cell types, given the proper signals.

DIFFERENTIATION

The process by which stem cells mature and develop into cells with specific structures and functions.

Stem cells are **undifferentiated cells**, which means they do not yet have specialized functions like pavement cells or trichrome cells, for example. Stem cells in meristems have the potential to divide and become any of the above-ground cell types in a plant (Figure 3B), through a complex process called **differentiation** [4]. In leaves, these specialized cell types include guard cells, pavement cells, and trichomes (Figure 3A), each with a specific function. Guard cells surround pores in the leaf called stomata, which regulate gas and water exchange between plants and the atmosphere. Pavement cells form the surface covering of leaves. Many leaves also have specialized hairs called trichomes, which can repel insects because they are spiky and unpleasant to eat. These cell types—and many others—are all quite different from one another, but can be found in a single leaf, produced through the differentiation of a single cluster of stem cells in the meristem. Stem cells receive signals (like a green traffic light) from the environment in which they are growing, or from proteins

or hormones produced by the plant itself. This signaling eventually results in the differentiation of the stem cells into specific types of plant cells.

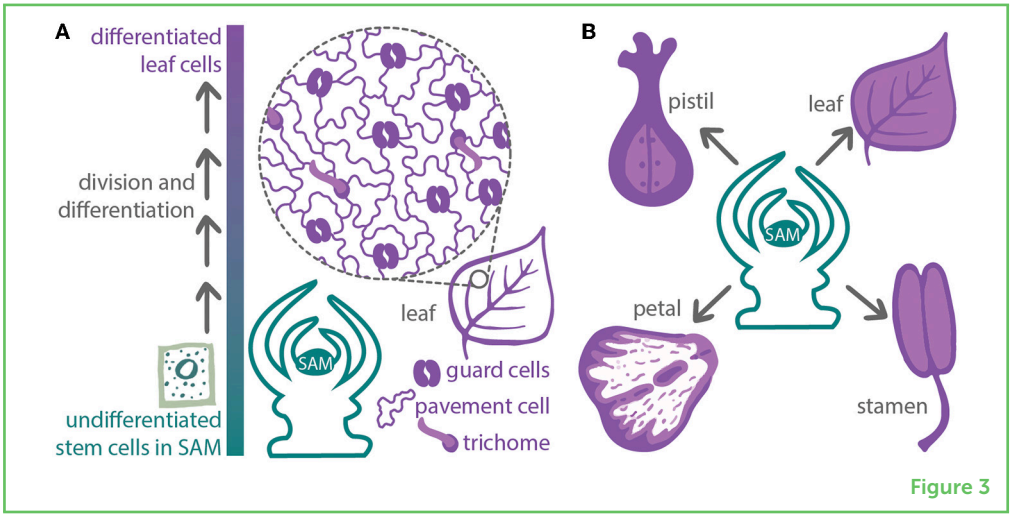

Figure 3

Shoot apical meristem (SAM) produces the above-ground organs of plants. **(A)** Stem cells in the SAM divide and differentiate into the cells that make up plant organs, like leaves. Leaves have cells with various functions that all differentiate from stem cells in the SAM, including guard cells, pavement cells, and trichomes. **(B)** This process of cell division and differentiation produces all the above-ground structures of plants, including leaves and the organs of flowers like petals, pistils, and stamens.

MERISTEMS ARE EVERYWHERE!

You can thank meristems for the food you eat, too! Meristems produce the leaves, seeds, and fruits that we eat, and larger meristems make more and bigger plant parts, which means more food. Many crop varieties grown by farmers have bigger meristems that increase crop yields. Meristems are also responsible for the amazing diversity of plant forms that we see around us. There are bushy plants with numerous branches and plants with only single main stems; plants with leaves that are arranged opposite to each other and plants with leaves arranged in spirals; plants with clusters of flowers and plants with only a single flower. What is responsible for all this variety? You guessed it—meristems!

WATCHING MERISTEMS WORK

Meristems are tiny, and they are usually buried under many layers of protection within buds, making it difficult to see them without a microscope. However, they are all around us—at the tips of almost every tree branch or plant stem—and the products of meristem cell division are also all around us, in the form of leaves, stems, and flowers. We can indirectly watch meristems work by taking time to observe the trees and plants around us for a year. Pick a tree in your yard or neighborhood, and mark one or two branches to follow with a piece of colored string or yarn. Observe these branches every week, or even every 2–3 days when things are changing quickly in the spring, summer, and fall. Draw the branch you are following, take pictures with your phone, and take notes about what you see and think. Use a magnifying glass to look at the surfaces of the leaves, to see if you

can find any interesting hairs or glands on the leaves. Take note of things like how many leaves emerge from the buds you are tracking, or whether every bud produces the same shape, size, and number of leaves. All these notes, drawings, and observations can help you see and appreciate the work of the meristems, chugging along to build the green world around us.

CONCLUSION

The shoot apical meristem plays an essential role in plant growth and development. Although this article focuses on the buds of trees, most plants have shoot apical meristems, and there are many kinds of meristems in which we can find stem cells building various plant parts. Meristems also allow plants to regrow after harsh events, such as after the winter cold, after forest fires, or after the lawn is mowed. Shoot apical meristems allow plants to produce new leaves year after year, transforming our landscapes, giving us shade to sit in, and providing us with food to eat.

ACKNOWLEDGMENTS

We thank members of the Bartlett Lab and Dr. Margaret Conover for their thoughtful discussion and comments on this study. This study was supported by the National Science Foundation (IOS-1652380 to MB and IOS-1148971 to BT), the Society for Developmental Biology, and the University of Massachusetts Amherst.

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SUBMITTED: 09 June 2022; **ACCEPTED:** 14 March 2023;
PUBLISHED ONLINE: 17 April 2023.

EDITOR: John T. Van Stan, Cleveland State University, United States

SCIENCE MENTORS: Marcus Yee and Manuel Esperon-Rodriguez

CITATION: Higgins I, Huang K, Rozza I, Thompson B and Bartlett M (2023) The Shoot Apical Meristem: A Tree's Best Bud. Front. Young Minds 11:965617. doi: 10.3389/frym.2023.965617

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

JOSEPHINE, AGE: 11

My name is Josephine, I am 11 years old and I am in 6th grade. I live with my mom and dad, my four parakeets and a husky. My favorite color is neon-orange, I figure skate, swim and play golf. I like to read and watch shows about animals, dragons and mythology. I love animals, but I do not have a favorite since all have different skills and features. I enjoyed working on the article and I hope to do another one.

OLIVE, AGE: 12

My name is Olive and I am a sixth grader. I love reading, science, biology, medicine, and taking care of animals, and I hope to study veterinary medicine when I get into university. Our family has one dog, one blue tongue skink, and one busy fish tank. I do Aikido and Outschool online classes. My hobbies are: crocheting, reading books, cooking, reading things on the computer, watching cartoons, and walking our dog.

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Isabella Higgins earned her B.Sc. in microbiology at the University of Massachusetts Amherst. She was a Society for Developmental Biology "Choose Development" scholar, and she researched plant development. She will continue to do research on developmental biology as a graduate student at the University of Pennsylvania. She loves the outdoors and spends her free time hiking, camping, and getting outside as much as she can.

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Karen Huang earned her B.Sc. in biochemistry and molecular biology at the University of Massachusetts Amherst, where she spent her undergraduate years studying plant genetics. She is a medical scribe at Marlborough Hospital while she

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Isabella Rozza earned her B.Sc. in biology and environmental science from the University of Massachusetts Amherst. During her studies, she did research involving plant genetics. She has a passion for botany and plant science. She is captivated by the amazing world of plants and collects and identifies them in her spare time. She hopes to work on plant conservation in her future career.

BETH THOMPSON

Beth Thompson is a professor at East Carolina University where she studies genes that control plant and flower development. She has long been fascinated with how plants and animals start as a single cell that divides and differentiates to ultimately make a functional organism with lots of different cell types and tissues. She loves learning something new every day and sharing cool plant biology with her students and anyone else who will listen.

MADELAINE BARTLETT

Madelaine Bartlett is a professor at the University of Massachusetts Amherst where she leads a group that studies the genes that regulate plant development, and how these genes have evolved. She grew up in South Africa, surrounded by amazing plants. She was always fascinated by the process of plant development and how tiny seeds grow into giant trees, and she is delighted that she gets to follow her curiosity and amazement as a job. *mbartlett@bio.umass.edu

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