FUNDING FOR THIS PROGRAM
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TO ADVANCE EXCELLENT TEACHING.

Narrator: THERE ARE MILLIONS
OF LIFE FORMS

ON THE PLANET EARTH,

RANGING FROM THE MINUTE

TO THE MASSIVE.

FROM ONE-CELLED ORGANISMS

TO THE HUMAN ANIMAL,

LIVING THINGS THRIVE
ALMOST EVERYWHERE YOU LOOK.

THIS ASTONISHING DIVERSITY FLOURISHES

EVEN IN THE MOST
INHOSPITABLE PLACES.

THIS CAPACITY TO GAIN A FOOTHOLD IN ALMOST ANY ENVIRONMENT,

TO ADAPT AND CHANGE,
TO PERSEVERE,

APPEARS TO BE AN ESSENTIAL QUALITY OF LIFE.

WHETHER IT'S A DANDELION

OR MOUNTAIN LION,

COCKROACH,

OR COCKATOO,

THE TREE OF LIFE
STANDS ITS GROUND,

EVEN ADDING BRANCHES,

AS NEW LIFE FORMS ARISE,

OFTEN IN THE FACE
OF GREAT ADVERSITY.

WHAT IS IT THAT MAKES LIFE
SO ADAPTABLE?

HOW IS IT THAT LIFE ALWAYS SEEMS TO FIND A WAY?

WELCOME BACK
TO ESSENTIAL SCIENCE,

A LIFE SCIENCE CONTENT COURSE FOR ELEMENTARY SCHOOL TEACHERS.

I'M DOUGLAS ZOOK, A BIOLOGIST
AT BOSTON UNIVERSITY.

AND I'M LINDA GRISHAM,
A BIOLOGIST AND TEACHER EDUCATOR

AT LESLEY UNIVERSITY.

WHETHER IT'S BETTER-CAMOUFLAGED INSECTS,

BACTERIA INHABITING
A SULFUR HOT SPRING,

OR GHOSTLY WHITE CRABS
LIVING IN DEEP-SEA VENTS,

POPULATIONS DO FIND A WAY
TO FIT INTO THE MOST SURPRISING

AND EVER-CHANGING ENVIRONMENTS.

BUT HOW IS THIS ACHIEVED?

IN OUR LAST TWO PROGRAMS,

WE EXPLORED THE LIFE CYCLES
OF ANIMALS AND PLANTS

AND THE FUNDAMENTAL ROLE OF DNA

IN ENSURING
THE CONTINUITY OF LIFE.

THIS INTRODUCED US
TO LIFE PROCESSES

THAT OCCUR
AT THE LEVEL OF POPULATIONS --

ORGANISMS OF THE SAME TYPE,

LIVING AND INTERACTING
WITH EACH OTHER.

IN TODAY'S SESSION,
WE'LL CONTINUE TO LOOK AT LIFE

AT THE LEVEL OF POPULATIONS.

WE'LL CONNECT WHAT WE KNOW
ABOUT LIFE CYCLES AND DNA

TO ONE OF THE MOST FUNDAMENTAL IDEAS IN THE LIFE SCIENCES --

EVOLUTION.

EVOLUTION, THE SCIENTIFIC STUDY

OF HOW LIFE FORMS
CHANGE OVER TIME,

IS NOT ABOUT HOW AN INDIVIDUAL MAY CHANGE DURING ITS LIFESPAN,

BUT EXAMINES CHANGES
TO AN ENTIRE POPULATION

OF INDIVIDUALS
OVER MANY LIFE CYCLES.

EVOLUTION MIGHT, FOR SOME,
BE CONTROVERSIAL.

BUT MANY STUDENTS ARE FAMILIAR WITH THE CONCEPT.

THEY MAY HAVE STUDIED DINOSAURS AND HAVE LEARNED

THAT LIFE FORMS ON EARTH HAVE CHANGED OVER MILLIONS OF YEARS.

THEY'VE PROBABLY HEARD THE WORD, "EVOLVE,"

AND MAY HAVE QUESTIONS
ABOUT THE PROCESS.

DURING THIS SESSION,
WE WILL EXPLORE IDEAS

THAT WILL HELP ANSWER
SOME OF THESE QUESTIONS.

IF WE LOOK AT ALL THE ORGANISMS ON THE PLANET TODAY,

THEY ALL HAVE
ONE DRIVING FORCE --

THEY MUST REPRODUCE
TO SURVIVE.

NOT ONLY THAT,
BUT THEIR OFFSPRING

MUST LIVE TO REPRODUCE, TOO --
IN AN ENVIRONMENT

THAT MAY BE DIFFERENT
THAN THAT OF THEIR PARENTS.

THE PROCESS OF EVOLUTION
ALLOWS THIS TO HAPPEN.

TO BIOLOGISTS,
EVOLUTION CAN BE UNDERSTOOD

AS A THEORY THAT REVOLVES
AROUND A FEW FUNDAMENTAL

AND INTERCONNECTED CONCEPTS --

VARIATION,

ADAPTATION OF POPULATIONS,

AND NATURAL SELECTION.

WE'LL CONSIDER EACH
OF THESE IDEAS AND SHOW HOW,

TOGETHER, THEY LEAD
TO A CONSISTENT THEORY,

ONE THAT EXPLAINS
HOW LIFE FORMS

BECOME WELL FITTED
TO THEIR ENVIRONMENT,

EVEN IN THE FACE
OF CHANGE.

WELL,
LET'S GET STARTED.

THE FIRST TOPIC, VARIATION, SHOULD BE FAMILIAR

TO ANYONE WHO HAS BEEN
TO A FAMILY REUNION.

Narrator: IN HUMAN POPULATIONS, IT'S EASY TO SEE

FAMILY RESEMBLANCES
BETWEEN PARENT AND CHILD,

OR BETWEEN BROTHERS AND SISTERS.

CHILDREN OFTEN ASK, "WHY DO I LOOK LIKE MY MOTHER OR FATHER?"

OR "HOW IS IT
THAT I LOOK

SO DIFFERENT
FROM MY BROTHER OR SISTER?"

WHAT THEY'RE TALKING ABOUT
IS VARIATION.

VARIATION ENCOMPASSES ALL

THE NATURALLY OCCURRING
DIFFERENCES

BETWEEN CLOSELY RELATED INDIVIDUALS.

DO CHILDREN EXPECT VARIATION?

TURNING TO THE SCIENCE STUDIO,
WE'LL HAVE THE OPPORTUNITY

TO LEARN FROM A GROUP
OF ELEMENTARY-AGE CHILDREN.

AS WE LISTEN TO THEIR THINKING,

IT CAN HELP US CLARIFY OUR OWN THINKING ABOUT THESE IDEAS.

Abrams: I'M GOING TO ASK YOU
TO PICK UP YOUR LENSES

AND LOOK AT THESE PLANTS
REALLY CAREFULLY.

NOW, IF YOU LOOK ON THE STEMS, WHAT DO YOU SEE?

HAIR, LIKE,

ON THIS PART RIGHT HERE,
THERE'S LIKE LITTLE PRICKS.

Abrams: SOME LITTLE HAIRS?
YEAH.

NOW, DO ALL THE PLANTS
HAVE THE SAME NUMBER OF HAIRS?

UH-UH, NO.

'CAUSE IT DOESN'T GROW,
LIKE, THE SAME.

LIKE, EVERYTHING
CAN'T BE THE SAME.

CAN YOU TELL ME
A LITTLE MORE ABOUT THAT?

YOU CAN'T BURY A SEED
AND EXPECT IT

TO COME OUT THE EXACT SAME WAY THAT YOU WANT IT.

IN SOME WAY, IT WILL
HAVE TO COME OUT DIFFERENT.

LIKE, ONE WILL BE SHORT,
ONE WILL BE LONG,

ONE WILL LOOK DIFFERENT,
ONE WILL HAVE HAIR ON IT,

OR ONE WON'T.

BUT IF YOU COULD PLANT THEM
ALL AT THE SAME TIME,

UNDER THE SAME CONDITIONS, THEY'D LOOK EXACTLY ALIKE?

NO.

WHAT MIGHT HAVE CAUSED
SOME OF THOSE DIFFERENCES?

UM, I WOULDN'T KNOW.

PERHAPS ROBERT HAS PLANTED SEEDS

AND OBSERVED THE RESULTING PLANTS HIMSELF.

THAT COULD EXPLAIN
WHY HE THINKS, CORRECTLY,

THAT ALL THE SPROUTS
WOULD BE DIFFERENT --

A GREAT EXAMPLE OF VARIATION.

WE ASKED OUR BOTTLE BIOLOGIST, DR. PAUL WILLIAMS,

A BOTANIST FROM
THE UNIVERSITY OF WISCONSIN,

TO DISCUSS THE IMPORTANCE
OF VARIATION

IN THE LIVING WORLD.

VARIATION IS THE ESSENTIAL CHARACTERISTIC OR QUALITY

OF LIFE ITSELF.

WE NEED TO UNDERSTAND THAT
AS DEEPLY AS POSSIBLE.

IT SEEMS
LIKE A TERRIBLY SIMPLE THEME,

BUT IT IS PROFOUNDLY
THE ONE NATURAL CHARACTERISTIC

OF LIVING ORGANISMS --
TO BE VARIABLE.

IF ORGANISMS WERE NOT VARIABLE,

IF THEY DID NOT HAVE BUILT
INTO THEIR GENETIC MECHANISM

THE CAPACITY TO BE VARIED,

THEN THEY SIMPLY WOULDN'T EXIST ON EARTH.

THAT'S HOW FUNDAMENTAL,
THAT'S HOW ESSENTIAL

THIS IDEA OF VARIATION IS
TO AN UNDERSTANDING OF LIFE.

WHAT I MEAN BY THAT IS
THAT THE PHYSICAL ENVIRONMENT,

THAT IS TO SAY THE WEATHER,
THE CLIMATE,

THE CHEMICAL ENVIRONMENT IN WHICH ORGANISMS FIND THEMSELVES

IS CONSTANTLY VARYING, TOO.

ORGANISMS HAVE TO VARY,

IN ORDER TO SURVIVE IN A VARYING PHYSICAL ENVIRONMENT.

IF YOU DON'T VARY,

AND THE ENVIRONMENT
AROUND YOU VARIES,

YOU'RE NOT GOING TO SURVIVE.

DR. WILLIAMS INTRODUCES US
TO THE IMPORTANCE

OF VARIATION
WITHIN A POPULATION.

HE EVEN SUGGESTS
THAT VARIATION MAKES IT POSSIBLE

FOR LIFE FORMS
TO SURVIVE CHANGES

IN THEIR ENVIRONMENT
OVER GENERATIONS.

BUT HOW DO STUDENTS MAKE SENSE OF VARIATION IN A POPULATION?

KATHY VANDIVER,
A 6th-GRADE SCIENCE TEACHER

IN LEXINGTON, MASSACHUSETTS,
IS USING FAST PLANTS

TO HELP HER STUDENTS LEARN ABOUT VARIATION WITHIN A POPULATION.

WELL, WHAT THE KIDS
ARE GOING TO DO TODAY IS

THEY'RE GOING TO MEASURE
THEIR PLANTS,

THEY ARE GOING TO BE ABLE TO SEE WHAT THE AVERAGE HEIGHT IS,

JUST IN A VISUAL, QUICK SENSE,

AND THEN WE'LL ACTUALLY CALCULATE THE AVERAGE, SO WE CAN

SEE THE AVERAGE AND THE RANGE
OF THE PLANT HEIGHT.

THE FIRST QUESTION IS,

"WHAT CAUSES THE VARIATION
YOU SEE IN PLANT HEIGHT?"

WHAT DO YOU THINK REALLY CAUSES THIS VARIATION?

WHAT DID YOUR GROUP HAVE, LAUREN?

UM, UNEVENLY MIXED SOIL.

OKAY.
ANYTHING ELSE?

AMOUNTS OF LIGHT THEY GET,
BECAUSE SOME

OF THE TALLER PLANTS GET MORE LIGHT THAN THE SMALLER ONES.

Vandiver: OKAY --
WE WERE *TRYING* REAL HARD

WITH OUR LIGHTING ARRANGEMENT
TO KEEP IT EVEN,

BUT THAT COULD HAVE BEEN
A POSSIBILITY.

THE SEEDS CAME
FROM DIFFERENT PLANTS.

SO MAYBE THAT
HAD SOME EFFECT ON, LIKE,

MAYBE THE SHORTER PLANTS
PASSED THROUGH THE GENES

TO MAKE THE PLANTS SHORTER,

YOU KNOW?

OKAY, SURE.
MAYBE THEY INHERITED THAT?

YEAH.
Vandiver: UH, SID?

UM, WELL, THEY GOT MORE SUNLIGHT, BECAUSE SOMETIMES, UM,

THEY BLOCK THE SMALLER PLANTS, AS LAUREN SAID BEFORE.

OOH, OKAY.

AND THEY GET
THE MOST AMOUNT OF SUNLIGHT.

I THINK THEY'RE VERY SAVVY
ABOUT WHAT THEY --

WHAT PROBABLY CAUSES
THE VARIABILITY,

BECAUSE WHEN KIDS LOOK AROUND
AT THEMSELVES

AND THOSE HEIGHT --

THAT'S ONE OF THE REASONS
WHY I CHOSE HEIGHT --

THEY KIND OF HAVE AN EXPECTATION IF THEY HAVE TALL PARENTS

THAT THEY'RE GOING TO BE TALL, AND SO THERE IS A NICE

KIND OF GENETIC CONNECTION,
I THINK,

WITH, PARTICULARLY
IN CHOOSING PLANT HEIGHT,

FOR KIDS' OWN CONNECTION WITH THEIR OWN LIVES ABOUT HEIGHT.

KATHY'S STUDENTS
MAY HAVE NOTICED

THAT TALL PARENTS GENERALLY
GIVE RISE TO TALL CHILDREN.

SO ASKING, "WHAT CAUSES
PLANT HEIGHT TO VARY,"

IS A GOOD QUESTION.

KATHY'S STUDENTS KNEW

THAT THE PLANTS
WERE ALL THE SAME TYPE --

BRASSICA RAPA, OR FAST PLANTS.

MANY FOCUSED
ON ENVIRONMENTAL FACTORS

AS THE CAUSE
OF THE HEIGHT DIFFERENCES.

IT *IS* POSSIBLE
THAT SOIL, WATER, AND SUNLIGHT

COULD AFFECT PLANT SIZE
WITHIN THAT GENERATION.

HOWEVER, THE PLANTS
USED IN THIS ACTIVITY

WERE RAISED IN A TIGHTLY CONTROLLED ENVIRONMENT.

KATHY GAVE THEM THE SAME CONDITIONS OF LIGHT AND WATER.

HER INTENT WAS
TO GET HER STUDENTS

TO GO BEYOND THINKING
ABOUT THE ENVIRONMENT

AS THE SOURCE OF VARIATION.

WHEN ONE STUDENT
MENTIONED GENES,

HE NOTICED HOW OFFSPRING
FROM DIFFERENT PARENTS

TAKE AFTER THOSE PARENTS.

CLEARLY, THERE MUST BE
SOMETHING AT WORK

TO ALLOW CLOSELY RELATED ORGANISMS,

LIVING UNDER THE SAME ENVIRONMENTAL CONDITIONS,

TO VARY IN PHYSICAL CHARACTERISTICS.

THIS LEADS US
TO AN IMPORTANT QUESTION --

WHERE CAN WE OBSERVE
VARIATION IN POPULATIONS?

Narrator: IF YOU EXAMINE
THIS COLLECTION

OF CAREFULLY PRESERVED
AND CATALOGUED BUTTERFLIES,

YOU WILL SEE THAT THEY VARY WIDELY IN COLOR FORM,

EVEN THOUGH THEY BELONG
TO THE SAME HELICONIUS SPECIES.

LOOK CLOSELY AT POPULATIONS
OF LIVING THINGS,

AND YOU CAN ALMOST ALWAYS
SEE VARIATION

IN PHYSICAL CHARACTERISTICS,
OR TRAITS.

VARIATION SEEMS TO BE THE RULE,

RATHER THAN THE EXCEPTION,
IN LIFE.

WE VISITED HOWARD UNIVERSITY'S NATIONAL HUMAN GENOME CENTER,

WHERE DR. ROBERT MURRAY DISCUSSES THE PREVALENCE

OF VARIATION IN POPULATIONS.

IN THE BIG SENSE,
VARIATION IS CRITICAL

TO THE SURVIVAL
OF ANY GROUP OF ORGANISMS,

WHETHER WE'RE TALKING
ABOUT BACTERIA OR VIRUSES,

OR WHETHER WE'RE TALKING

ABOUT HUMANS OR ELEPHANTS.

THE CREATURES THAT ARE
ON THE VERGE OF EXTINCTION

ARE OFTEN CREATURES
THAT DO NOT VARY VERY MUCH

OR ARE NOT VERY ADAPTABLE -- THEY CAN'T ADJUST TO CHANGE.

ONE EXAMPLE IS THE PANDA.

THE PANDA'S BEHAVIORAL CHARACTERISTICS ARE SUCH

THAT IT'S
ON THE VERGE OF EXTINCTION,

BECAUSE IT CAN ONLY FUNCTION
IN A VERY LIMITED ENVIRONMENT,

WITH A LIMITED DIET,
ET CETERA.

HUMANS HAVE A TREMENDOUS
AMOUNT OF VARIATION

THAT WE ARE JUST UNCOVERING
MORE AND MORE OF.

THE DEGREE TO WHICH
THE PEOPLE IN A GROUP

ARE DIFFERENT FROM ONE ANOTHER

IS CRITICAL
TO THEIR SURVIVAL OVER TIME.

WE HEAR ALL THE TIME
ABOUT NEW DISEASES --

HIV, AIDS
IS A RELATIVELY NEW DISEASE.

SARS, A NEW DISEASE.

HOW CAN WE SURVIVE?

WE SURVIVE BECAUSE
THERE IS VARIATION

IN THE POPULATION
OF HUMAN BEINGS,

AND *SOME* PEOPLE CAN SURVIVE IN SPITE OF THE TERRIBLE DISEASE.

AND THE VARIATION
IS ALREADY THERE.

IT'S NOT INTRODUCED.

IT'S PRESENT, AS IF IT'S
WAITING FOR SOMETHING TO HAPPEN.

BY LOOKING AT JUST
A FEW EXAMPLES LIKE THESE,

WE CAN START TO UNDERSTAND

THAT VARIATION IS PREVALENT THROUGHOUT THE LIVING WORLD.

AND THIS MAY RAISE
A PRESSING QUESTION --

WHAT MIGHT CAUSE THIS VARIATION?

IN THE SCIENCE STUDIO,

FIFTH GRADERS GREG AND MAGGY

ARE LOOKING AT A FAMILY OF MICE,

ALL OF WHOM
ARE BROTHERS AND SISTERS.

ELEANOR ABRAMS,
OUR SCIENCE STUDIO FACILITATOR,

ASKS ABOUT VARIATION BETWEEN OFFSPRING AND THEIR PARENTS.

OKAY, I'M BRINGING YOU
THIS FAMILY OF MICE.

AND WHAT WE'RE GOING TO LOOK AT IN THESE FAMILIES

ARE PROPERTIES, OR TRAITS
OF THE MICE.

WHAT DO YOU THINK
THE PARENTS LOOK LIKE?

THE PARENTS WOULD PROBABLY
HAVE A LIGHT BROWN FUR,

BASING ON HOW THEY'VE
GOT ALL DIFFERENT --

P.J.: MY THEORY IS --

THEY HAVE THE WHITES,
THE BROWNS,

THE LIGHTISH-BROWN,
AND PROBABLY LIKE ABOUT THIS,

BUT BIGGER, I'D SAY.

I THINK -- WELL,
ARE THE PARENTS IN HERE?

Abrams: NO.
NO, I DIDN'T -- OH, OKAY.

THE PARENTS, WELL,
I'D SAY ONE OF THE PARENTS

IS EITHER LIGHT BROWN
OR GRAY --

WELL, I THINK THE PARENTS ARE
A COMBINATION OF THESE COLORS.

LIKE ONE WOULD BE A BROWN,
ONE WOULD BE A WHITE.
YEAH.

LIKE SOME OF THEM TURNED OUT EXACTLY TO BE LIKE --

LET'S JUST SAY
THE MOM IS BROWN.

MOM OR DAD OR LIKE,
HALF AND HALF --

YEAH, THAT'S WHAT I THINK.

Narrator: IT'S CLEAR
THAT THE CHILDREN BELIEVE

THAT THE PARENTS PASS ON TRAITS,

AND THAT TWO PARENTS
WITH VARYING FUR COLORS --

SAY, SOLID BROWN
OR SPOTTED GRAY AND WHITE --

CAN PRODUCE OFFSPRING
WITH YET DIFFERENT FUR COLORS,

SAY, SOLID GRAY
OR SPOTTED BROWN AND WHITE.

Abrams: AND HOW DO YOU GET
THIS CINNAMON-COLORED ONE?

YOU GET THAT ONE --
I'D SAY IT'S JUST A MIXTURE.

IT'S A MIXTURE OF THE --
OF THE TWO COLORS.

OF THE GENES.
THE DNA.

YEAH.
Abrams: WHAT'S DNA?

I MEAN GENES.
YEAH, IT'S LIKE A --

IT'S THE STUFF THAT
MAKES PEOPLE OR ANIMALS

OR ANYTHING THAT'S LIVING
WHAT THEY ARE.

Narrator: GREG AND MAGGY
ARE ALSO STARTING TO UNDERSTAND

THAT BOTH PLANTS AND ANIMALS VARY FROM THEIR PARENTS --

AND FROM THEIR SIBLINGS.

THEY THINK THIS HAS SOMETHING
TO DO WITH GENES AND DNA.

LET'S SEE HOW THEY HANDLE
THE QUESTION,

"WHAT ARE GENES?"

Abrams: WELL,
WHAT ARE THEY?

WHAT WOULD THEY LOOK LIKE,
WHAT WOULD THE GENES LOOK LIKE?

LITTLE, LIKE, KIND OF
LIKE ATOMS, I GUESS?

'CAUSE I'VE NEVER REALLY SEEN
A GENE OR AN ATOM, SO...

I'M JUST GUESSING.

Abrams: BUT WHERE
WOULD YOU FIND THEM?

I DON'T KNOW, I THINK
IT'S JUST SOMETHING YOU HAVE.

I DON'T THINK YOU CAN REALLY
SEE THEM OR FIND THEM ANYWHERE.

OR YOU COULD SEE THEM,
BUT, I MEAN, THERE'S NOT --

SUPER-SUPER-MICROSCOPIC.

LIKE, UM...
I DON'T KNOW,

YOU CAN'T SEE THEM,
BUT YOU HAVE THEM.

[Laughing]
LIKE, LIKE --

Abrams: SO DO YOU THINK
THEY'RE ALL IN ONE PLACE,

OR DO YOU THINK
THEY'RE ALL OVER THE BODY?

Both:
THEY'RE ALL OVER THE BODY.

I GUESS.

YOU CAN SEE THEM
IN A PERSON,

BUT YOU CAN'T SEE
THE GENE ITSELF.

YEAH, YOU CAN SEE THE WAY
THE GENES HAVE CHANGED YOU,

LIKE THE COLOR
OF YOUR HAIR
YEAH, EXACTLY.

AND THE COLOR OF YOUR EYES
AND STUFF,

BUT YOU CAN'T REALLY SEE
THE GENES THEMSELVES.

Abrams: OKAY.

ALTHOUGH THEY'RE NOT SURE
WHAT GENES ARE,

OR WHAT THEIR RELATIONSHIP
IS TO DNA,

THE CHILDREN CONNECT GENES
WITH HEREDITY.

WHAT *IS* THE RELATIONSHIP
BETWEEN DNA AND GENES?

AND WHAT DO GENES HAVE TO DO WITH VARIATION?

IN ORDER TO UNDERSTAND
HOW VARIATION

CAN ARISE IN A POPULATION,

LET'S LOOK MORE CLOSELY
AT THE GENES.

Narrator: THE KEY TO ANSWERING THE QUESTION,

"WHAT CAUSES VARIATION EVEN WHEN ENVIRONMENTAL CONDITIONS

HAVE BEEN CAREFULLY CONTROLLED?"
LIES IN THE MOLECULAR WORLD

OF DNA AND GENES.

WHAT ARE GENES?

RECALL THAT THE HEREDITARY MATERIAL, DNA,

IS ORGANIZED INTO CHROMOSOMES,

A COMPLETE SET IN EACH CELL
OF AN ORGANISM.

GENES ARE SEGMENTS OF DNA

THAT FORM THE LENGTH
OF EACH CHROMOSOME,

EACH GENE OCCUPYING
A FIXED PLACE

ALONG A SPECIFIC CHROMOSOME.

SCIENTIFIC STUDY HAS SHOWN
THAT THERE ARE OVER 30,000 GENES

DISTRIBUTED
AMONG THE 46 CHROMOSOMES

THAT MAKE UP THE HUMAN GENOME.

DNA IS THE STUFF OF HEREDITY.

IT IS THE CHEMICAL MATERIAL
WHICH PASSES ON THE INFORMATION

THAT DETERMINES
WHAT A CREATURE WILL BE,

HOW IT WILL FUNCTION,
AND HOW IT WILL REPRODUCE.

IT IS A LONG, THREAD-LIKE MOLECULE

IN WHICH THE INFORMATION
THAT TELLS THE ORGANISM

WHAT TO DO,
HOW TO FUNCTION,

AND HOW TO REPRODUCE,
IS CONTAINED IN A CODE.

Narrator: DR. MURRAY
HAS INTRODUCED US

TO THE STRUCTURE OF DNA.

DNA IS BUILT FROM MOLECULAR SUB-UNITS, OR BASES,

CALLED ADENINE, THIAMINE, CYTOSINE, AND GUANINE --

ABBREVIATED HERE
AS A, T, C, AND G.

THESE BASES LINK TOGETHER
AS PAIRS

THAT FORM THE DOUBLE HELIX
OF DNA.

WITHIN THIS ORDERED STRUCTURE,
GENES ARE FOUND.

A GENE IS MADE UP
OF A SEQUENCE OF BASE PAIRS

ARRANGED IN A SPECIFIC ORDER,

AN ORDER FORMED
BY WHAT CAN BY LIKENED

TO AN ALPHABETIC CODE
THAT JUST USES FOUR LETTERS --

A, T, C, AND G.

THE ORDER OF THE BASE PAIRS
FORMS THE CODE FOR THE GENE.

AND THIS CODE
PROVIDES INFORMATION

THAT ULTIMATELY
DETERMINES TRAITS.

IF THE ORDER OF BASE PAIRS DETERMINES THE CODE,

WHAT DO YOU THINK RESULTS
FROM CHANGES IN THE ORDER?

IN OUR TESTING,
WE USE VARIOUS MEANS

TO DEMONSTRATE
THE PRESENCE OF GENES

THAT DO PARTICULAR THINGS,
PARTICULAR JOBS.

AND ONE OF THE EXAMPLES THAT HAS BEEN USED FOR MANY YEARS

IS SOMETHING CALLED
THE TASTER TEST.

THE TASTER TEST IS USUALLY DONE USING SPECIAL PAPER

AND THIS PAPER IS IMPREGNATED WITH A CHEMICAL

WHICH IS CALLED
PHENYLTHIOCARBAMIDE,

OR PTC FOR SHORT.

AND AN AMAZING FINDING,

BY ACCIDENT,
SHOWED THAT SOME PEOPLE,

TO SOME PEOPLE,
PTC HAS A VERY BITTER TASTE.

AND OTHER PEOPLE
TASTE NOTHING AT ALL.

TASTES LIKE PAPER.

IT'S PRETTY GROSS.

EW.

NO TASTE.

Man: IT'S BAD?
IT'S BAD.

CAN I TAKE IT OUT?

THIS DOESN'T
HAVE ANY TASTE TO IT.

EW.
OH, IT'S REALLY BITTER.

I DON'T TASTE ANYTHING,
IT TASTES LIKE PAPER.

YEAH, THERE'S A BITTER TASTE.

I KNOW, FOR EXAMPLE...

BECAUSE I'VE DONE THIS
MANY TIMES --

UGH --

THAT I AM A TASTER.

MY WIFE, ON THE OTHER HAND,
IS NOT.

WHEN I GIVE HER
ONE OF THESE PAPERS,

SHE WONDERS
WHY I MAKE THIS HORRIBLE FACE,

'CAUSE I CAN STILL TASTE
THAT STUFF ON MY TONGUE.

AND, IT TURNS OUT
THAT OUR CHILDREN

ARE ALL TASTERS.

THERE'S A GENE WHICH DETERMINES

WHETHER YOU ARE A TASTER
OR A NON-TASTER.

IT ONLY TAKES ONE TASTER GENE
TO ENABLE YOU TO TASTE

THE BITTER CHEMICAL
IN THIS PAPER.

Narrator: TRACING THE SOURCE
OF A PARTICULAR TRAIT,

LIKE THE ABILITY TO TASTE PTC,

BACK TO A GENE ON A CHROMOSOME,
CAN BE PAINSTAKING.

BUT RESEARCHERS HAVE NOW FOUND WAYS TO COMPARE SEQUENCES OF DNA

FROM A VARIETY OF INDIVIDUALS,

TO DETERMINE
WHERE BASE PAIRS DIFFER.

WE HAVE TECHNOLOGY
THAT TAKES ADVANTAGE

OF THE CHEMISTRY AND PHYSICS
OF THE CHEMICAL CHANGE

IN A WAY THAT ALLOWS US
TO IDENTIFY

PLACES WHERE CHANGES
HAVE OCCURRED IN THE DNA.

Narrator: AT THE NATIONAL
HUMAN GENOME CENTER

AT HOWARD UNIVERSITY,

RESEARCHERS ARE SEQUENCING SAMPLES OF DNA

FROM MANY DIFFERENT INDIVIDUALS IN AN ATTEMPT TO FIND

THE GENETIC BASES FOR A NUMBER OF IMPORTANT HUMAN DISEASES --

DISEASES THAT MIGHT BE CAUSED

BY ONLY ONE CHANGE IN THE ORDER OF THE BASES, OR NUCLEOTIDES.

Dunston: WE CAN COLLECT
THAT SAMPLE

AND PUT THAT IN A SEQUENCER,

WHICH IS ABLE TO TELL US

WHAT IS THE ACTUAL ORDER
OF NUCLEOTIDES IN THE STRAND.

Narrator: AT THE END
OF THE PROCESS,

THE SEQUENCES OF BASES
FROM THE GENE OF INTEREST

ARE DISPLAYED
FROM LEFT TO RIGHT.

THE GENETIC CODES
FOR DIFFERENT INDIVIDUALS

ARE DISPLAYED IN ROWS
FROM TOP TO BOTTOM.

IT TELLS YOU WHAT THE SPECIFIC LETTERS ARE AT A GIVEN POSITION

IN THE STRAND --
IN ESSENCE, IT IS SEQUENCING,

OR IT IS ORDERING,
THE NUCLEOTIDES IN THAT SAMPLE

THAT YOU ARE TESTING.

Narrator: SEQUENCING
THE DNA OF ANY ORGANISM

PROVIDES RESEARCHERS
WITH KEY INFORMATION

ABOUT VARIATION.

DIFFERENCES IN JUST ONE OR TWO BASE PAIRS

MAY DETERMINE WHAT CAUSES
A PARTICULAR VARIATION --

IN HUMANS, FOR EXAMPLE,
WHETHER THEY CAN TASTE PTC.

I HAVE ONE OF THESE
TEST STRIPS RIGHT HERE.

LET ME GIVE IT A TRY.

I CAN'T TASTE ANYTHING.

WELL, IT SEEMS THAT YOUR DNA DOESN'T CONTAIN THE INFORMATION

TO CODE PTC DETECTION.

LUCKY YOU.

BUT I *CAN* TASTE
A BITTERNESS IN THE PAPER.

THIS IS JUST ONE EXAMPLE OF HOW VARIATION EXPRESSES ITSELF

WITHIN A POPULATION.

WITH OVER 30,000 GENES
AND 3 BILLION BASE PAIRS

IN HUMAN DNA, IMAGINE
HOW MANY POSSIBLE VARIATIONS

COULD ARISE WITHIN OUR GENES

AND CAUSE US
TO VARY FROM ONE ANOTHER.

NO WONDER ALL OF US
ARE UNIQUE INDIVIDUALS.

AND THIS UNIQUENESS RAISES
AN INTERESTING QUESTION --

HOW DO VARIATIONS ARISE
IN THE FIRST PLACE?

THERE REALLY ARE SEVERAL WAYS.

LET'S TAKE A LOOK AT ONE --
MUTATION.

Murray: EVERY TIME
A CELL DIVIDES,

THE DNA HAS TO BE COPIED.

THE DNA CONTAINS 30,000 GENES,

AND IT CONTAINS THREE BILLION,
WHAT WE CALL, BASE PAIRS.

SO IMAGINE THAT YOU HAVE TO, WITHIN A MATTER OF MINUTES,

LITERALLY, COPY
THREE BILLION THINGS EXACTLY.

WELL, NATURE IS GOOD,
BUT NOT PERFECT.

AND SO, ALMOST ALWAYS, SOMEWHERE IN THAT THREE BILLION BASES,

A CHANGE IS MADE BY ACCIDENT.

AND THOSE LITTLE ACCIDENTAL CHANGES ARE MUTATIONS.

THE ORGANISMS
HAVE LITTLE DEVICES

TO TRY TO FIX THOSE CHANGES.

BUT THE REPAIR PROCESS
IS NOT PERFECT.

SO A FEW LITTLE CHANGES
SNEAK THROUGH.

Narrator: WE'VE SEEN
THAT MUTATIONS ARISE

WHEN DNA IS COPIED
IN REPRODUCTION.

THESE CHANGES TO THE GENE SEQUENCES OCCUR RANDOMLY,

THE RESULT OF NATURAL CAUSES.

HERMANN JOSEPH MULLER
CARRIED OUT EXTENSIVE STUDIES

OF MUTATION IN FRUIT FLIES
IN THE 1920s.

OFTEN KNOWN AS "THE FATHER
OF RADIATION GENETICS,"

MULLER WANTED TO FIND WAYS TO INCREASE THE RATE OF MUTATION,

IN ORDER TO STUDY IT.

HE EXPOSED FRUIT FLIES TO HIGH DOSES OF MAN-MADE RADIATION

AND OBSERVED THE RESULTS.

MULLER FOUND THAT THE OFFSPRING

OF IRRADIATED FRUIT FLIES
WERE MORE VARIED

THAN THE OFFSPRING
IN THE CONTROL GROUPS.

FLIES WITH BULGING EYES,

WHITE EYES, BLACK,
AND EYELESS FLIES,

WINGLESS FLIES,
FLIES WITH NO BRISTLES,

AND FLIES WITH CURLY BRISTLES --

ALL OF THESE VARIATIONS APPEARED.

HE HAD INCREASED
THE RATE OF MUTATION.

MUTATION IS ONE WAY
VARIATION CAN ARISE.

ANOTHER WAY THAT IS GAINING FURTHER RECOGNITION

IS SYMBIOSIS.

SYMBIOSIS OCCURS WHEN,
BY CHANCE,

ONE LIFE FORM
BECOMES INTIMATELY ASSOCIATED

WITH AN ENTIRELY DIFFERENT
LIFE FORM.

WHEN SUCCESSFUL, THIS OFTEN RESULTS IN A NEW ORGANISM

WITH A NEW COMBINATION
OF TRAITS.

LET'S LOOK
AT AN EXAMPLE HERE --

LICHENS.

A LICHEN IS ACTUALLY
A COMBINATION

OF A FUNGUS AND AN ALGA.

HERE WE SEE THE LIGHTER-COLORED AREAS, BEING THE FUNGUS,

AND THE GREENISH AREAS,
BEING THE ALGA.

LICHENS CAN LIVE IN PLACES
WHERE NEITHER THE FUNGUS

NOR THE ALGA COULD SURVIVE INDIVIDUALLY.

THE FUNGUS PROVIDES A MOIST
AND PROTECTIVE ENVIRONMENT

FOR THE ALGA.

THE ALGA, IN TURN, PROVIDES
A SUPPLY OF FOOD FOR THE FUNGUS

THROUGH PHOTOSYNTHESIS.

Grisham: CORALS
ARE ANOTHER SYMBIOSIS.

THIS COMPLEX REEF HABITAT EXISTS BECAUSE EACH CELL OF THE CORAL

IS PARTNERED WITH AN ENCLOSED PHOTOSYNTHETIC ALGA.

THIS SYMBIOTIC UNION
IS WHAT BUILDS THE REEF.

IN ORDER FOR AN ORGANISM
TO GAIN A SIMILAR ABILITY,

THAT IS, TO PHOTOSYNTHESIZE,

IT WOULD TAKE
INNUMERABLE MUTATIONS

AND THOUSANDS OF GENERATIONS,
IF EVER.

WELL, SYMBIOSIS REALLY SHORT-CIRCUITS THE PROCESS,

WE COULD SAY,
BECAUSE ONE ORGANISM

ACQUIRES ALL THE GENETIC INFORMATION OF ANOTHER ORGANISM

IN JUST, REALLY,
A SINGLE STEP.

FOR MORE INFORMATION ON HOW VARIATION ARISES IN POPULATIONS,

PLEASE VISIT OUR WEB SITE.

NOW THAT WE'VE EXPLORED TWO WAYS

THAT VARIATION CAN ARISE
IN A POPULATION,

LET'S LOOK AT HOW VARIATION

CAN BE MANIPULATED
FOR HUMAN PURPOSES.

Narrator:
OVER A NUMBER OF YEARS,

PAUL WILLIAMS CAREFULLY MANIPULATED PLANT VARIANTS

TO BREED A NEW FORM OF PLANT --

RAPID-CYCLING BRASSICAS,
OR FAST PLANTS.

FAST PLANTS CYCLE FROM SEED
TO SEED IN ABOUT A MONTH --

MAKING THEM IDEAL FOR ACTIVITIES IN LAB AND SCHOOL SETTINGS.

PAUL BEGAN
BY COLLECTING SPECIMENS

FROM A FAMILY OF PLANTS
THAT HAVE BEEN CULTIVATED

FOR THOUSANDS OF YEARS.

BRASSICAS ARE COMMON VEGETABLES

IN THE HUMAN DIET
AROUND THE WORLD.

MOST NOTABLE,
THOSE THAT WE WOULD RECOGNIZE,

ARE CABBAGE, CAULIFLOWER, BROCCOLI, TURNIP, KOHLRABI,

AND IN THE ASIAN FORMS,
CHINESE CABBAGE, BOK CHOI --

THESE ARE ALL RELATIVES
OF ONE ANOTHER.

SO THESE PLANTS, THOUGH, INTERESTINGLY ENOUGH,

BY AND LARGE,
TAKE ABOUT TWO YEARS

TO GO THROUGH THEIR LIFE CYCLE.

I COLLECTED, WOULD YOU IMAGINE,

UPWARDS OF 2,000 TO 3,000 DIFFERENT VARIETIES

OF THESE KINDS OF PLANTS,

STARTED TO GROW THEM
IN MY GREENHOUSE,

JUST LIKE THIS GREENHOUSE,

AND I GREW THEM UNDER CRITERIA

THAT I WANTED THEM
TO SURVIVE UNDER.

SO I GREW HUNDREDS AND THOUSANDS OF THESE PLANTS OUT,

AND LO AND BEHOLD, A VERY FEW, LESS THAN 1%,

SHOWED ME
THAT THEY FLOWERED EARLY.

THEY FULFILLED THE CRITERIA

UNDER WHICH
I WANTED THEM TO PERFORM.

NOW, THEY WEREN'T PERFECT, THEY WERE A LONG WAY FROM PERFECT.

SO ONLY THOSE
THAT FLOWERED EARLIER THAN,

LESS THAN ONE YEAR OR TWO,

WERE INTER-POLLINATED,
THEY WERE INTER-MATED.

THEY BROUGHT
THEIR GENETIC POOL TOGETHER.

AND FROM THEIR PROGENY,
FROM THEIR CHILDREN,

I FOUND THAT THEY FLOWERED
MUCH FASTER.

SO WE WERE BRINGING TOGETHER,
IN THE LABORATORY,

THE GENETIC TRAITS
FOR FAST FLOWERING,

FROM DIVERSE SOURCES.

WHEN WE DID THAT,
WE ACCELERATED THE SPEED.

WE DIDN'T KNOW
WHAT THE OUTCOME WAS,

BUT WE FOUND OUT THAT
THAT WAS THE CASE.

SO THEN WE TOOK THOSE FASTEST-FLOWERING ONES

AND INTER-MATED *THEIR* PROGENY THAT FLOWERED FASTEST.

INTERESTINGLY ENOUGH,
THEY CONTINUED TO SPEED UP

IN FLOWERING,
SO I DROPPED THE FLOWERING TIME

FROM ONE YEAR TO HALF A YEAR,
TO A QUARTER OF A YEAR,

AND WITH EACH SUCCESSIVE GENERATION

I WAS GETTING
MORE GENERATIONS PER YEAR.

EVENTUALLY,
THEY BECAME VERY UNIFORM

WITH RESPECT
TO THEIR FLOWERING TIME,

AND THEY ALSO FLOWERED
VERY QUICKLY.

IT DIDN'T TAKE ANY EXOTIC
KIND OF EQUIPMENT TO GROW THESE.

I WANTED A VERY ROBUST,
BUT SIMPLE, MODEL ORGANISM

TO CARRY OUT
MY GENETIC RESEARCH.

AFTER SEVEN OR EIGHT YEARS,
I WAS ABLE TO ACHIEVE

WHAT I THOUGHT WAS
A SATISFACTORY MODEL PLANT.

PAUL'S SELECTIVE
BREEDING TECHNIQUES

ARE CALLED
ARTIFICIAL SELECTION

BECAUSE *PEOPLE*
ARE DOING THE SELECTING,

NOT THE LARGER
NATURAL WORLD.

SOME OF THE BEST EXAMPLES
OF ARTIFICIAL SELECTION

CAN BE FOUND IN THE PRODUCE SECTION OF THE SUPERMARKET.

BROCCOLI, TOMATOES,
AND WATERMELON AND CUCUMBERS --

ALL OF THESE HAVE BEEN BRED
TO ENHANCE THE CHARACTERISTICS

DESIRED BY SHOPPERS.

RIGHT, AND CORN IS
A GREAT EXAMPLE

OF ARTIFICIAL SELECTION
AT WORK.

MANY ANTHROPOLOGISTS
BELIEVE MEXICAN TEOSINTE

TO BE THE ANCESTOR
OF MODERN CULTIVATED CORN.

THIS TEOSINTE PLANT BEARS
LITTLE RESEMBLANCE

TO THE PLUMP EARS OF CORN
THAT WE EAT TODAY.

WE PROBABLY WOULDN'T EVEN RECOGNIZE THE ANCESTORS

OF MANY OF OUR FAVORITE FOODS.

JUST LIKE IT'S HARD TO IMAGINE THAT ALL THE BREEDS OF DOGS

THAT WE HAVE TODAY
ORIGINALLY SPRANG FROM THE WOLF.

Grisham: FOR EVERY SUPER-LEAFY VEGETABLE OR CURLY-TAILED PET,

BREEDERS APPLY
THEIR KNOWLEDGE OF VARIATION

TO ARTIFICIAL SELECTION.

BUT YOU CAN PROBABLY SEE
THAT THERE'S NOTHING RANDOM

OR NATURAL
ABOUT THIS BREEDING PROCESS.

IT'S DESIGNED TO CAUSE CHANGE
IN A POPULATION

AS QUICKLY AS POSSIBLE,

AT LEAST IN TODAY'S INDUSTRIALIZED AGRICULTURE.

THIS RAISES A QUESTION THAT IS CENTRAL TO TODAY'S SESSION --

HOW CAN *NATURAL* POPULATIONS CHANGE OVER TIME?

THIS INTRODUCES US
TO THE CONCEPT OF ADAPTATION

AS IT APPLIES TO EVOLUTION.

ADAPTATION OCCURS
WHEN NATURAL POPULATIONS

CHANGE OVER MANY GENERATIONS

IN WAYS THAT FIT THEM BETTER
TO THEIR ENVIRONMENT.

Narrator: CHILDREN
IN OUR SCIENCE STUDIO

ARE DISCUSSING WAYS THAT ADAPTATION MIGHT OCCUR

IN A POPULATION,
WITHOUT HUMAN INTERVENTION.

THEY'RE LOOKING
AT ONE PARTICULAR TRAIT --

THE AMOUNT OF HAIR ON THE LEAVES AND STEMS OF THE BRASSICA PLANT.

LISTEN TO THEIR IDEAS ABOUT HOW A PLANT POPULATION MIGHT ADAPT

IN RESPONSE TO A CHANGING ENVIRONMENT.

Abrams: OKAY, SO I WANT YOU TO LOOK AT ONE TRAIT OR PROPERTY

THAT YOU JUST MIGHT HAVE
NOT NOTICED,

BUT IT'S THE HAIRINESS
OF THE STEMS.

SO IF YOU TAKE THE LENS,
YOU CAN KIND OF LOOK AND SEE --

YEAH, I NOTICED
THAT IT HAS LITTLE --

THEY WEREN'T THORNS,
BUT THEY WERE LIKE --

IT LOOKS LIKE THORNS
UP CLOSE,

BUT IT LOOKS
LIKE LITTLE, LIKE, NEEDLES.

YEAH, I CAN SEE WITHOUT
THE MAGNIFYING GLASS.

I JUST STABBED MYSELF WITH ONE, BUT I CAN'T EVEN FEEL IT.

YEAH.

Abrams: ARE SOME
HAIRIER THAN OTHERS?
YEAH, I THINK SO.

I THINK IT WOULD TAKE A LONG TIME TO COUNT ALL THE HAIRS.

P.J.: WELL, I MEAN,
JUST BY OBSERVATION.

UM, THIS ONE DOESN'T HAVE
ANY HAIR ON IT.

YES, IT DOES,
LOOK UNDER THE LEAVES.

OH, IT'S GOT A LOT
UNDER THERE.

THIS ONE'S GOT
PRACTICALLY NONE.

P.J.: LOOK UNDER IT, REMEMBER,
THAT'S WHERE ALL THE HAIR IS.

YEAH, COULD YOU LIFT IT UP?

AND NOTHING UNDER THERE.

P.J.: YEAH, THIS ONE DOESN'T
REALLY HAVE MUCH HAIR --

OH, IT'S GOT A LOT,
LOOK DOWN THERE,

BUT THAT'S STILL
NOT MUCH FOR A PLANT.

WELL, ONE OF THESE --

COMPARED TO THE OTHERS,
THIS ONE DOESN'T HAVE A LOT.

Abrams: COULD YOU THINK
OF A REASON

THAT IT MIGHT BE BENEFICIAL
TO BE HAIRY?

Michael: UM, I KNOW I'VE
BEEN TOLD THIS BEFORE.

PROBABLY BECAUSE, UH --

NO, I DON'T THINK
THAT WOULD --

UM, THIS IS A WILD GUESS,
BUT FOR WARMTH, MAYBE?

Michael: HOW WOULD IT BE
FOR WARMTH?

THEY'RE TOO SMALL.

THERE, JUST WHEN YOU
GET UP JUST RIGHT,

THAT'S THE ONLY TIME I CAN ACTUALLY SEE THE HAIRS.

ONE HERE, HERE, HERE, HERE...

Abrams: SO IF IT
WAS FOR WARMTH --

LET'S JUST SAY IF IT WAS
FOR WARMTH RIGHT NOW --

IT WOULDN'T
DO MUCH GOOD.

[ABRAMS LAUGHING]

WHAT IF IT DID,
IT *WAS* BENEFICIAL?
YEAH.

WHAT DO YOU THINK THIS PLANT MIGHT LOOK LIKE UP NORTH?

MUCH, MUCH,
MUCH HAIRIER.

IT WOULD BE
A FUZZ-BALL.

[ALL LAUGHING]

DO YOU THINK THAT THESE PLANTS COULD BECOME FUZZ-BALLS?

IF I TOOK THIS ONE
AND WENT UP --

I LIVE IN NORTHERN MAINE, SAY -- I WENT UP TO NORTHERN MAINE

AND I PLANTED THIS PARTICULAR ONE, WOULD IT TURN INTO --

WOULD IT
GET HAIRIER?

NO.
IT WOULD SHRIVEL UP AND DIE.

MAYBE A LITTLE, BUT THEN EVENTUALLY IT WOULD DIE.

BECAUSE LIKE WE SAID --
THE SAME THING WITH THE MICE --

IT HAS TO HAPPEN GRADUALLY.

Abrams: SO DOES IT HAVE TO HAPPEN GRADUALLY TO THIS *ONE*,

OR DOES IT
HAVE TO HAPPEN GRADUALLY

OVER GENERATIONS OF PLANTS?

OVER GENERATIONS.
Michael: OVER GENERATIONS
OF PLANTS, PROBABLY --

YEAH, DEFINITELY.

Abrams: OKAY.
AND EXPLAIN THAT TO ME.

WHY DOES THAT MAKE SENSE?

WELL, IT'S NOT GONNA HAPPEN
IN TWO YEARS...

P.J.: YEAH, EVOLUTION
OR ADAPTATION,

IT TAKES A VERY LONG TIME.

Michael: I MEAN,
IF *I* TRIED TO ADAPT --

IT PROBABLY WOULDN'T WORK.

IT PROBABLY WOULDN'T WORK,
BUT BESIDES THAT,

UM...
WELL, PHYSICALLY,
AT LEAST.

I PROBABLY WOULDN'T BE ALIVE WHEN IT HAPPENED,

WHEN THEY ACTUALLY
HAD THE FULL ADAPTATION.

YEAH, LIKE,
IF HE WORE, LIKE,

IF HE JUST --
WELL, IF --

I DON'T KNOW,
NEVER MIND.

Abrams: WELL, HOW ABOUT
IF I TOOK THIS PLANT,

AND I WANTED TO MAKE IT,
I WANTED TO HAVE HAIRIER PLANTS.

HOW COULD I DO THAT
BY MOVING...

WELL, YOU'D PROBABLY
PLANT ONE, LIKE, A --

A COUPLE, LIKE,
LET'S SAY 100 MILES NORTH?

AND YOU JUST KEEP ON,
YOU KEEP ON GOING
HIGHER AND HIGHER,

AND THEN LET IT GROW FOR,
I'D SAY, WHAT DO YOU THINK --

I DON'T KNOW.

A YEAR?

YEAH, MAY--
NO, NOT A HUNDRED, THAT'S
TOO SMALL OF A DIFFERENCE.

I'D SAY, LIKE,
200 TO 300 MILES.
YEAH.

I THOUGHT WE WERE
GONNA HOLD THEM, THOUGH.

WELL, YOU COULD
HAVE HELD THEM.

CAN WE ASK HIM AGAIN?

SURE, YOU CAN.
OKAY.

SAY, IF THIS PLANT WAS A --

SAY IF THE HAIRS WERE
TO KEEP THE PLANT WARM.

AND THIS WAS
A FAIRLY TROPICAL PLANT.

AND I WANTED TO PLANT
THE PLANT UP NORTH.

COULD I DO THAT?

WELL, YEAH, BECAUSE IT WOULD PROBABLY ADAPT OVER THE YEARS,

BUT IT WOULD PROBABLY
DIE AT FIRST,

BUT THEN IT WOULD SHRIVEL UP
AND MAKE SOME OTHER PLANT

AS IT DIED,
OR SOMETHING.

WELL, PROBABLY IT WOULD,
AND THEN THAT PLANT

WOULD ADAPT
TO THE HIGH CLIMATE.

YEAH, AND KEEP GOING
AND GOING ON

FOR GENERATIONS
AND GENERATIONS,

AND IT WOULD, EACH PLANT
WOULD ADAPT IN ITS OWN WAY.

AT ITS OWN TIME.
Abrams: OKAY.

IT WOULD BE KIND OF A BRAND-NEW KIND OF PLANT EACH TIME?

WELL, I GUESS IT WOULD
CHANGE OVER THE YEARS,

BUT IT'S NOT GONNA ADAPT
THE *SECOND* YOU PUT IT

INTO THE GROUND, IT'S GONNA
TAKE SOME TIME, BUT --

IT'LL TAKE A LOT OF TIME.
YEAH.

BECAUSE ONE YEAR --
THE FIRST TIME WE PUT IT IN,

IT'LL BE SOME
SHRIVELED-UP LITTLE THING,

AND THEN THE NEXT YEAR,
IT'LL BE THIS BIG,

LEAFY PLANT WITHOUT,
WITHOUT VERY MUCH FLOWERS,

BECAUSE THE FLOWERS COULDN'T SPROUT IN SUCH COLD WEATHER,

OVER THE YEARS, IT'LL START LOOKING MORE LIKE A PLANT.

THE FLOWERS WILL START
TO BLOOM AGAIN,

BECAUSE THE ROOTS
WILL ADAPT TO THE...

SNOW.
SNOW AND WHATEVER,
WHAT HAVE YOU.

Abrams: SO WOULD THIS HAPPEN OVER THE LIFE OF THE PLANT,

OR WOULD IT TAKE
MANY DIFFERENT --

IT WOULD TAKE MANY DIFFERENT GENERATIONS OF PLANTS.

P.J. AND MICHAEL AGREE
THAT ORGANISMS DO HAVE TO ADAPT

TO THEIR ENVIRONMENTS
IF THEY ARE TO SURVIVE.

AND THEY BELIEVE THAT
THE PROCESS TAKES A LONG TIME.

THEY ALSO THINK
THAT A CHANGE IN THE ENVIRONMENT

SOMEHOW CAUSES A CHANGE
IN AN INDIVIDUAL'S GENES.

BECAUSE IT IS COLDER,
GENES CHANGE,

AND MORE HAIR GROWS,
FOR EXAMPLE.

BUT IS IT REALLY POSSIBLE
THAT INDIVIDUAL PLANTS ADAPT

DURING THEIR LIFE SPANS,
BY A CHANGE IN THEIR GENES?

THE STUDENTS
ARE REALLY THINKING CAREFULLY.

BUT THEY HAVE ACCOUNTED
FOR CHANGE

IN A WAY THAT ISN'T SUPPORTED
BY RESEARCH DATA.

THEIR THINKING MIRRORS SCIENTIFIC IDEAS

THAT PERSISTED
QUITE A LONG TIME,

IDEAS THAT WERE

EVENTUALLY DISCARDED

BECAUSE OF LACK OF EVIDENCE.

Narrator: THE IDEA
THAT CHANGES TO A POPULATION

OCCUR WHEN INDIVIDUALS
CHANGE IN RESPONSE

TO CHALLENGES
IN THEIR ENVIRONMENT

ISN'T NEW.

IT WAS A WIDELY HELD BELIEF

BY EVOLUTIONARY SCIENTISTS
IN THE 1800s.

ONE SCIENTIST IN PARTICULAR, JEAN LAMARCK,

CLAIMED THAT THESE SO-CALLED "ACQUIRED CHARACTERISTICS"

WERE PASSED ON TO OFFSPRING
FROM THEIR PARENTS.

ONE OF HIS FAVORITE EXAMPLES WAS THE LONG NECK OF THE GIRAFFE.

HE PROPOSED A SCENARIO
WHERE THE LEAVES

ON THE LOWER BRANCHES OF TREES,
UPON WHICH GIRAFFES FED,

WERE GRADUALLY DEPLETED.

GIRAFFES BEGAN
TO HAVE TO STRETCH THEIR NECKS

TO REACH LEAVES
ON HIGHER BRANCHES.

THIS RESULTED IN THE DEVELOPMENT OF LONGER NECKS.

WHEN GIRAFFES MATED,
THIS NEWLY ACQUIRED LONGER NECK

WOULD SOMEHOW BE INHERITED
BY THE OFFSPRING.

OVER TIME, ADAPTATION TO
THE CHALLENGE OF REACHING LEAVES

WOULD RESULT IN THE OVERALL POPULATION

HAVING INCREASINGLY LONGER NECKS.

THERE WERE A LOT OF PROPONENTS FOR LAMARCK'S THEORY

OF THE INHERITANCE
OF ACQUIRED TRAITS.

BUT IT'S NOT A REASONABLE EXPLANATION FOR EVOLUTION.

IF OFFSPRING WERE ABLE
TO INHERIT TRAITS

THAT THEIR PARENTS ACQUIRED DURING THEIR LIFE SPANS,

WOULDN'T A BODYBUILDER'S CHILDREN BE BULKED UP, TOO?

AN UNDERSTANDING OF HEREDITY REVEALS THE FLAW IN THIS THEORY.

INCREASED USE
OF EXISTING TRAITS,

LIKE A NECK OF ANY LENGTH,

OR MUSCLES OF ANY SIZE,

MAY CAUSE CHANGE
IN AN INDIVIDUAL.

BUT THE POTENTIAL
FOR THAT CHANGE

ALREADY EXISTS IN THE GENES.

USE OR DISUSE
OF AN EXISTING TRAIT

DOES NOT HAVE ANY IMPACT WHATSOEVER

ON AN INDIVIDUAL'S GENES.

SO CHANGE LIKE THIS CANNOT
BE PASSED ON TO OFFSPRING.

FOR EXAMPLE, A TREE RESPONDS
TO ENVIRONMENTAL CHANGES

BY SHEDDING ITS LEAVES
IN THE FALL AND WINTER MONTHS

AND RE-GROWING THEM
IN THE SPRING AND SUMMER.

THE GENETIC BASIS
FOR THIS TYPE OF VARIATION

ALREADY EXISTS
IN THE POPULATION OF TREES

AND IS NOT THE RESULT OF NEW VARIATION IN THE TREE'S GENES.

WHAT WE HAVE LEARNED SO FAR ABOUT VARIATION AND ADAPTATION

HELPS US UNDERSTAND THE CENTRAL TENET OF EVOLUTION --

NATURAL SELECTION.

TO UNDERSTAND NATURAL SELECTION,

WE HAVE TO THINK
ABOUT ADAPTATION

AT THE LEVEL
OF POPULATION OVER GENERATIONS.

EVEN THOUGH A POPULATION
MAY BE HIGHLY VARIED,

ULTIMATELY, ONE OR TWO VARIANTS

ARE LIKELY TO FIT
THEIR ENVIRONMENT

BETTER THAN OTHERS.

THOSE VARIANTS WILL LEAVE MORE OFFSPRING OVER THE GENERATIONS.

THIS IS THE REAL MEANING
OF ADAPTATION IN EVOLUTION.

SO NOW WE CAN SEE THAT NATURAL SELECTION SIMPLY DETERMINES

WHO IS LEFT STANDING
AND WHO IS NOT.

Narrator: IMAGINE
THE HYPOTHETICAL CASE

THAT PHENYLTHIOCARBAMIDE,

THE CHEMICAL
ON THE PTC TEST PAPER,

IS FOUND IN PLANTS
THAT ARE HARMFUL TO EAT.

IF SOMEHOW THIS PLANT
STARTED TO GROW

IN AN AREA WHERE IT
HAD NEVER GROWN BEFORE,

HAVING THE ABILITY
TO TASTE THE PTC COMPOUND

MIGHT HELP AN ANIMAL
THAT FED ON THESE PLANTS,

SAY, A RABBIT, TO SURVIVE,

BECAUSE IT WOULD LEARN
TO AVOID THIS PLANT.

WE'LL CALL THIS A TASTER.

BUT NOW,
LET'S IMAGINE ANOTHER RABBIT,

THAT LACKS THE ABILITY TO TASTE THE COMPOUND -- A NON-TASTER.

IF THIS RABBIT ATE A LOT
OF THE PLANT,

IT COULD BECOME VERY SICK
OR EVEN DIE.

IF WE TAKE THIS
TO THE POPULATION LEVEL,

WE CAN SEE HOW HAVING
ONE VARIATION OR THE OTHER

MIGHT CHANGE
THE NATURE OF THE POPULATION.

TASTERS ARE, IN GENERAL,
BETTER NOURISHED.

THEY WOULD HAVE MORE,
AND HEALTHIER, BABIES.

NON-TASTERS WOULD HAVE
FEWER BABIES.

WHEN THE ADULTS DIED OFF,

THE NEW POPULATION OF RABBITS

WOULD HAVE A HIGHER PERCENTAGE OF TASTERS THAN NON-TASTERS.

THIS PROCESS WOULD HAPPEN AGAIN.

THESE BABIES WOULD GROW UP
AND HAVE OFFSPRING,

AND THE PERCENTAGE OF TASTERS WOULD INCREASE IN THE POPULATION

A LITTLE MORE.

IF YOU REPEAT THIS CYCLE
OVER MANY, MANY GENERATIONS,

EVEN A SLIGHT INCREASE

IN REPRODUCTIVE SUCCESS

WILL LEAD TO A PREDOMINANCE
OF TASTERS.

THE POPULATION AS A WHOLE

WOULD BE ADAPTING
TO THEIR ENVIRONMENT.

THIS IS WHAT IS MEANT
BY ADAPTATION,

IN AN EVOLUTIONARY SENSE.

AND THE PROCESS
RESPONSIBLE FOR ADAPTATION

IS CALLED NATURAL SELECTION.

WHAT IF THE ORIGINAL
RABBIT POPULATION

HAD NO VARIANTS
THAT COULD TASTE PTC?

IF POISONOUS PLANTS CONTAINING THE COMPOUND WERE INTRODUCED,

THE RESULT WOULD BE EXTINCTION.

WITH NATURAL SELECTION, INDIVIDUALS POSSESSING

A VARIATION OF A TRAIT
THAT IS ADVANTAGEOUS

LEAVE MORE OFFSPRING
THAN THOSE THAT DON'T.

IN THIS WAY,
ADAPTATION IS THE RESULT

OF NATURAL SELECTION,
AND IT OCCURS

BECAUSE OF EXISTING VARIATION WITHIN THE POPULATION.

SO HOW MIGHT ADAPTATION
THROUGH NATURAL SELECTION

ACCOUNT FOR THE LONG NECKS
OF GIRAFFES?

LONGER-NECKED INDIVIDUALS ALREADY EXISTED

IN POPULATIONS OF GIRAFFES.

THESE LONGER-NECKED INDIVIDUALS WERE ABLE

TO GET TO MORE FOOD SOURCES,
FOR EXAMPLE,

WHEREAS THE SHORTER-NECKED GIRAFFES,

THAT COULDN'T GET TO THOSE,
DIED OUT.

THIS WAS
AN ADVANTAGEOUS VARIATION

THAT LED TO ONE TYPE OF GIRAFFE BEING MORE FIT

AND LEAVING MORE OFFSPRING
THAN OTHERS.

THIS SOUNDS A LOT LIKE A CONCEPT WE'VE ALL HEARD BEFORE --

SURVIVAL OF THE FITTEST.

Narrator: IN 1859,

CHARLES DARWIN
FIRST DESCRIBED IN DETAIL

THE THEORY OF EVOLUTION.

DARWIN OBSERVED
THAT OFFSPRING VARY

FROM THEIR PARENTS
AND FROM EACH OTHER,

AND THAT MANY VARIATIONS
ARE INHERITED.

INFLUENCED BY THE THINKING

OF THE ECONOMIST
THOMAS ROBERT MALTHUS,

WHO CLAIMED THAT POPULATIONS TEND TO GROW AND GROW

UNTIL RESOURCES ARE STRETCHED
TO THE LIMIT,

DARWIN ENVISIONED A WORLD
WHERE ORGANISMS ARE LOCKED

IN A COMPETITIVE STRUGGLE
FOR EXISTENCE.

DARWIN PROMOTED THE IDEA, ASTONISHING FOR ITS TIME,

THAT THOSE INDIVIDUALS POSSESSING VARIATIONS

THAT SOMEHOW GIVE THEM
AN ADVANTAGE OVER OTHERS

WOULD BE MORE LIKELY TO SURVIVE AND REPRODUCE SUCCESSFULLY.

IF THIS CONTINUED
FOR MANY GENERATIONS,

INDIVIDUALS
WITH THESE VARIATIONS

WOULD BECOME MORE COMMON, AND THE POPULATION WOULD CHANGE.

DARWIN CALLED THIS
"NATURAL SELECTION,"

AND THE PROCESS WAS NICKNAMED "SURVIVAL OF THE FITTEST."

NATURAL SELECTION
IS NOT A PROCESS

LEADING TOWARD PERFECTION.

THOSE IN A POPULATION
THAT REMAIN ARE SIMPLY THE ONES

THAT FIT INTO THE ENVIRONMENT BEST AT THAT TIME.

LET'S TAKE A BREAK NOW,
AND GO TO BOTTLE BIOLOGY.

HI, AND WELCOME BACK.

YOU'LL NEVER GUESS WHAT HAPPENED THIS WEEK IN BOTTLE BIOLOGY.

THE BRASSICA AND BUTTERFLY SYSTEM

TURNED INTO A BUTTERFLY GARDEN.

LUCKILY, OUR CAMERAS WERE THERE TO CAPTURE

THE BUTTERFLIES EMERGING
AFTER METAMORPHOSIS.

IN THE ECOCOLUMN,
WE PUT DIFFERENT KINDS OF SEEDS

INTO THE SOIL TO FIND OUT

IF THE ANIMALS HAVE
ANY FEEDING PREFERENCES.

WE'RE NOW READY TO EXPERIMENT WITH THE FIELD POPULATION,

EXPLORING THE FUNDAMENTALS
OF EVOLUTION.

TODAY WE'RE ASSESSING VARIATION AMONG INDIVIDUALS

IN THE BRASSICA POPULATION.

YOU CAN PROBABLY SEE
SEVERAL WAYS

IN WHICH INDIVIDUAL PLANTS VARY.

THIS VARIATION WILL SET
THE STAGE FOR OUR EXPERIMENT.

ONE MORE THING BEFORE WE GO --

WE'VE ADDED SOME MOIST BREAD
TO THE TERRAQUA COLUMN.

WHAT DO YOU PREDICT
WILL HAPPEN TO IT?

VISIT BOTTLE BIOLOGY
ON OUR WEB SITE

TO KEEP TRACK
OF THE EXPERIMENTS,

AND TO GET YOUR OWN STARTED.

THANKS, PAUL.

THE FIELD POPULATION SYSTEM
SOUNDS LIKE A FUN WAY

TO BRING THE FUNDAMENTALS
OF EVOLUTION INTO THE CLASSROOM.

NOW LET'S REJOIN
KATHY VANDIVER

AND HER STUDENTS AS THEY
GRAPPLE WITH QUESTIONS

ABOUT NATURAL SELECTION.

Vandiver: DO YOU THINK
THAT A POPULATION

OF BRASSICA RAPA PLANTS
COULD BECOME TALLER IN NATURE?

IT'S VERY FINE FOR US
TO PICK THE TALL PLANTS

AND TO POLLINATE THEM,

BUT I WAS CURIOUS
WHETHER YOU COULD THINK ABOUT

HOW THIS COULD POSSIBLY
EVER, EVER HAPPEN IN NATURE,

THAT YOU WOULD GET SOME PLANTS TO BE GETTING TALLER,

OKAY, BRASSICA RAPA PLANTS.
UM, JORDAN?

WELL, IT'S REALLY, LIKE,
NATURAL SELECTION

OR SURVIVAL OF THE FITTEST,
AND LIKE, THE --

[ALL LAUGHING]

AND THE BEES WOULD PROBABLY
GO TO THE TALL PLANTS.

Vandiver: ALL RIGHT, SO WE'VE GOT LOTS OF TALL PLANTS

BECAUSE THE BEES LIKE THEM BETTER, HUH?

IF YOU HAVE
A LOT OF PLANTS GROWN,

AND DO YOU JUST, LIKE,
KILL ALL THE SHORT ONES,

AND YOU KEEP DOING THAT UNTIL ONLY TALL ONES GROW?

SO THAT WOULD BE
A POSSIBLE WAY.

SO COULD THAT HAPPEN IN NATURE, THAT YOU GET PREFERENTIALLY,

SOME, ONLY THE TALLER PLANTS REPRODUCING?

IN NATURE, LIKE,
IT'S NOT VERY LIKELY AT ALL

THAT A POPULATION
COULD BECOME TALLER

UNLESS THE CONDITIONS
WERE PRETTY MUCH PERFECT,

BECAUSE, LIKE, IF YOU HAVE
A NICE PATCH OF LAND AND STUFF

AND IT GETS
JUST ENOUGH SUNLIGHT,

THEY MIGHT GROW VERY TALL,
AND THERE ARE NO TREES,

SO IT GETS A LOT OF RAIN,
AND THEN THE SEEDS OF THOSE

ARE GOING TO BE PROBABLY
PRETTY MUCH LIKE THEM,

SO, AND THE POLLINATION,
THERE WOULD HAVE TO BE BEES,

BECAUSE...AND IT'S PROBABLY
NOT VERY LIKELY.

Boy: MAYBE IF THERE
WAS EVER A HUGE DROUGHT,

THEN THE SMALLER PLANTS, THEY WOULDN'T HAVE AS BIG OF ROOTS

AS THE BIG PLANTS, SO THEY WOULDN'T HOLD AS MUCH WATER,

AND SO THEY WOULD DIE OFF
BEFORE THE BIGGER PLANTS.

SO MAYBE THEN
IF THE DROUGHT ENDED,

THEN ONLY THE BIG PLANTS
WOULD BE LEFT,

AND THEN THEY'D JUST KEEP ON GOING ON.

ONE OF THE CHILDREN DID
THINK OF A CIRCUMSTANCE

IN WHICH A POPULATION CHANGE, SHIFT, MIGHT REALLY OCCUR

IN CHARACTERISTICS, AND THAT WAS AN EXAMPLE OF A DROUGHT

IN WHICH THE PLANTS WITH PERHAPS THE DEEPER ROOTS WOULD SURVIVE

AND THOSE MIGHT BE
THE TALLER PLANTS,

AND THEREFORE,
THE NEXT GENERATION

AND THE FOLLOWING GENERATIONS MIGHT BE TALL PLANTS.

BEN'S DROUGHT SCENARIO
WAS VERY INSIGHTFUL.

LET'S USE IT TO REVIEW
WHAT WE FOCUSED ON TODAY.

FIRST WE DISCUSSED VARIATION.

AS BEN NOTED,
THE PLANTS DIFFER --

SOME HAVE TALL STEMS
AND LONG ROOTS, SOME HAVE SHORT.

THIS EXAMPLE SHOWS HOW,
IN A POPULATION,

THERE MAY BE TWO OR MORE WAYS THAT INDIVIDUALS MAY VARY,

FOR ANY GIVEN TRAIT.

TALL PLANTS WITH LONGER ROOTS

ARE VARIANTS THAT ALREADY EXIST IN THE POPULATION.

THIS VARIATION ARISES

FROM INFORMATION
IN THE PLANTS' GENES.

AND BEN'S SCENARIO ALSO DEMONSTRATES ADAPTATION.

HE SUGGESTED
THAT UNDER DROUGHT CONDITIONS,

TALL PLANTS WITH LONGER ROOTS

WOULD BE BETTER ABLE
TO REACH WATER.

THIS WOULD RESULT
IN MORE SUCCESSFUL FLOWERING

AND REPRODUCTION.

OVER MANY GENERATIONS, THIS VARIANT WOULD BECOME MORE COMMON

BECAUSE IT FIT BETTER

INTO THIS ENVIRONMENT.

Grisham:
FINALLY, BEN'S EXAMPLE

WOULD BE AN INSTANCE
OF NATURAL SELECTION.

CONDITIONS IN NATURE WOULD FAVOR TALL PLANTS WITH LONG ROOTS.

SO THESE VARIANTS WOULD LEAVE MORE OFFSPRING OVER TIME.

IN THAT SENSE,
NATURE SELECTS THE SURVIVORS.

WELL,
THANKS FOR JOINING US.

SEE YOU NEXT TIME,
AS WE CONTINUE TO EXPLORE

THE FUNDAMENTALS OF EVOLUTION

TO EXPLAIN
HOW NEW LIFE FORMS ARISE.

BYE-BYE.
GOODBYE.

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