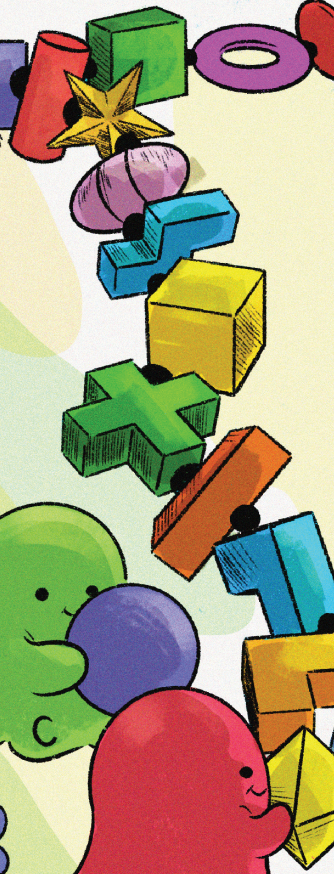
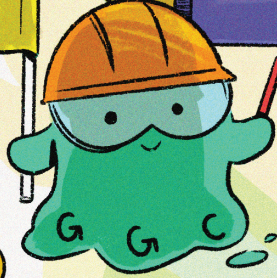


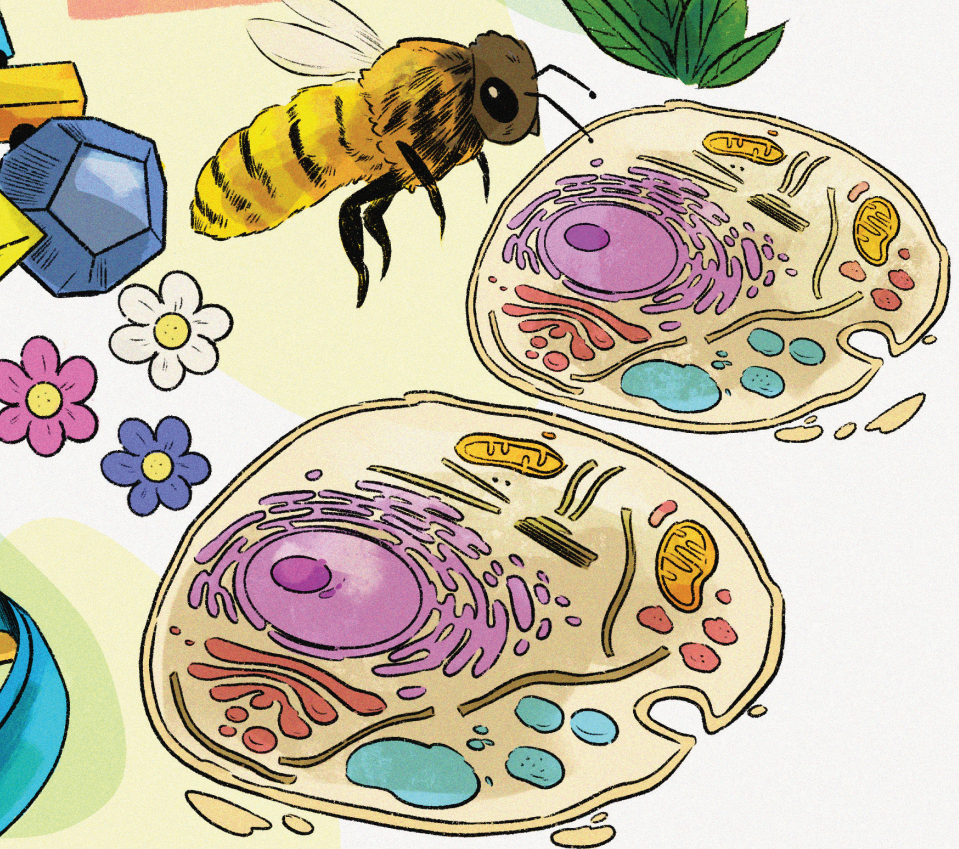
MYSTERY OF THE MONKEY FLOWER

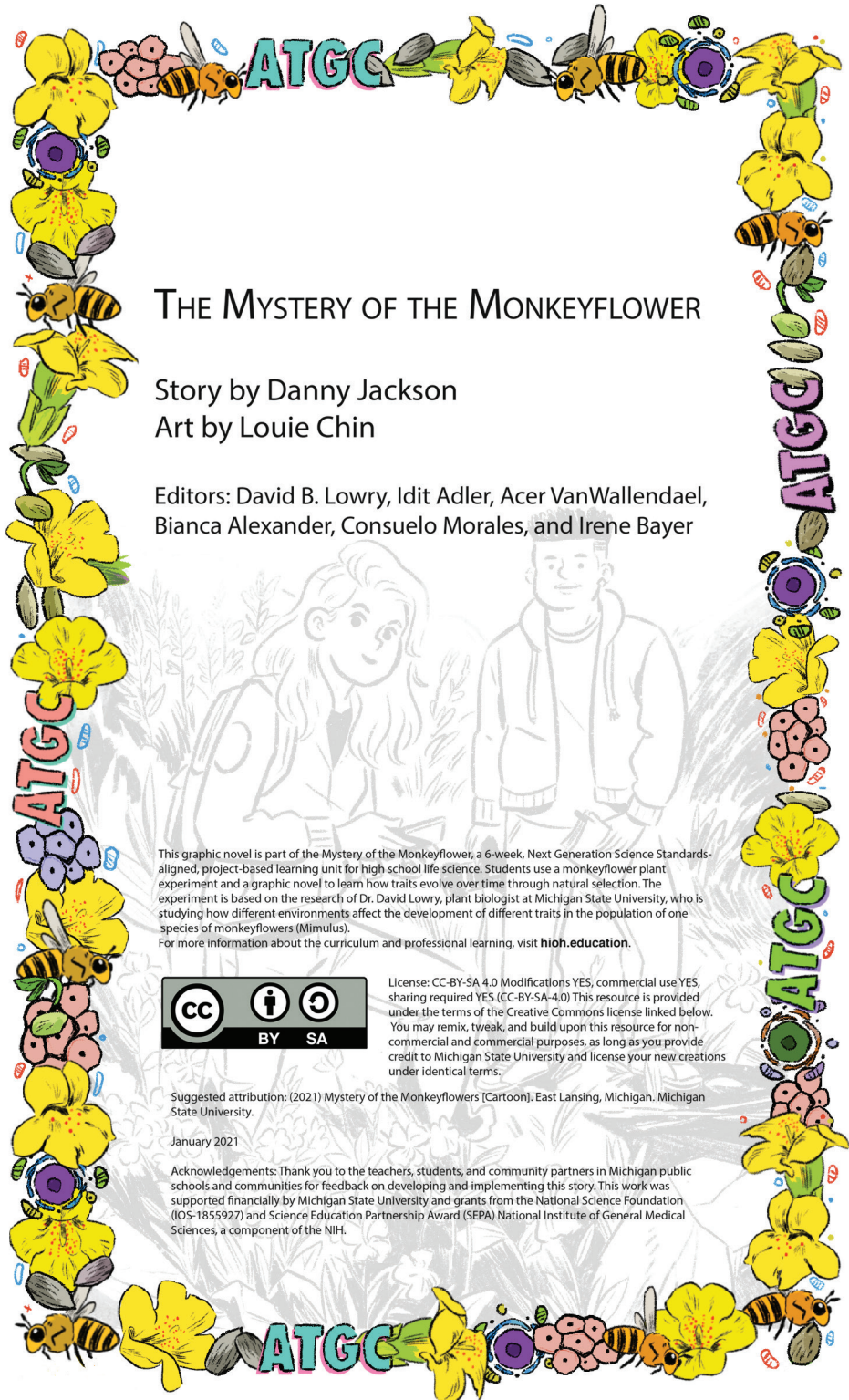


ATGCA TGC A TGC
G A C C T G A C T G A

amino acids





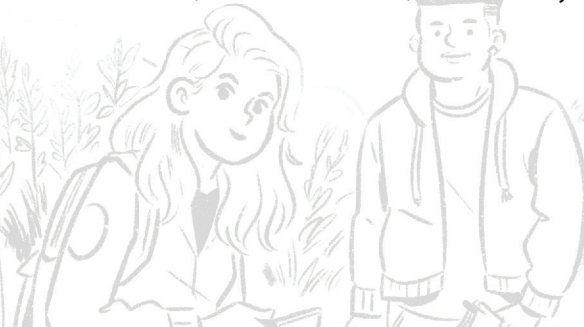


THE MYSTERY OF THE MONKEYFLOWER

Story by Danny Jackson

Art by Louie Chin

Editors: David B. Lowry, Idit Adler, Acer VanWallendael,
Bianca Alexander, Consuelo Morales, and Irene Bayer



This graphic novel is part of the Mystery of the Monkeyflower, a 6-week, Next Generation Science Standards-aligned, project-based learning unit for high school life science. Students use a monkeyflower plant experiment and a graphic novel to learn how traits evolve over time through natural selection. The experiment is based on the research of Dr. David Lowry, plant biologist at Michigan State University, who is studying how different environments affect the development of different traits in the population of one species of monkeyflowers (*Mimulus*).
For more information about the curriculum and professional learning, visit high.education.



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January 2021

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For Cloning
Specially Formed
Cells



MODULE 1:

A TALE OF TWO FLOWERS

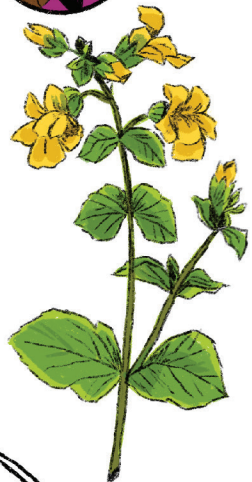
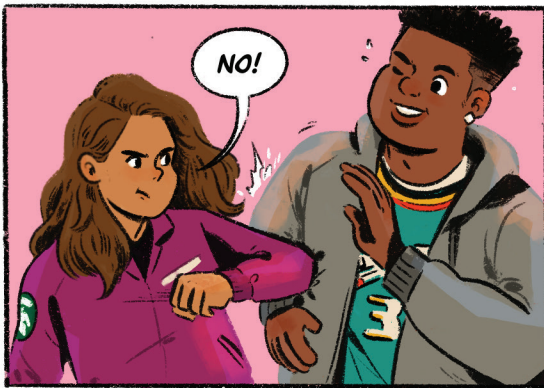
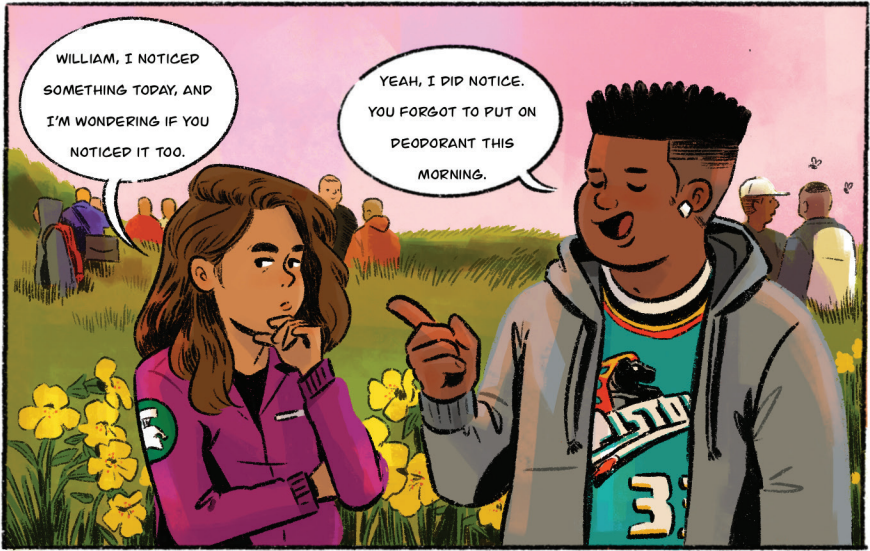
SLIVERS OF PINK SUN CUT THROUGH THE EVENING FOG OVER THE PACIFIC OCEAN AS THE SUN SET IN BOPEGA BAY, A HOTSPOT FOR BIOLOGISTS JUST NORTH OF SAN FRANCISCO, AND MAIA AND WILLIAM SAT IN THEIR MUDDY SWEATSHIRTS ON THE BACK OF THEIR PICKUP TRUCK.



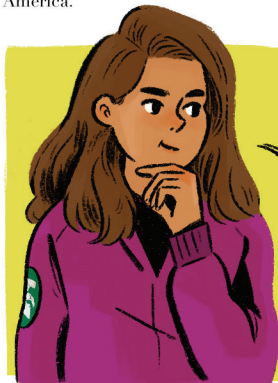


THEY'D HAD A LONG DAY RECORDING BEE BEHAVIORS, AND THEY WERE READY TO GET HOME, BUT LIKE ALL GOOD SCIENTISTS THEY WERE SETTING ASIDE TIME TO APPRECIATE THE BEAUTIFUL WORLD AND TO REFLECT ON THE THINGS THEY'D THOUGHT THAT DAY.





Mimulus guttatus, yellow monkeyflower. Common along creeks and streams, distributed throughout California and western North America.



WE'VE WATCHED BEES VISITING THESE YELLOW FLOWERS ALL WEEK, AND I KNOW WE'RE OUT HERE TO STUDY THE BEES...



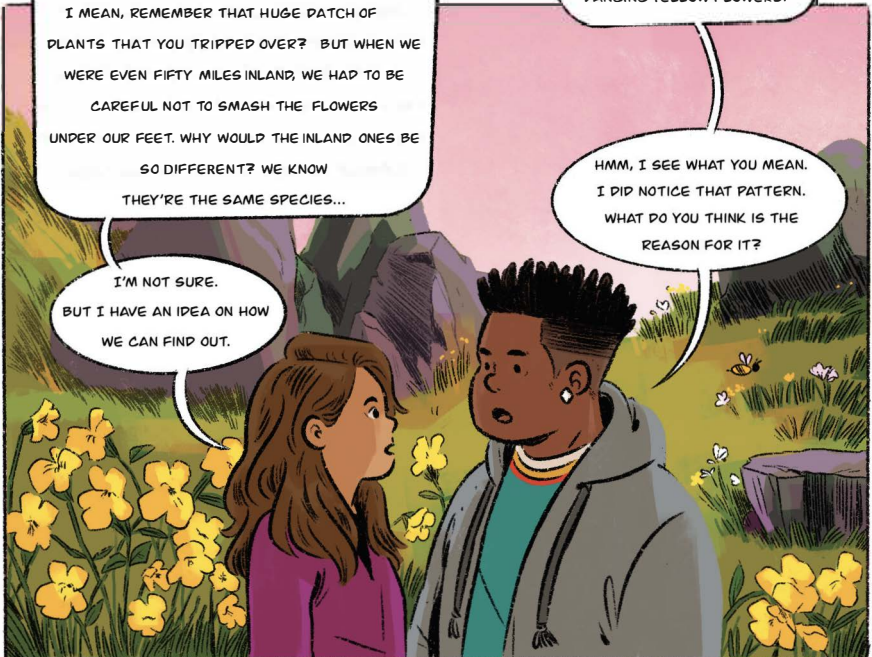
...BUT SOMETHING IS GOING ON WITH THESE FLOWERS. THEY ALL LOOK PRETTY SIMILAR, BUT NOT TOO SIMILAR, YOU KNOW?

FAIR, BUT STICK WITH ME. THE FLOWERS BY THE OCEAN LOOK VERY SIMILAR TO EACH OTHER. RIGHT? I MEAN, REMEMBER THAT HUGE PATCH OF PLANTS THAT YOU TRIPPED OVER? BUT WHEN WE WERE EVEN FIFTY MILES INLAND, WE HAD TO BE CAREFUL NOT TO SMASH THE FLOWERS UNDER OUR FEET. WHY WOULD THE INLAND ONES BE SO DIFFERENT? WE KNOW THEY'RE THE SAME SPECIES...

HOW DO YOU MEAN? I CAN'T REALLY THINK STRAIGHT. IT'S BEEN A LONG DAY AND MY BRAIN IS A MUSHY GLOP OF BEES AND DANCING YELLOW FLOWERS.

HMM, I SEE WHAT YOU MEAN. I DID NOTICE THAT PATTERN. WHAT DO YOU THINK IS THE REASON FOR IT?

I'M NOT SURE. BUT I HAVE AN IDEA ON HOW WE CAN FIND OUT.



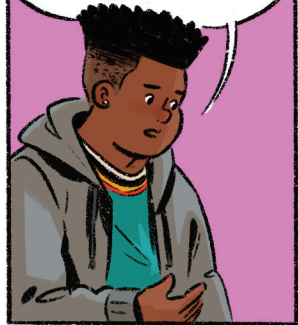
OH NO.

I KNOW THAT LOOK. YOU'RE PLANNING OUT ANOTHER EXPERIMENT. WE'RE NOT EVEN DONE WITH THIS BEE STUDY!

WE'VE ONLY COLLECTED THE ROUGH DATA, WE'VE STILL GOT TO CLEAN IT UP, ANALYZE IT, PROBABLY COME BACK AND COLLECT MORE DATA.



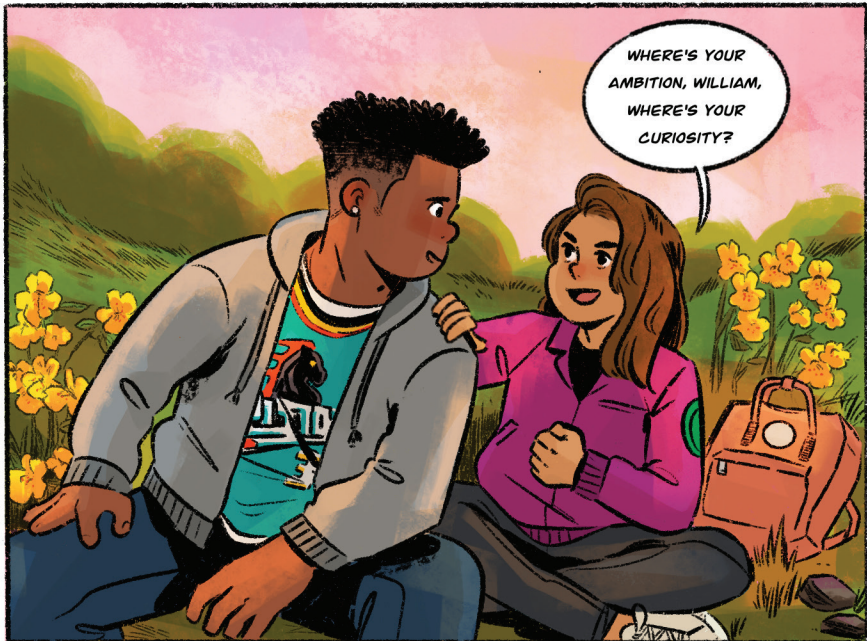
PLUS YOU'RE TEACHING A CLASS THIS SEMESTER, AND I'VE GOT TO HELP PLAN OUT MY SISTER'S WEDDING, IT'S TOO MUCH MAIA.

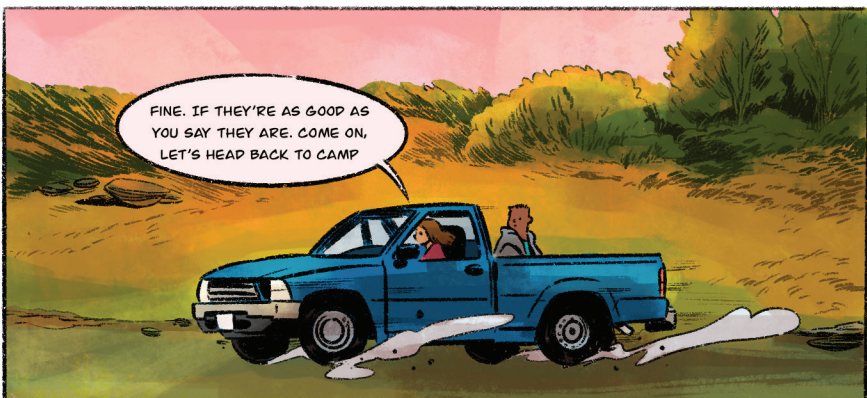


LET IT GO.



WHERE'S YOUR AMBITION, WILLIAM, WHERE'S YOUR CURIOSITY?





MODULE 2:

ON THE FLIP SIDE OF THE SAME SPECIES

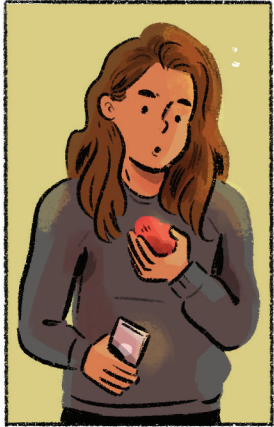




Maia: they've got all the plants growing



William: amazing. amazing. knew they'd have our back.



William: do the plants still look different when they've grown them up in a classroom?

William: what observations have they made?

Maia: idk. I haven't gotten a report yet.



Maia: I know the experiment isn't done, but I'm so curious



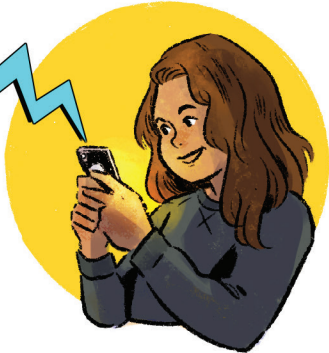
William: I'll ask them. I'm sure they'd be happy to fill us in

William: I gotta go though

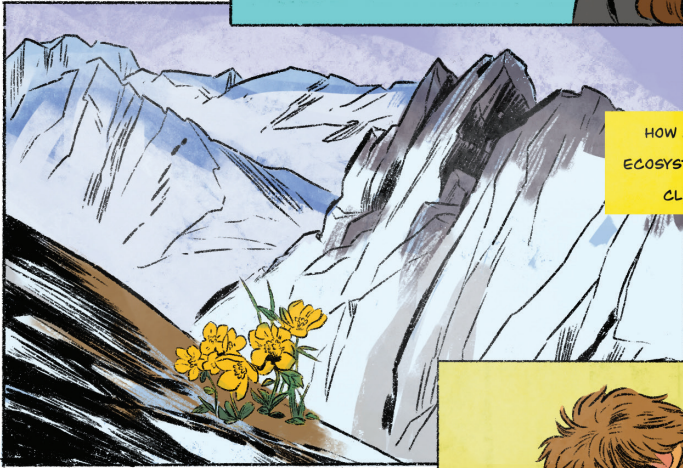
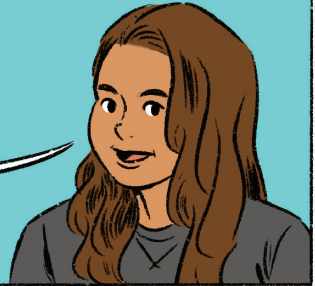
William: I'm out in the field and my phone is about to die. I'll be back in the lab this afternoon.

Maia: Shoot. I don't want to wait that long. I'll just ask them

Dear plant researchers,
What have you learned so far about the cause of the difference in these plants?

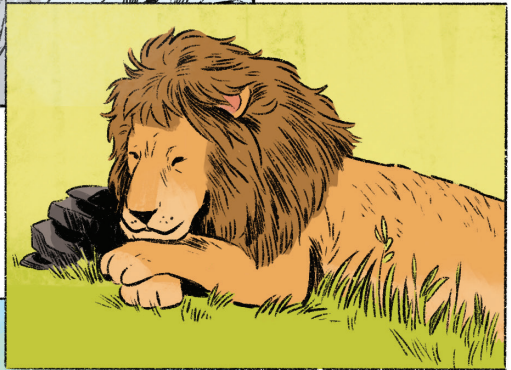


THE WORK THAT WE'VE BEEN DOING IS JUST ONE SMALL STORY IN THE HUGE NARRATIVE OF CONTEMPORARY SCIENCE. PEOPLE DOWN THE HALL FROM ME ARE WORKING HARD ON PROJECTS WITH SCIENTISTS ALL OVER THE WORLD.

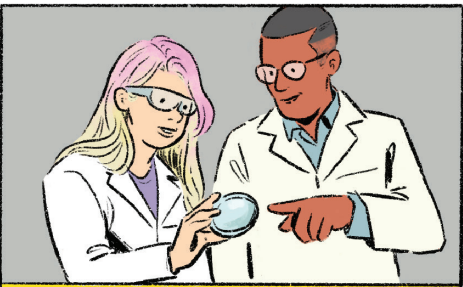


HOW ARE MOUNTAIN TOP ECOSYSTEMS RESPONDING TO CLIMATE CHANGE?

WHAT DOES CANCER LOOK LIKE IN OTHER MAMMALS?



WHY DO SOME SPECIES THRIVE IN CITIES WHILE OTHERS DON'T?



WE ARE WORKING TO UNDERSTAND
HOW GENETICS AFFECT HUMAN HEALTH.



WHY DO SOME PEOPLE SHOW
NO SYMPTOMS AT ALL WHEN THEY HAVE
THE NOVEL CORONAVIRUS?



WE ARE STUDYING THE GENETICS
OF ENDANGERED BIRDS TO AID IN
THEIR CONSERVATION EFFORTS.



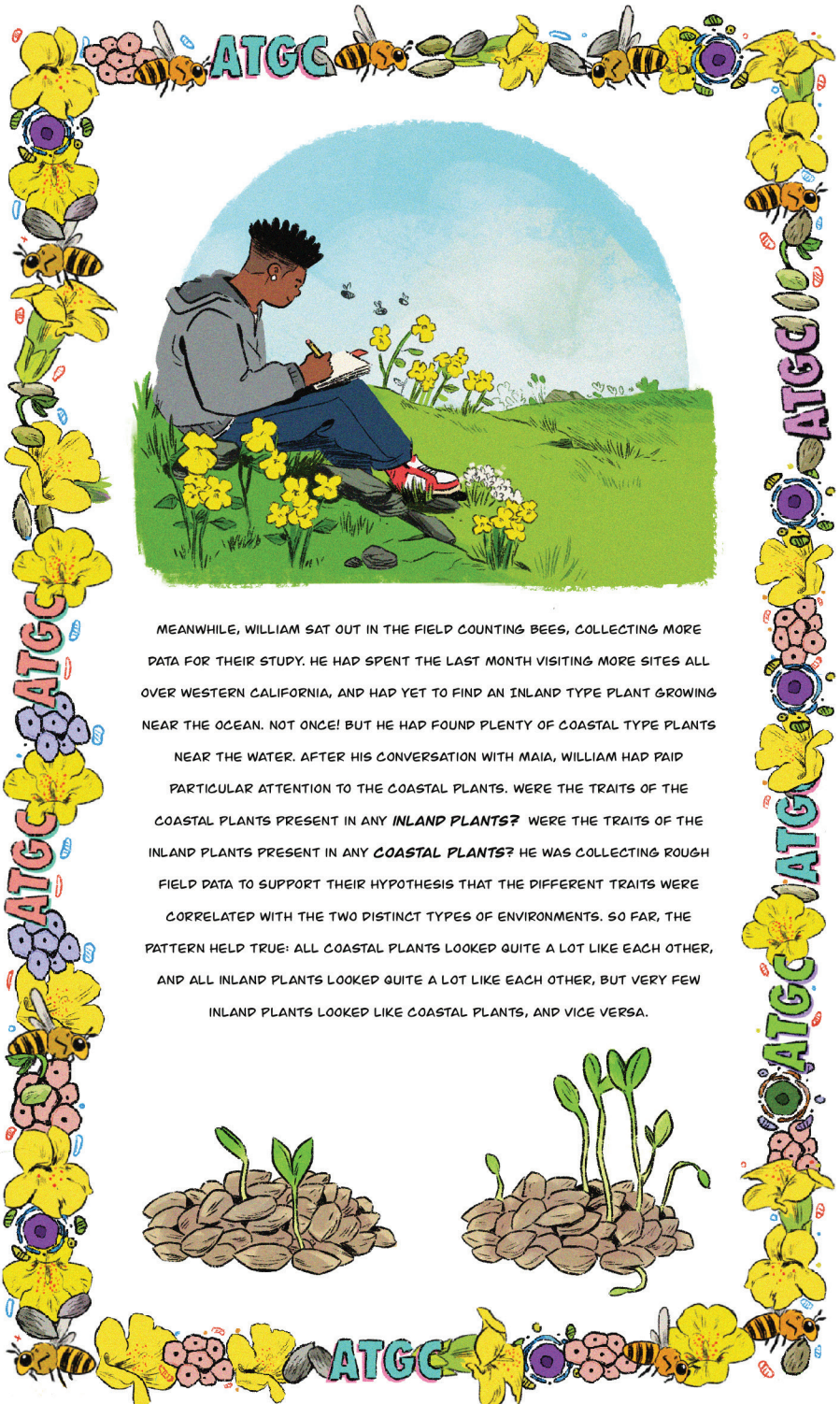
ARE BIRD MIGRATION ROUTES CHANGING
IN RESPONSE TO CLIMATE CHANGE?



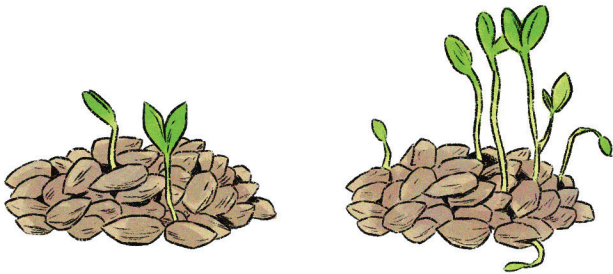
HOW DO WE IMPROVE CROPS TO FEED A
GROWING HUMAN POPULATION IN A
CHANGING WORLD?

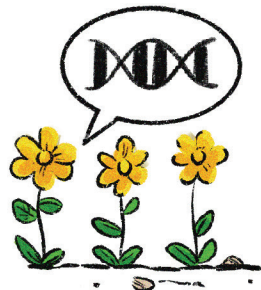
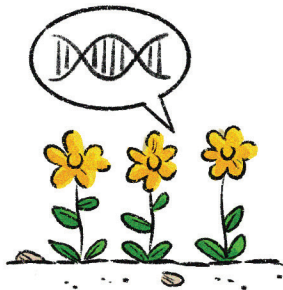
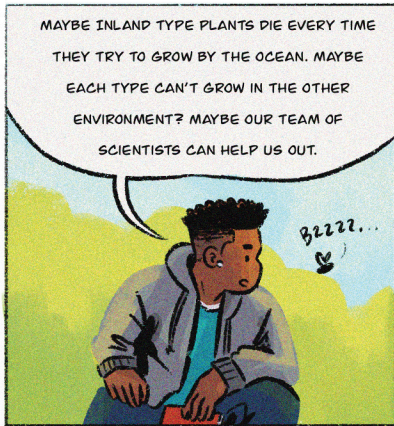
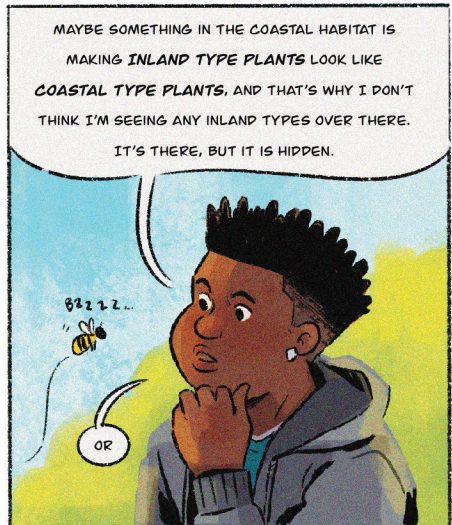
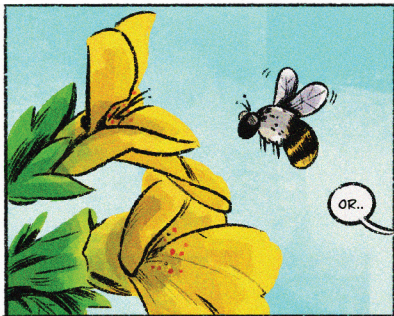
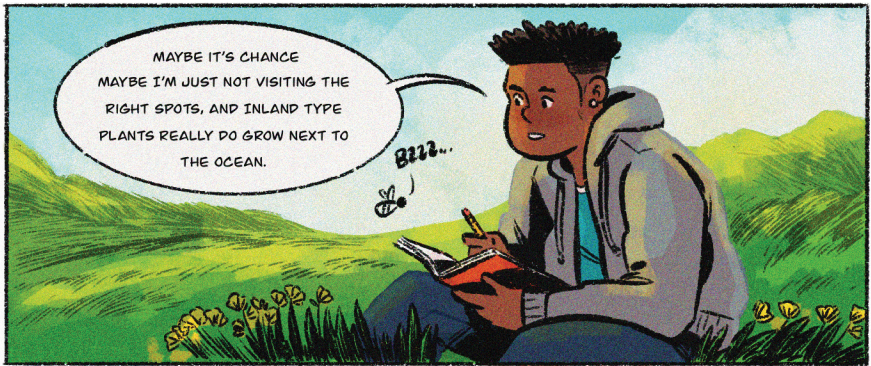


HOW DID INDIGENOUS PEOPLES OF THE
AMERICAS DOMESTICATE BEANS?



MEANWHILE, WILLIAM SAT OUT IN THE FIELD COUNTING BEES, COLLECTING MORE DATA FOR THEIR STUDY. HE HAD SPENT THE LAST MONTH VISITING MORE SITES ALL OVER WESTERN CALIFORNIA, AND HAD YET TO FIND AN INLAND TYPE PLANT GROWING NEAR THE OCEAN. NOT ONCE! BUT HE HAD FOUND PLENTY OF COASTAL TYPE PLANTS NEAR THE WATER. AFTER HIS CONVERSATION WITH MAIA, WILLIAM HAD PAID PARTICULAR ATTENTION TO THE COASTAL PLANTS. WERE THE TRAITS OF THE COASTAL PLANTS PRESENT IN ANY **INLAND PLANTS**? WERE THE TRAITS OF THE INLAND PLANTS PRESENT IN ANY **COASTAL PLANTS**? HE WAS COLLECTING ROUGH FIELD DATA TO SUPPORT THEIR HYPOTHESIS THAT THE DIFFERENT TRAITS WERE CORRELATED WITH THE TWO DISTINCT TYPES OF ENVIRONMENTS. SO FAR, THE PATTERN HELD TRUE: ALL COASTAL PLANTS LOOKED QUITE A LOT LIKE EACH OTHER, AND ALL INLAND PLANTS LOOKED QUITE A LOT LIKE EACH OTHER, BUT VERY FEW INLAND PLANTS LOOKED LIKE COASTAL PLANTS, AND VICE VERSA.





MODULE 3:

LET'S PROCEED INSIDE THE SEED



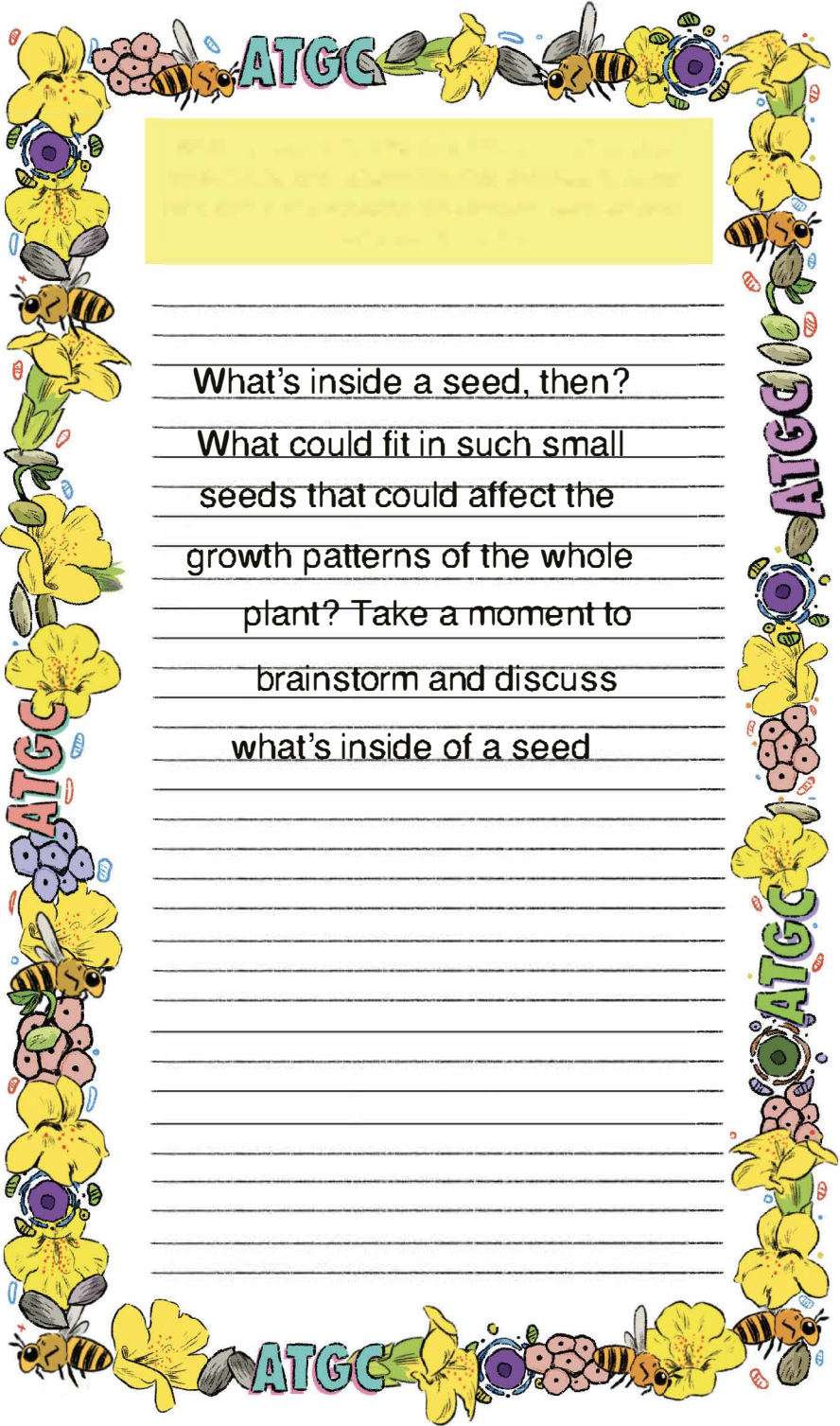
Hello plant researchers,

I had a thought. Your teacher shared with me some observations that you'd all made of these plants, and it seems that they're growing... differently. So what's causing the difference?

You put them in the same soil. You're giving them the same amount of light, and the same amount of water. You're talking to them just the same amount, too, I hope.

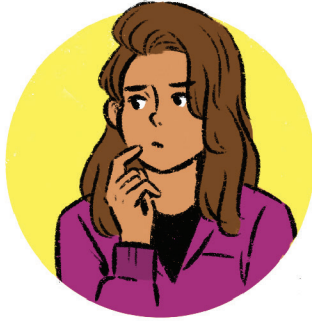
The only thing we didn't control for is what's in the seeds, right?





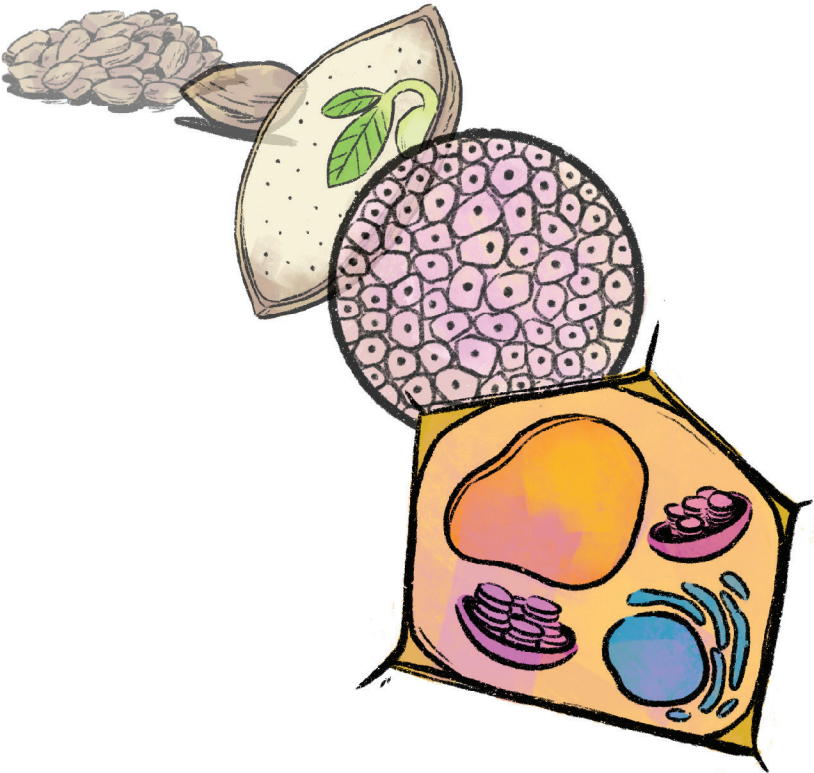
What's inside a seed, then?

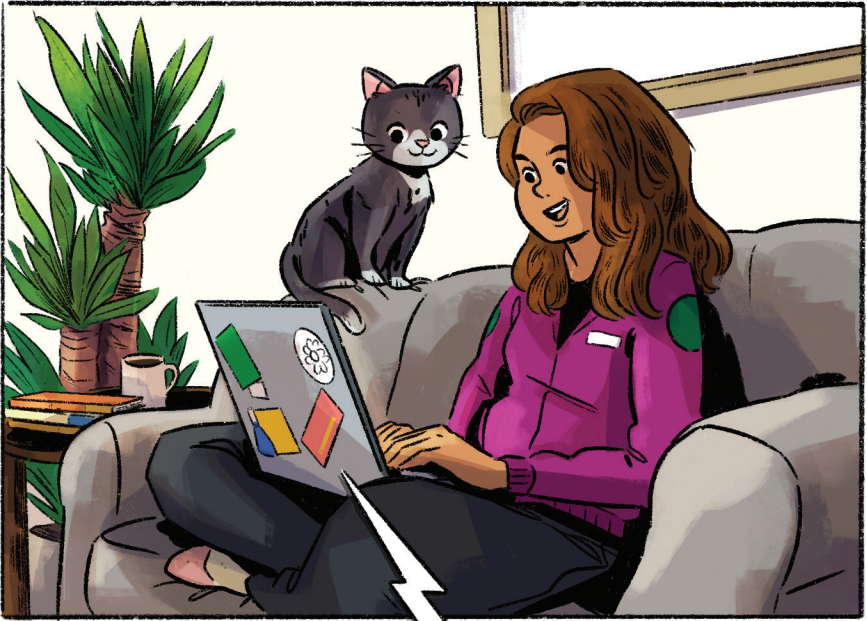
What could fit in such small seeds that could affect the growth patterns of the whole plant? Take a moment to brainstorm and discuss what's inside of a seed



It's a tricky question, I know, and that's why I asked you all to think on it. People spent centuries asking the same thing, and not coming to any great conclusions, so I didn't expect you all to know right away. Have you all heard of DNA? Or of genes?

These are terms used to describe certain molecules that are found inside every living thing, and I have a suspicion that the differences you're observing in these plants come from genetic differences. The flower pots have the same soil, the same light, the same water, even similar looking seeds, but inside the seeds there might be different molecules, different DNA.

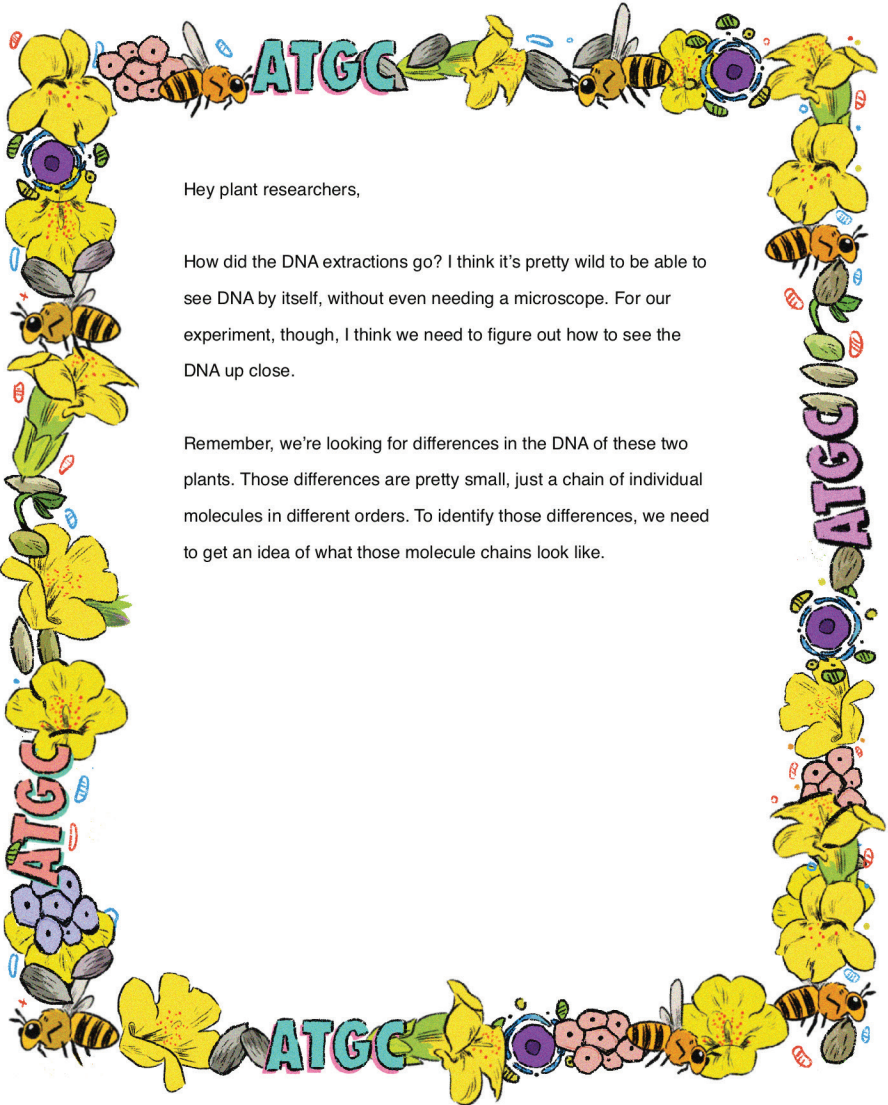




Ok, maybe we need to step back and learn a bit about genes before we move forward. I know this cool experiment that extracts DNA from strawberries, I'll send you the protocol. It'll show you that DNA is something real, something you can see.

Best,
Maia

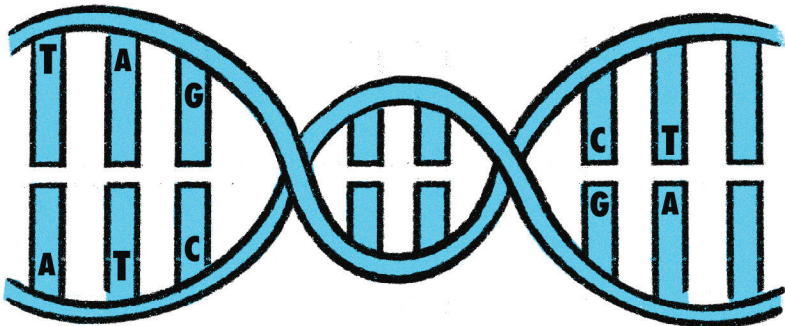
A screenshot of an email interface. On the left is a list of email messages with circular profile pictures and checkboxes. The third message, which has a purple flower icon as its profile picture, is highlighted in red. On the right is the content of the selected email, showing a paragraph of text and a signature. A mouse cursor is pointing at the signature.

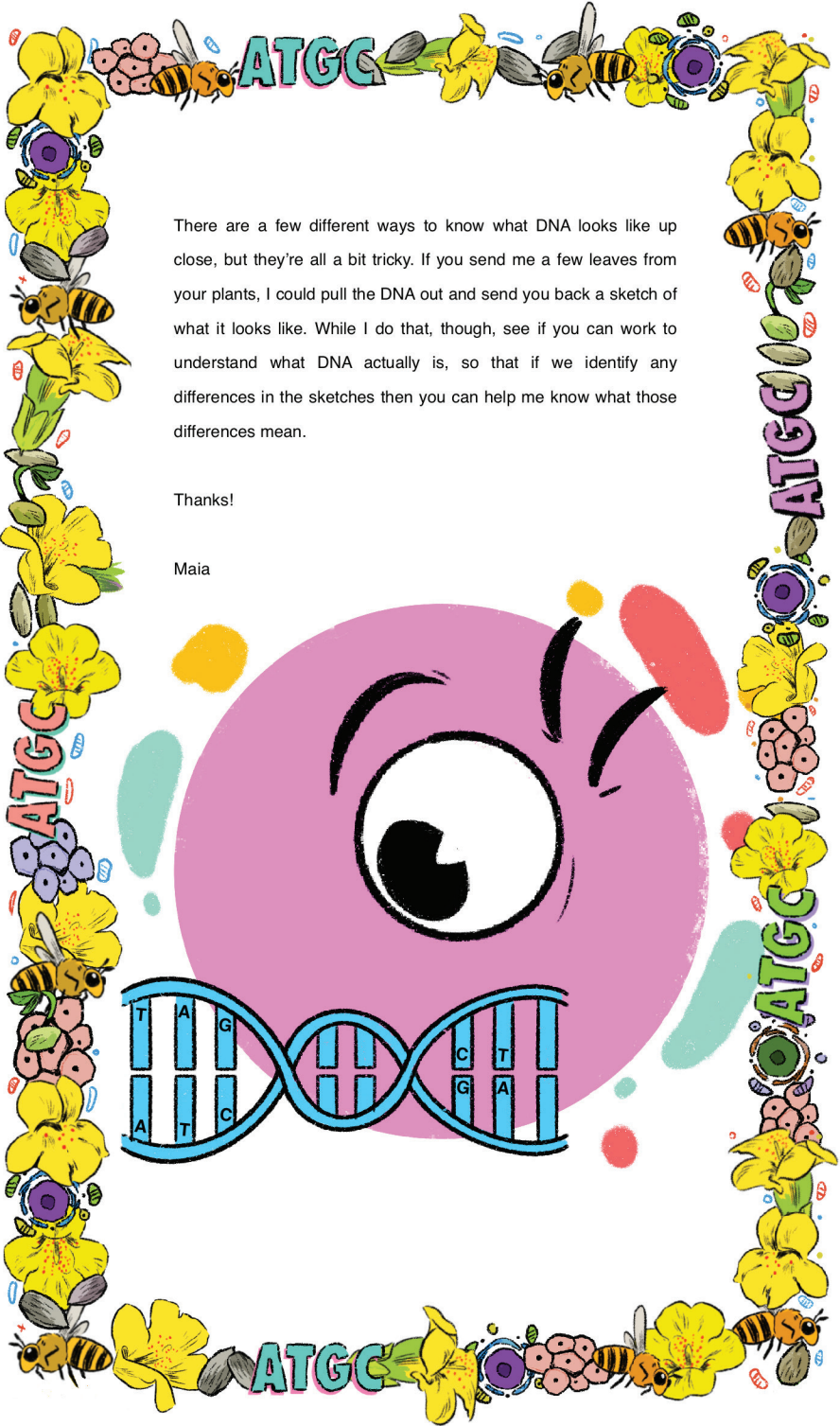


Hey plant researchers,

How did the DNA extractions go? I think it's pretty wild to be able to see DNA by itself, without even needing a microscope. For our experiment, though, I think we need to figure out how to see the DNA up close.

Remember, we're looking for differences in the DNA of these two plants. Those differences are pretty small, just a chain of individual molecules in different orders. To identify those differences, we need to get an idea of what those molecule chains look like.

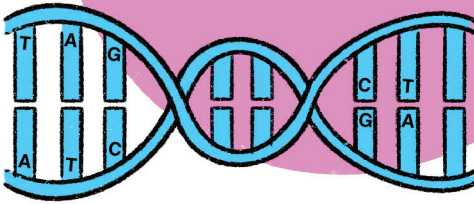




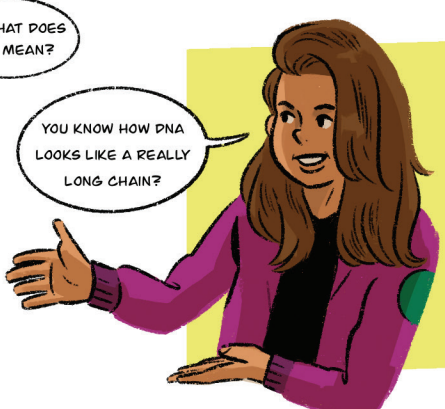
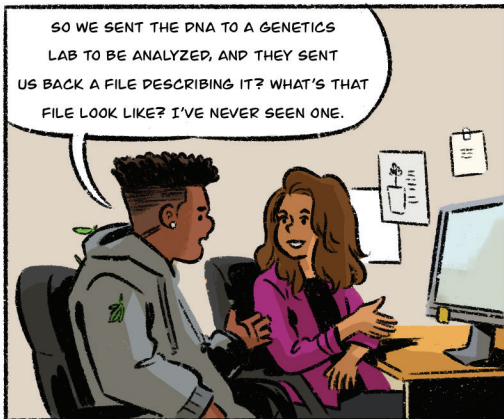
There are a few different ways to know what DNA looks like up close, but they're all a bit tricky. If you send me a few leaves from your plants, I could pull the DNA out and send you back a sketch of what it looks like. While I do that, though, see if you can work to understand what DNA actually is, so that if we identify any differences in the sketches then you can help me know what those differences mean.

Thanks!

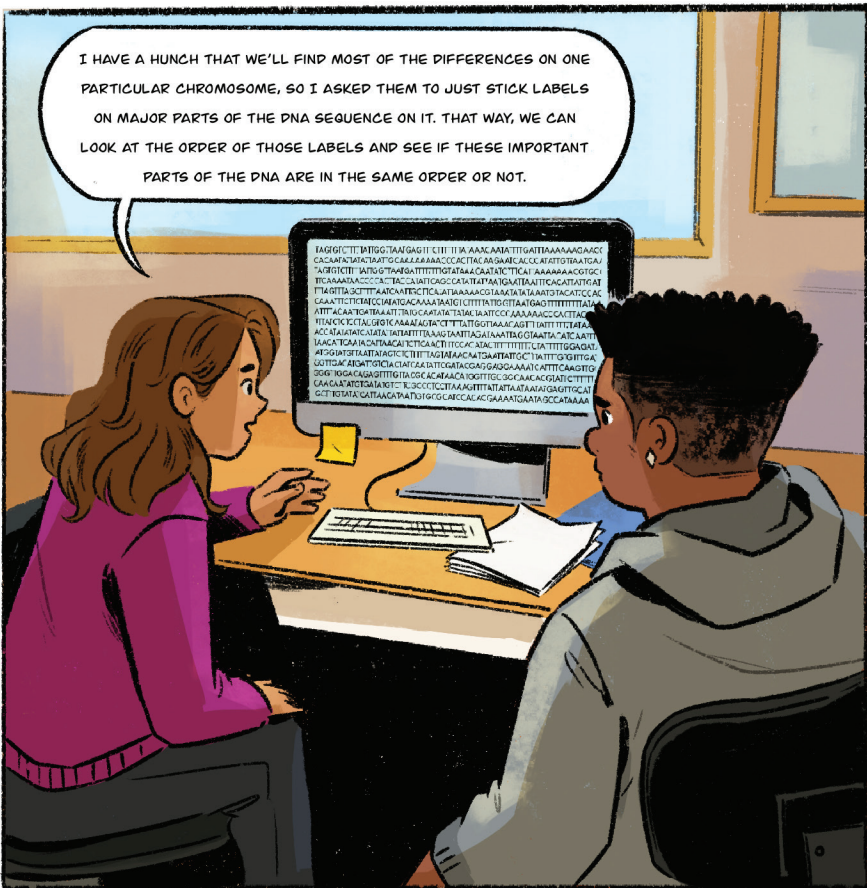
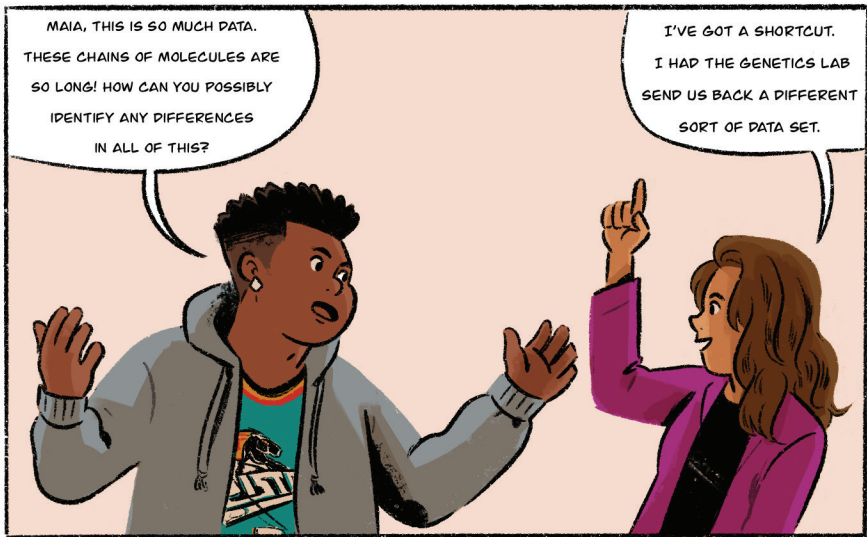
Maia

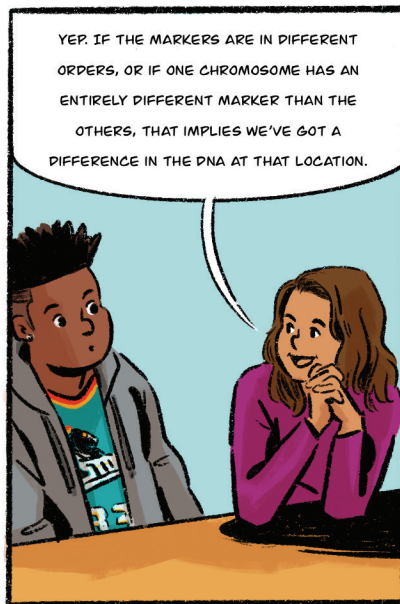
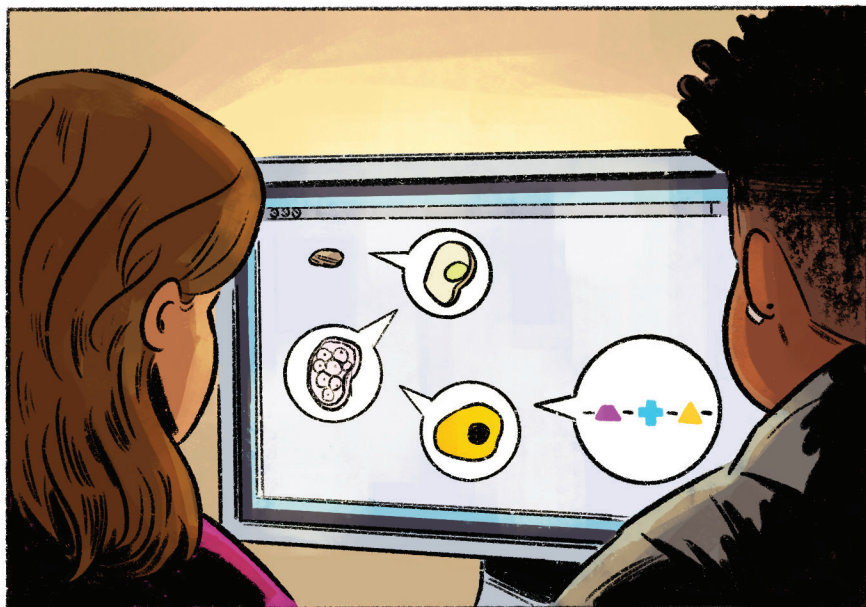






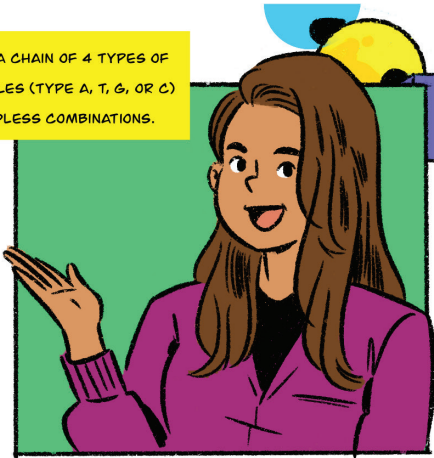
WELL EACH LINK ON THAT CHAIN CAN BE ONE OF FOUR MOLECULES, SO WHEN WE TALK ABOUT 'GENETIC DIFFERENCES' WE'RE DESCRIBING DIFFERENCES IN THE ORDER OF THE MOLECULES ON THAT CHAIN. TO SIMPLIFY THINGS, THE GENETICS LAB SENT ME BACK THIS CODE. EACH LETTER IS USED TO STAND FOR A SPECIFIC MOLECULE, A, G, C, OR T, AND WE CAN LOOK TO SEE IF THESE LETTERS ARE IN A DIFFERENT ORDER BETWEEN COASTAL PLANT AND INLAND PLANT. LIKE ATTTA VS ATGTA.





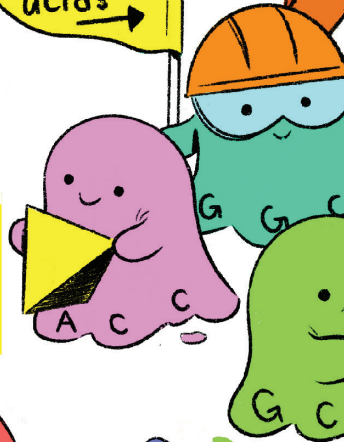
ATGATGATGCAATG
GATGATGCAATG
CTG

DNA IS A CHAIN OF 4 TYPES OF MOLECULES (TYPE A, T, G, OR C) IN ENDLESS COMBINATIONS.



amino acids →

THOSE PROTEINS BUILD ALL THE PARTS OF THE CELL AROUND THE DNA. DIFFERENCES IN THE DNA RESULT IN DIFFERENCES IN THE PROTEINS, WHICH RESULT IN DIFFERENCES BETWEEN ORGANISMS.

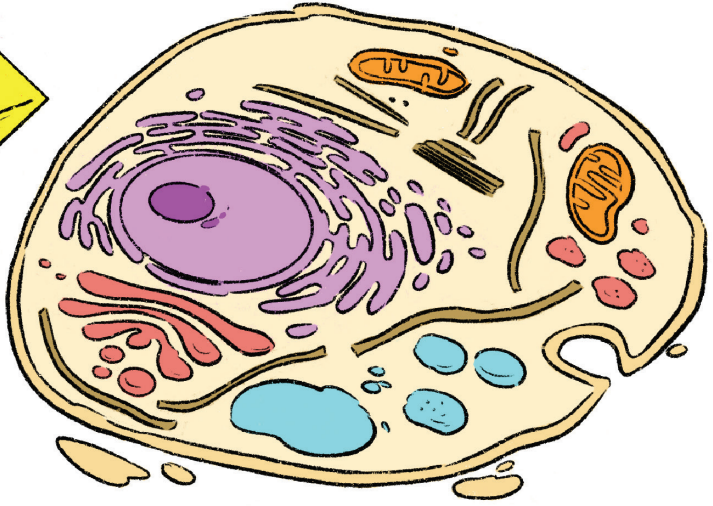
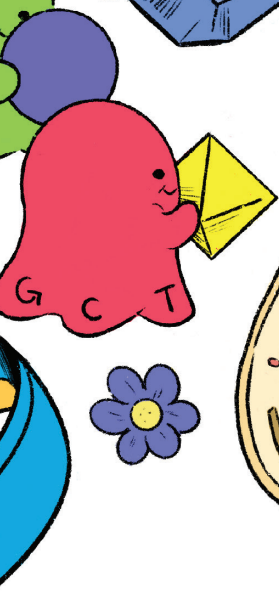


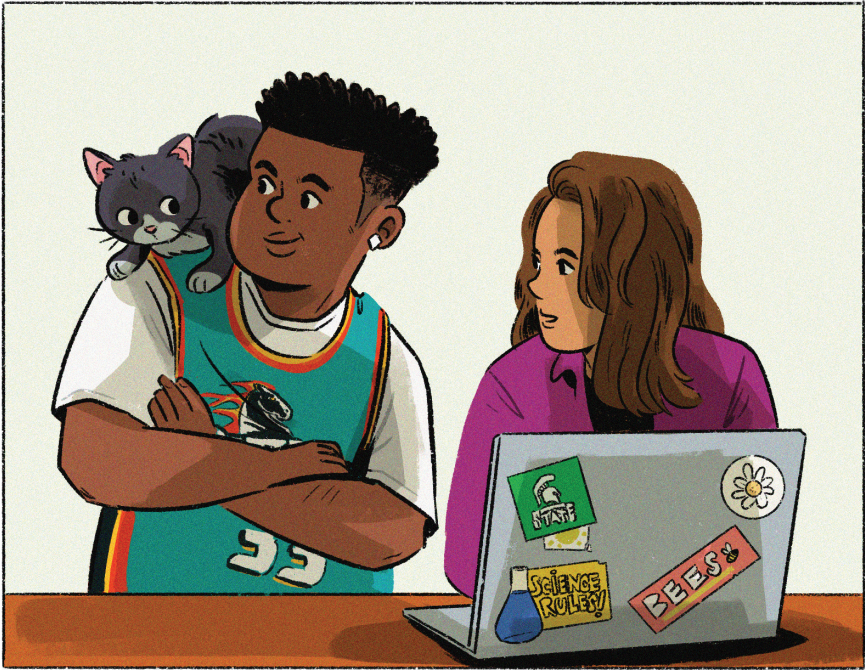
THAT CHAIN IS SO LONG THAT IT IS STORED IN A WOUND UP KNOT. WE CALL THESE KNOTS, "CHROMOSOMES". HUMANS HAVE 23 TYPES OF DNA KNOTS (CHROMOSOMES) IN THEIR CELLS.





A GENE IS A SMALL CHUNK OF DNA THAT INTERACTS WITH OTHER MOLECULES, WHICH RESULTS IN A PROTEIN BASED ON THE UNIQUE ORDER OF A, T, G, AND C MOLECULES. DNA IN ONE ORDER, ATT FOR INSTANCE WOULD RESULT IN A DIFFERENT PROTEIN THAN DNA IN ANOTHER ORDER, LIKE GTT.





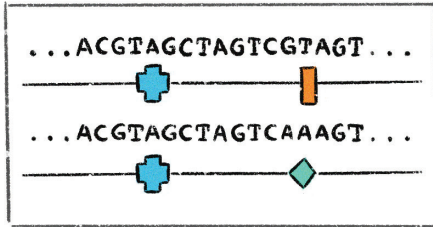
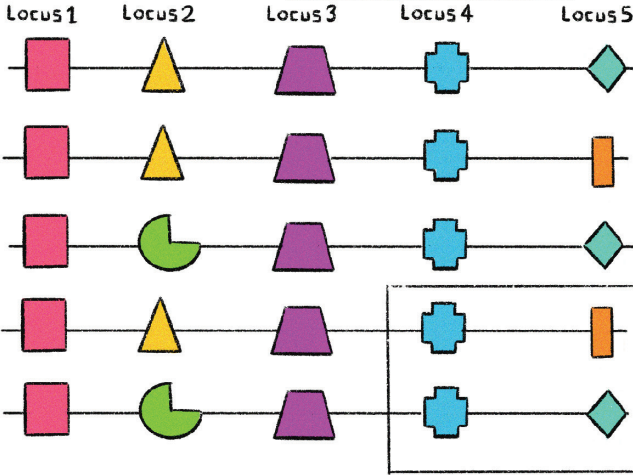
Dear plant researchers:

Below, you'll find figures depicting one chromosome from some of the plants that you sent me. They're all labeled by plant type as either "Coastal" or "Inland". This view shows markers (DNA pieces) as different shapes. Look it over, and let us know if you see any differences in the structure of this chromosome. Is any marker specific to one plant type? Is the overall order the same?

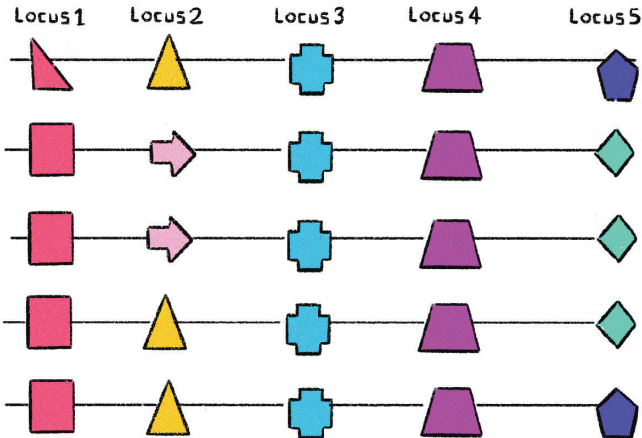
Thanks!

Maia and William

COASTAL

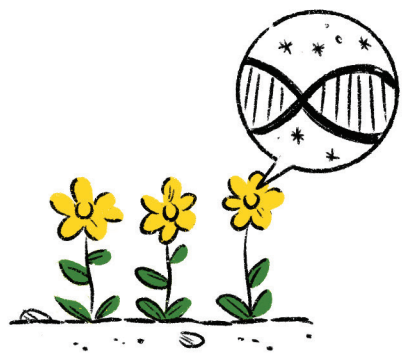


INLAND



MODULE 4:

**A SEED HERE, A SEED THERE,
SOMETHING DIFFERENT IN THE AIR**



CAN YOU BELIEVE IT, MAN?
THE PLANTS AT THE COAST HAVE
DIFFERENT GENETICS THAN THE
PLANTS FURTHER INLAND!
PRETTY AMAZING.

Bzzz....



BUT WHY?

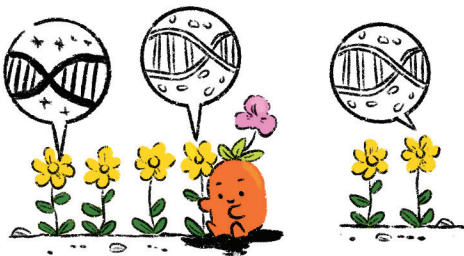


WHAT IS IT ABOUT THESE GENETICS THAT KEEPS THE
COASTAL PLANTS FROM SURVIVING IN THE INLAND
ENVIRONMENT? I WONDER IF WE COULD JUST PLANT AN
INLAND ONE ALONG THE COAST AND SEE IF IT SURVIVES.

Bzzzzz...



YOU'RE RIGHT. I'D MESS UP THE ECOSYSTEM, AND
THAT WOULDN'T BE RIGHT. I STILL WANT TO KNOW
THOUGH...WOULD AN INLAND PLANT SURVIVE
ALONG THE COAST? DO YOU THINK WE COULD
MODEL THAT IN THE LAB?





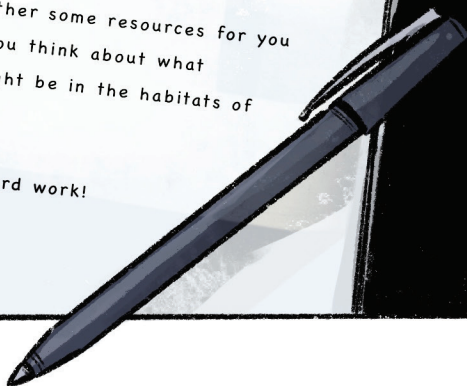
Dear researchers,

Do y'all know how to replicate a coastal environment? I want to know what would happen if the plants from the inland tried to grow along the coast.

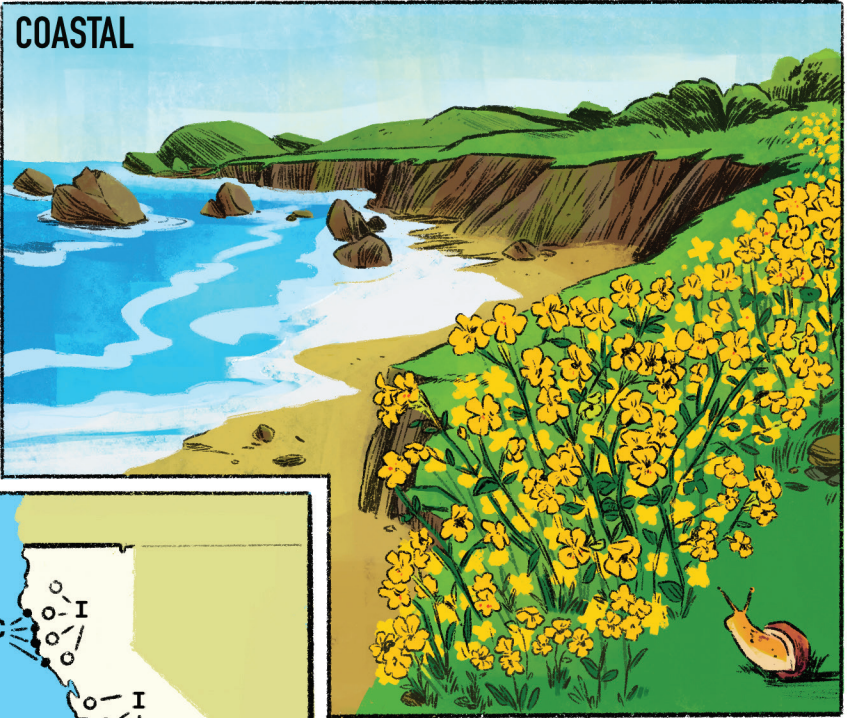
Maia and I put together some resources for you to reference while you think about what differences there might be in the habitats of these plants.

Thanks for all your hard work!

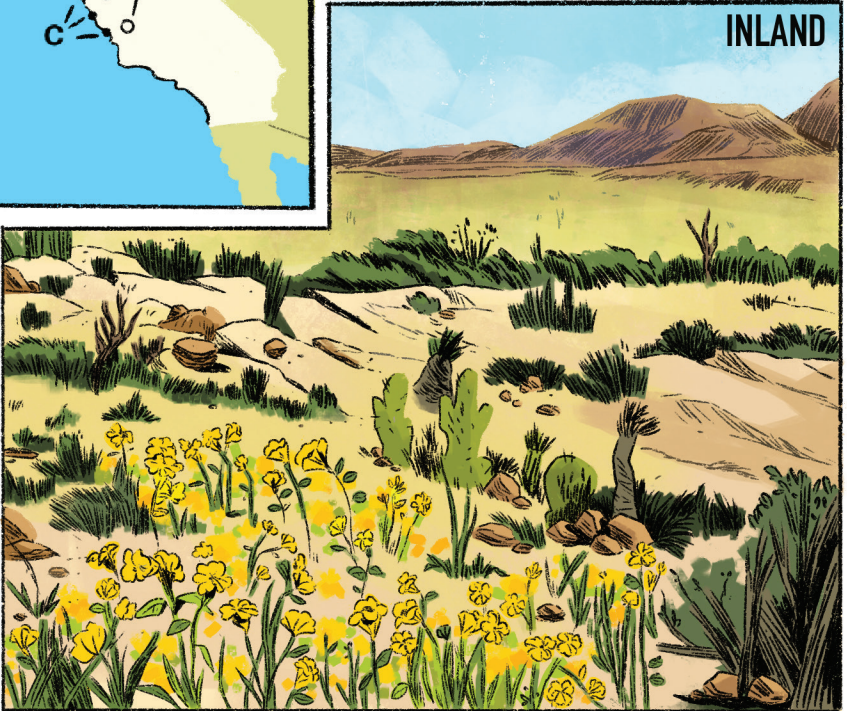
William

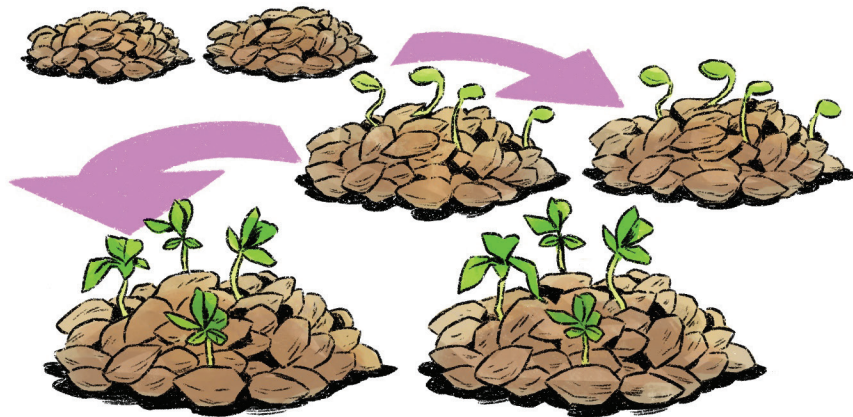
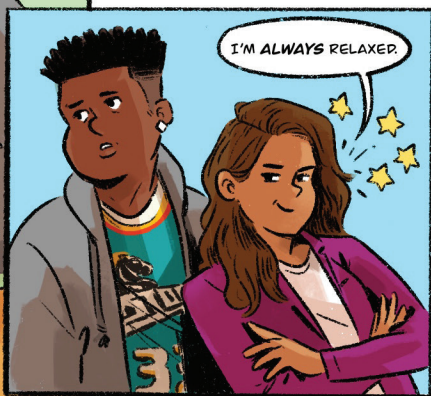



COASTAL



INLAND





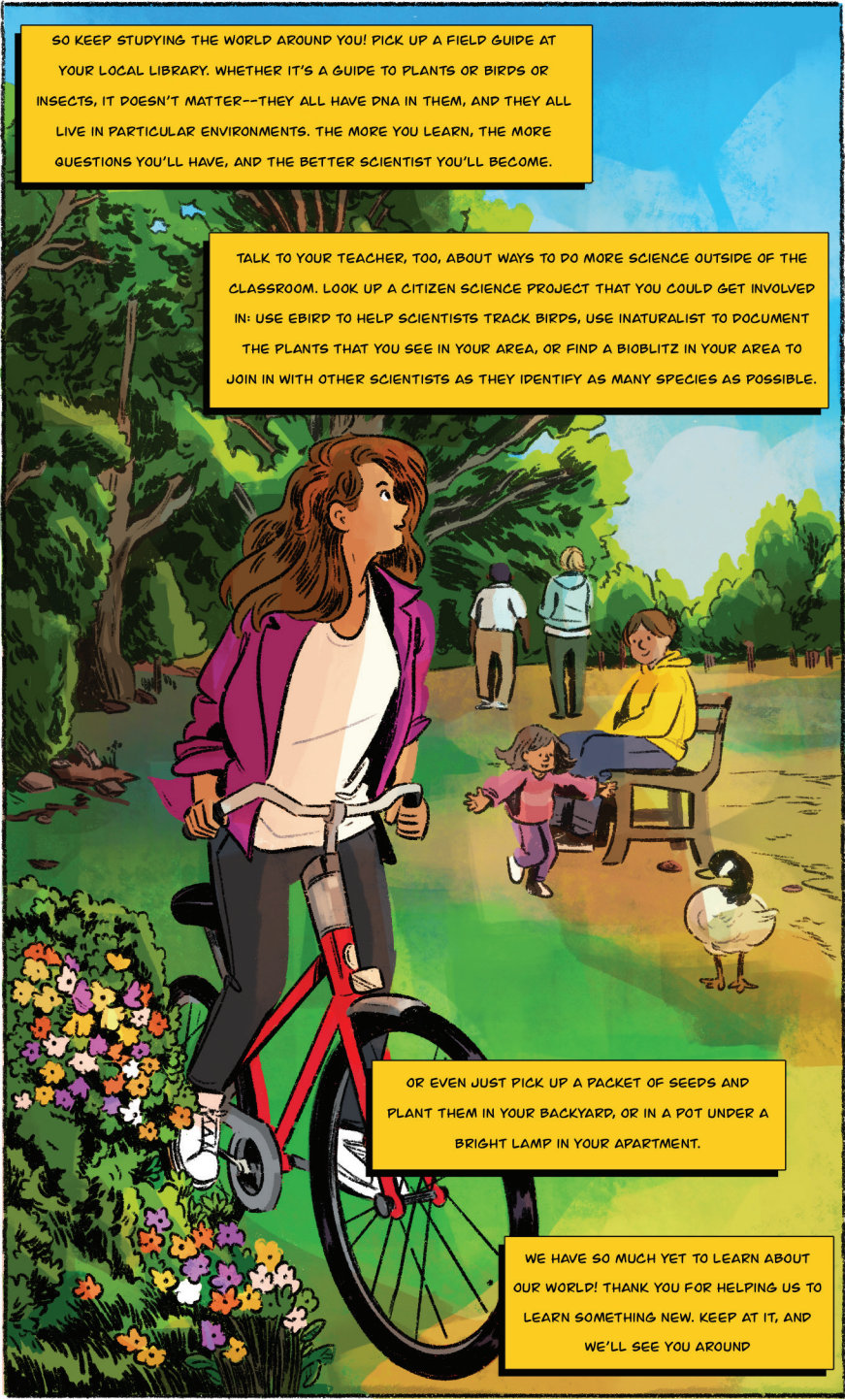


WHAT AN AMAZING JOB! YOU REALLY ARE SOME STELLAR SCIENTISTS. MAIA AND I HOPE YOU'LL KEEP DOING COOL WORK LIKE THIS. THERE ARE A WHOLE LOT OF WAYS TO DO SCIENCE OUTSIDE OF THE CLASSROOM.

ON YOUR WAY HOME, WHETHER YOU TAKE THE BUS OR RIDE YOUR BIKE OR WALK OR CATCH A RIDE IN A CAR, LOOK AROUND AND SEE WHAT PLANTS ARE GROWING IN YOUR AREA.

DO THEY LOOK THE SAME IN ALL PLACES? DO YOU THINK THE PLANTS GROWING AROUND YOUR HOME ARE THE WAY THAT THEY ARE BECAUSE OF THEIR GENETICS, BECAUSE OF THEIR ENVIRONMENT, OR BECAUSE OF BOTH?

ALL RESEARCH STARTS WITH A CAREFUL STUDY OF WHAT'S AROUND YOU. ALL OF THESE QUESTIONS STARTED BECAUSE MAIA AND I SPENT DAYS JUST WATCHING BEES AND FLOWERS ON THE COAST, AND PAYING ATTENTION TO WHAT WE WERE SEEING



SO KEEP STUDYING THE WORLD AROUND YOU! PICK UP A FIELD GUIDE AT YOUR LOCAL LIBRARY. WHETHER IT'S A GUIDE TO PLANTS OR BIRDS OR INSECTS, IT DOESN'T MATTER--THEY ALL HAVE DNA IN THEM, AND THEY ALL LIVE IN PARTICULAR ENVIRONMENTS. THE MORE YOU LEARN, THE MORE QUESTIONS YOU'LL HAVE, AND THE BETTER SCIENTIST YOU'LL BECOME.

TALK TO YOUR TEACHER, TOO, ABOUT WAYS TO DO MORE SCIENCE OUTSIDE OF THE CLASSROOM. LOOK UP A CITIZEN SCIENCE PROJECT THAT YOU COULD GET INVOLVED IN: USE EBIRD TO HELP SCIENTISTS TRACK BIRDS, USE NATURALIST TO DOCUMENT THE PLANTS THAT YOU SEE IN YOUR AREA, OR FIND A BIOBLITZ IN YOUR AREA TO JOIN IN WITH OTHER SCIENTISTS AS THEY IDENTIFY AS MANY SPECIES AS POSSIBLE.

OR EVEN JUST PICK UP A PACKET OF SEEDS AND PLANT THEM IN YOUR BACKYARD, OR IN A POT UNDER A BRIGHT LAMP IN YOUR APARTMENT.

WE HAVE SO MUCH YET TO LEARN ABOUT OUR WORLD! THANK YOU FOR HELPING US TO LEARN SOMETHING NEW. KEEP AT IT, AND WE'LL SEE YOU AROUND

