FUNDING FOR THIS PROGRAM IS PROVIDED BY ANNENBERG/CPB
TO ADVANCE EXCELLENT TEACHING.
Narrator: EVERY AUTUMN THE TREES IN THE NEW ENGLAND FORESTS
ARE TRANSFORMED IN
A FLASHY PAGEANT OF COLOR.
LEAVES ONCE LUSH AND VERDANT
TURN YELLOW, ORANGE, AND RED.
THE FINAL ACT OF THIS DRAMA
IS THE FALL OF MILLIONS
AND MILLIONS OF LEAVES.
AND A DRAB, LIFELESS LAYER
COATS THE FOREST FLOOR.
IN THE SPRING,
THE PAGEANT STARTS UP AGAIN.
THIS IS ONE OF NATURE'S
LONGEST RUNNING SHOWS,
ONE THAT HAS
CONTINUED UNINTERRUPTED
FOR MILLIONS OF YEARS.
IN THIS LAVISH PRODUCTION,
THE MATERIAL COSTS
TO TREES ARE HIGH.
SO WHERE DO LEAF-MAKING MATERIALS COME FROM?
AND WHERE DO ALL THE MILLIONS
OF DEAD LEAVES GO?
WELCOME TO SESSION EIGHT OF "ESSENTIAL SCIENCE,"
A LIFE SCIENCE
CONTENT COURSE
FOR ELEMENTARY SCHOOL
TEACHERS.
TODAY WE'LL CONTINUE
TO BUILD ON THE THEMES
OF PREVIOUS SESSIONS.
WE'VE EXPLORED HOW
EVOLUTION HAS RESULTED
IN DIVERSE COMMUNITIES OF
INTERDEPENDENT SPECIES.
AND LAST TIME WE SAW HOW
ENERGY MAKES A ONE-WAY TRIP
THROUGH COMMUNITIES.
A COMMUNITY
IS DEPENDENT
UPON A CONSTANT
SUPPLY OF ENERGY
FOR ITS
VERY EXISTENCE.
WHAT ELSE DOES
A COMMUNITY REQUIRE?
WHEN WE THINK
ABOUT ORGANISMS
AND THE ENVIRONMENT
THAT THEY INHABIT,
WE TYPICALLY THINK ABOUT
WHAT WE MIGHT SEE --
TREES, ROCKS, AND INSECTS,
FOR EXAMPLE.
BUT HAVE YOU EVER
ASKED YOURSELF
WHAT ALL OF THESE
ARE ACTUALLY MADE OF?
LIKE ALL PHYSICAL OBJECTS, LIVING AND NONLIVING,
THEY ARE MADE OF
PARTICLES OF MATTER,
ATOMS AND MOLECULES.
FROM MICROSCOPIC BACTERIA
TO GIANT SEQUOIA TREES,
ALL ORGANISMS NEED
MATTER FOR LIFE.
IN THIS, OUR LAST SESSION,
WE'RE GOING TO LOOK AT
ATOMS AND MOLECULES
THAT ARE ESSENTIAL TO LIFE.
WE WILL TRACE THE FLOW OF MATERIALS
AMONG ORGANISMS
AND THEIR ENVIRONMENTS.
WHEN WE STUDY THE INTERACTIONS BETWEEN ORGANISMS
AND THE EXCHANGE OF MATERIALS
BETWEEN ORGANISMS
AND THE PHYSICAL ENVIRONMENT,
WE ARE LOOKING
AT HOW ECOSYSTEMS FUNCTION.
AS WE LEARN ABOUT MATTER
AND ECOSYSTEMS,
WE'LL TIE TOGETHER THE EXTREMES OF LIFE'S ORGANIZATIONAL LEVELS,
FROM THE SMALLEST BUILDING BLOCKS,
ATOMS AND MOLECULES,
TO ECOSYSTEMS, COMMUNITIES OF
ORGANISMS CO-EXISTING
AND INTERACTING WITH EACH OTHER AND THE PHYSICAL ENVIRONMENT.
Zook: WE'LL START OUT BY ASKING SOME
GENERAL QUESTIONS
ABOUT MATTER AND LIFE.
THEN WE'LL LOOK AT HOW MATERIALS ARE
ACQUIRED AND USED
AS THEY MOVE THROUGH LINKS
IN FOOD CHAINS,
FROM PRODUCERS TO CONSUMERS
TO DECOMPOSERS.
Grisham: OUR INVESTIGATION
WILL LEAD US
TO ASK SOME CHALLENGING QUESTIONS LIKE...
THESE QUESTIONS
ARE PART OF LESSON PLANS
DEVELOPED BY DR. TINA GROTZER
AT HARVARD UNIVERSITY'S
PROJECT ZERO.
Grotzer: WE WERE LOOKING AT
THE KINDS OF MISUNDERSTANDINGS
THAT KIDS HAD WHEN THEY WERE TRYING TO LEARN
SCIENCE CONCEPTS IN SCHOOL.
ON THE TOPIC
OF MATERIAL CYCLING,
WE FOUND THAT STUDENTS OFTEN THOUGHT
THAT THINGS DIDN'T DECAY
OR THAT THEY
DEPENDED ON UNRELIABLE KINDS
OF PROCESSES TO DECAY.
SO FOR EXAMPLE, A HUMAN BEING
WOULD HAVE TO COME
AND WALK ON THE LEAVES.
OR, YOU KNOW, AN ANIMAL
MIGHT HAPPEN BY,
LIGHTNING MIGHT STRIKE,
AND THAT THAT WAS RESPONSIBLE FOR DECAY.
SO WE STARTED TO THEN SAY,
OKAY, YOU KNOW,
HOW DO WE GET KIDS TO UNDERSTAND THAT
FOR ALL THE DECAY
THAT TAKES PLACE IN THE WORLD,
YOU NEED TO HAVE A MORE DEPENDABLE PROCESS,
THAT SOMETHING ELSE
MUST BE GOING ON
SINCE THOSE THINGS
DON'T HAPPEN REGULARLY?
Child:
HOW MUCH WAS THIS?
Child: IT'S FOUR RED,
FOUR RED.
WHERE ARE
THE GUMMY WORMS?

PUT SOME OVER HERE.
Grotzer: IF WE DON'T GIVE THEM THE WAYS
OF THINKING ABOUT THIS,
THE CAUSAL STRUCTURES
THAT HELP THEM TO STRUCTURE
THAT KNOWLEDGE,
THEY'LL FIND WAYS
TO STRUCTURE IT THAT
DISTORT THE INFORMATION
AND DON'T FIT WITH
THE SCIENTIFIC UNDERSTANDINGS.
AND I THINK THAT THAT'S
WHAT THIS IS ABOUT.
IT'S GIVING STUDENTS
THE LANGUAGE, OR THE FORMS,
TO STRUCTURE
THEIR UNDERSTANDINGS.
WHAT'S ALL THAT?
GRASS AND LEAVES.
YEP.
THEY'LL EAT ANYTHING
THAT ONCE WAS ALIVE.
ORGANIC OR INORGANIC?
INORGANIC.
ORGANIC.
ORGANIC.
WE'LL ALSO PUT IN SOME
OF THIS STUFF.
Narrator: THE STUDENTS
IN MARY ANN BERNSTEIN'S
THIRD GRADE CLASS ARE CONDUCTING AN
INVESTIGATION
TO LEARN MORE ABOUT THE CAUSES OF
DECOMPOSITION.
STUDENTS SET UP TWO TANKS,
ADDING FOOD ITEMS
AND NONLIVING MATTER
TO A BASE OF SAND AND SOIL.
THE ONLY DIFFERENCE
BETWEEN THE TANKS
IS THAT ONE HAS WORMS IN IT
AND THE OTHER DOESN'T.
Bernstein:
WHAT THE KIDS WILL NOTICE
OVER THE WEEKS THAT
THE TANKS ARE IN OPERATION
WILL BE THAT SOME CHANGES WILL TAKE
PLACE IN THE WORM TANK.
THERE WILL BE CHANGES
THAT WE'LL BE ABLE TO RECOGNIZE.
BUT THERE WILL ALSO BE CHANGES TAKING
PLACE
IN THE WORM-FREE TANK.
THAT TENDS TO SET UP
SOME REAL QUESTIONS.
SO IT LETS THEM
DISCOVER THE IDEA
THAT THERE ARE
OTHER DECOMPOSERS AT WORK
THAT MAYBE THEY CAN'T SEE.
WHAT DO YOU THINK MIGHT HAPPEN IN THOSE
TANKS?
LIKE SOME OF THE STUFF
WON'T BE EATEN IN THE WORM TANK
AND THE OTHER STUFF WON'T BE
LIKE MOLDY.
IT COULD BE, UM --
LIKE IF THERE IS FROOT LOOPS,
THERE MIGHT BE A LOT OF
FROOT LOOPS IN THE WORM TANK
AND ALL MOLDY FROOT LOOPS
IN THE WORM-FREE TANK.
I THOUGHT, LIKE,
IN THE OTHER HABITAT CLASS,
YOU SAID, LIKE, SOME DECOMPOSERS EAT
OTHER DECOMPOSERS.
Bernstein: OKAY.
THEN THE WORMS MIGHT JUST, EVEN IF SOME
OF THAT ORGANIC MATERIAL
TURNED TO MOLD, YOU THINK
THE WORMS MIGHT EAT IT.
YEAH.
ANYBODY HAVE A DIFFERENT IDEA ABOUT
THAT?
KELLY.
ALL THE ORGANIC STUFF
WILL BE GONE.
IN WHICH TANK, KELLY?
IN BOTH TANKS.
IN BOTH TANKS.
BECAUSE THE WORM TANK IS --
HAS THE WORMS THAT WILL
BREAK IT DOWN.
AND IN THE TANK THAT
DOESN'T HAVE THE WORMS,
IT WILL JUST BREAK,
IT WILL COME DOWN
INTO, UM, MOLD.
MARY ANN BERNSTEIN USED THE TERMS
"ORGANIC" AND "INORGANIC"
TO DESCRIBE THE CONTENTS
OF THE TANK.
EARLIER IN THIS COURSE, WE TALKED ABOUT
THIS DISTINCTION,
WHICH CAN BE CONFUSING,
ESPECIALLY WITH THE POPULARITY
OF ORGANIC FOOD
AND ORGANIC FARMING.
IN A SCIENTIFIC SENSE,
ALL FARMING WOULD
BE CONSIDERED ORGANIC
BECAUSE THE TERM IS USED
TO DESCRIBE THE MOLECULES
THAT LIFE IS MADE OF,
CARBON-BASED MATTER.
ALL OF THE FOOD
IN THE TANKS IS ORGANIC --
THE FROOT LOOPS, BREAD,
AND GUMMY WORMS --
BECAUSE THEY'RE DERIVED
FROM LIVING MATTER.
"INORGANIC" IS USED TO DESCRIBE THE
NONLIVING WORLD AROUND US,
SUCH AS THE CHEMICAL COMPONENTS OF THE
ENVIRONMENT.
THE SAND, THE TANKS THEMSELVES, AND
WATER
ARE EXAMPLES OF INORGANIC MATTER USED
IN THIS LESSON.
Zook: OVER A LIFETIME,
AN ORGANISM BUILDS UP ITS PHYSICAL BODY.
AND THOSE ATOMS HAVE
TO COME FROM SOMEWHERE.
BUT WHERE?
WE ASKED THE CHILDREN
IN THE SCIENCE STUDIO,
WHERE DO LIVING THINGS
GET *THEIR* MATTER?
Abrams: SO THEN WHERE DID
THOSE MOLECULES COME FROM?
WELL, THEY CAME FROM --
THE ENERGY CREATED
THE MOLECULES INSIDE IT.
YEAH.
SO CAN ENERGY
CREATE MATTER?
YEAH, BASICALLY.
Narrator: THE RELATIONSHIP BETWEEN MATTER
AND ENERGY
CONTINUES TO BE
A SOURCE OF CONFUSION,
JUST AS WE SAW IN SESSION SEVEN.

PJ AND MICHAEL CORRECTLY BELIEVE THAT
MATTER AND ENERGY
ARE ESSENTIAL TO GROWTH.
AND WE KNOW THAT ENERGY IS PACKAGED IN THE FORM OF FOOD.
BUT MATTER DOESN'T COME
FROM ENERGY.
A SIMPLIFIED WAY
OF SEPARATING THESE IDEAS
IS TO THINK OF ENERGY
AS THE FUEL OF LIFE
AND MATTER AS
THE BUILDING BLOCK OF LIFE.
Woman: IN THIS FOOD CHAIN,
YOU KNOW, ONE THING'S
GETTING EATEN BY THE OTHER, GETTING EATEN BY THE OTHER,
GETTING EATEN
BY THE OTHER.
WHAT'S GETTING PASSED
FROM THING TO THING?
FOOD.
AND WHAT'S IN THE FOOD?
NUTRIENTS.
YEAH, NUTRIENTS.
THAT HELPS THEM GROW.
YEAH, IT HELPS THEM GROW
AND MAKE THEM BIGGER.
WELL, I GUESS THIS FISH COULD BECOME AS BIG AS THE BIG FISH.
IT'S A, UM -- MAGGY?
[MAGGY LAUGHING]
UM, IT'S LIKE KIND OF
LIKE A VITAMIN.
NOT LIKE THE VITAMINS YOU EAT,
BUT LIKE THE VITAMIN
LIKE VITAMIN A
AND VITAMIN B,
I THINK.
IT'S KIND OF LIKE THAT.
IT'S NOT THAT, IT'S NOT THAT, BUT IT'S LIKE IT, I THINK.
I DON'T KNOW.
Narrator: MAGGY LINKS NUTRIENTS TO VITAMINS,
AND SHE ISN'T TOO FAR OFF.
BOTH ARE MATERIALS
ESSENTIAL TO LIFE.
BUT HOW DOES THE LITTLE FISH BECOME A BIG FISH?
WHERE DOES THE MATTER
IMPORTANT TO LIFE COME FROM?
IN THINKING ABOUT THIS QUESTION,
IT CAN BE HELPFUL
TO THINK ABOUT MATTER
IN TERMS OF ITS BASIC CONSTITUENTS -- ELEMENTS.
ELEMENTS ARE PARTICULAR
TYPES OF ATOMS.
AND THERE ARE OVER
100 ELEMENTS ON EARTH.
AND YET EIGHT MAKE UP 99% OF
THE BODIES OF ALL ORGANISMS.
Zook: THESE EIGHT ELEMENTS
ARE THE INGREDIENTS
OF WHAT WE CALL "SPONCH CaFe,"
A MNEMONIC THAT HELPS KEEP TRACK
OF LIFE'S ESSENTIAL ELEMENTS --
Grisham: CALCIUM AND IRON ARE ESSENTIAL ELEMENTS
FOUND IN SMALLER AMOUNTS
AND REPRESENTED BY "CaFe,"
THE ATOMIC SYMBOLS
FOR CALCIUM AND IRON.
ALL ORGANISMS -- FROGS, FLOWERS,
EVEN MOLD AND BACTERIA --
ARE BUILT FROM COMBINATIONS
OF THESE ELEMENTS.
BUT HOW DO MATERIALS LIKE THESE
CONTRIBUTE TO GROWTH?
NOW, WHEN WE ARE LOOKING
AT THIS PLANT,
AND THIS PLANT STARTED OFF
TO BE A LITTLE SEED,
HOW DID IT TURN INTO
THIS BIG PLANT WITH FLOWERS?
IT GREW USING SUNLIGHT
AND FOOD.
AND NUTRIENTS.
YEAH.
Abrams: AND ARE ALL
OF THOSE THINGS MATTER?
YEAH.
WELL, I MEAN, LIKE,
FOOD IS MATTER.
AND IT CAN BUILD YOU UP.
WHEN YOU GROW, YOU HAVE
MORE ATOMS IN YOUR BODY
AS YOU GROW.
BUT ATOMS KIND
OF ARE JUST THERE
AND THEY ADD WHEN
THEY NEED TO.
THEY DON'T DO ANYTHING.
THEY DON'T STOP YOU
FROM DOING ANYTHING,
THEY'RE JUST THERE.
AND WHEN YOU GROW,
THEY KIND OF, THEY GET --
THERE'S MORE ATOMS
IN YOUR BODY.
GREG AND MAGGY HAVE A SENSE THAT
MATTER ACCUMULATES.
BUT THEY ALSO SUGGEST THAT ATOMS CAN
REPRODUCE THEMSELVES.
IS THAT TRUE?
CAN MATTER BE CREATED
OUT OF NOTHING?
ONE OF THE BIG IDEAS IN SCIENCE
IS THE PRINCIPLE
OF CONSERVATION OF MATTER.
SCIENTISTS HAVE OBSERVED
OVER AND OVER AGAIN THAT,
EXCEPT IN VERY SPECIAL CIRCUMSTANCES,
MATTER CAN'T
BE CREATED OR DESTROYED.
IF YOU SEE MATTER
ACCUMULATING SOMEWHERE,
IT HAS TO HAVE BEEN TRANSFERRED FROM
SOMEWHERE ELSE.
THIS MEANS THAT ATOMS
CAN'T REPRODUCE,
AS THE CHILDREN SUGGEST.
NEARLY ALL THE MATTER
ON OUR PLANET TODAY
HAS BEEN HERE FOR
THE PAST 4.5 BILLION YEARS.
THERE IS A FINITE AMOUNT
OF MATTER ON EARTH.
AND IT MOVES FROM
ONE PLACE TO ANOTHER,
RECOMBINING IN DIFFERENT WAYS.
WHILE ALL OF THE ELEMENTS
OF THE SPONCH CaFe
ARE ESSENTIAL BUILDING
BLOCKS OF LIFE,
IN THIS PROGRAM WE'RE FOCUSING ON
CARBON AND NITROGEN
BECAUSE THEY ARE
REPRESENTATIVE EXAMPLES.
WHERE DO WE FIND THE ELEMENTS ESSENTIAL
TO LIFE?

WE PUT THIS QUESTION TO
DR. ADRIEN FINZI,
AN ECOLOGIST AND COLLEAGUE OF MINE HERE
AT BOSTON UNIVERSITY.
THERE ARE MANY ELEMENTS THAT ARE
IMPORTANT TO LIFE ON LAND,
BUT CARBON, NITROGEN,
AND PHOSPHOROUS ARE AMONG
THE MOST IMPORTANT
FOR TERRESTRIAL ECOSYSTEMS,
LIKE THE FOREST
THAT YOU SEE HERE.
THESE ELEMENTS CAN BE FOUND
IN THE ATMOSPHERE,
IN THE PLANTS THEMSELVES,
AND ALSO IN SOILS.
NITROGEN AND PHOSPHOROUS ARE ALSO KEY
ELEMENTS IN LIFE.
AND THEY EXIST IN VERY LOW QUANTITIES IN
SOILS,
WHICH MAKES THEM A VERY PRECIOUS
RESOURCE FOR PLANT GROWTH.
PLANTS HAVE ADAPTED THEMSELVES
TO DEALING WITH THIS LOW AVAILABILITY
OF THESE KEY ESSENTIAL ELEMENTS.
ONE OF THE MOST
DRAMATIC EXAMPLES
IS THE RESORPTION
OF THESE NUTRIENTS,
THAT IS, THE REMOVAL OF
THE NUTRIENTS FROM THE LEAVES
IN THE AUTUMN.
YOU SEE THIS BRIGHTLY COLORED FOLIAGE IN
THE BACK.
THIS IS AN INDICATION THAT PLANTS ARE
ACTIVELY WITHDRAWING
NITROGEN AND PHOSPHOROUS
FROM THE LEAVES
BEFORE THOSE LEAVES DIE.
THE CARBON THAT
ENTERS INTO PLANTS
THROUGH THE PROCESS OF PHOTOSYNTHESIS
CAN BE STORED IN
MANY DIFFERENT PLACES.
AND ONE OF THE MOST
IMPORTANT STORAGES
IS IN
THE PRODUCTION OF WOOD.
THE CONTENT OF WOOD IS
ABOUT 50% CARBON.
SO THAT WHEN YOU'RE LOOKING AT THE STEM
OF A TREE,
YOU CAN ESTIMATE THAT 50%
OF THE MASS OF THAT STRUCTURE
IS CARBON ALONE.
TO FIND OUT HOW
ELEMENTS LIKE CARBON
ENTER THE FOOD CHAIN,
LET'S START WITH
THE FIRST LINK,
THE PRODUCERS.
WHERE DO THEY GET
THE CARBON THEY NEED?
Zook: WHEN WE LOOK AT PHOTOSYNTHESIS,
WE SEE THAT PLANTS TAKE CARBON DIOXIDE
FROM THE AIR
AND CONVERT IT TO SUGARS.
IN THIS PROCESS, THE CARBON
IN CARBON DIOXIDE IS FIXED,
WHICH MEANS IT'S USED TO BUILD SUGAR
MOLECULES
THAT THE PLANT CAN
THEN USE FOR FOOD.
Grisham: ACQUIRING CARBON
IS A DIRECT PROCESS FOR PLANTS.
BUT ELEMENTS LIKE NITROGEN CAN BE MORE
DIFFICULT
AS WE FOUND OUT
FROM DR. NICKY SHEATS,
A POST-DOCTORAL FELLOW
AT COLUMBIA UNIVERSITY'S
EARTH INSTITUTE.
WE NEED NITROGEN FOR LIFE,
ALL FORMS OF LIFE
THAT WE KNOW OF.
AND IN MANY CASES, NITROGEN
IS THE LIMITING FACTOR,
WHICH MEANS THERE'S NOT ENOUGH
NITROGEN TO GO AROUND.
YOU'D HAVE MORE LIFE,
MORE ABUNDANCE OF LIFE,
IF YOU HAVE MORE NITROGEN.
AND THE KIND OF IRONY OF THIS IS
THAT THERE IS A LARGE POOL
OF NITROGEN ALL AROUND US
IN THE AIR.
THE ATMOSPHERE IS 78% NITROGEN.
THE PROBLEM IS, IT'S NOT IN
THE FORM THAT LIFE CAN USE.
AND TO GET INTO THAT FORM
IS DIFFICULT.
AND ONLY CERTAIN BACTERIA
CAN ACTUALLY TAKE THE NITROGEN FROM
THE AIR
AND PUT IT IN A FORM
THAT LIFE CAN USE.
WE CALL IT
MAKING IT "BIO-AVAILABLE."
THEN THAT NITROGEN CAN BE
USED BY OTHER LIFE
AND IT'S IN THE FOOD WEB.
WE CALL IT
"NITROGEN FIXATION."
THESE BACTERIA FIX THE NITROGEN.
Narrator: MANY SPECIES OF NITROGEN-FIXING
BACTERIA
IN THE SOIL DO THIS.
ANOTHER EXAMPLE OF BRINGING MATTER IN A
NONLIVING FORM
INTO THE LIVING WORLD
IS SYMBIOTIC PARTNERSHIPS.
THESE CLOVER PLANTS SOLVE
THEIR NITROGEN SUPPLY NEEDS
BY JOINING FORCES WITH NITROGEN-FIXING
BACTERIA.
CLOVER, ALONG WITH MANY MEMBERS OF THE
LEGUME FAMILY,
HAVE DEVELOPED ROOT NODULES
THAT HOUSE NITROGEN-FIXING BACTERIA.
LET'S TAKE A CLOSER LOOK.
IN ONE OF THE EXAMPLES,
WE'VE REMOVED THE SOIL
SO THAT WE CAN MORE EASILY
SEE THE ROOTS.
AND WE HAVE A SIMPLE
MAGNIFYING GLASS HERE
THAT WE CAN
TAKE A CLOSER LOOK.
AND THEY'RE CERTAINLY THERE.
THEY'RE SMALL.
THESE NODULES ARE
THROUGHOUT THE ROOTS.
AND THE RELATIONSHIP IS SYMBIOTIC
BECAUSE THE TWO ORGANISMS DEVELOP A
NEW STRUCTURE --
IN THIS CASE THE NODULES --
THAT ALLOW FOR THE EXCHANGE
OF MATERIALS.
THE BACTERIA RECEIVES SUGAR
FROM THE PLANT
AND TRANSFER NITROGEN TO IT.
NOW, THERE ARE ALSO

EXTREME STRATEGIES
FOR OBTAINING
ESSENTIAL ELEMENTS.
LET'S SEE HOW THE PITCHER PLANTS DR.
AARON ELLISON STUDIES
GET THE ELEMENTS THAT THEY NEED.
Ellison: THE PITCHER PLANTS ARE
CARNIVOROUS PLANTS.
AND THEY GET THEIR NUTRIENTS
BY CATCHING INSECTS,
WHEREAS MOST OTHER PLANTS
ARE GETTING THEIR NUTRIENTS
OUT OF THE SOIL.
AND THE NUTRIENTS --
SUCH IMPORTANT NUTRIENTS
SUCH AS NITROGEN AND PHOSPHOROUS AND
POTASSIUM --
ARE ACTUALLY USED TO MAKE
THE ENZYMES
THAT ARE INVOLVED IN PHOTOSYNTHESIS.
THE PLANT MAKES NECTAR AROUND THE EDGE
OF THE MOUTH
IN ORDER TO ATTRACT THE INSECTS TO COME
INTO THE PLANTS.
SO THE WASP HERE IS WALKING
AROUND THE LIP,
COLLECTING NECTAR
OFF OF THE PLANT.
AND SOMETIMES THE INSECT WILL GET
CONFUSED BY THE LIGHT
AND WILL CONTINUE TO WALK DOWN INTO
THE TUBE,
AND THEN IT WON'T BE ABLE
TO GET BACK OUT.
AND THEN THEY ARE DECOMPOSED
BY THE BACTERIA AND PROTOZOA
AND ROTIFERS AND MITES THAT LIVE INSIDE
OF THE PITCHER,
AS WELL AS BY DIGESTIVE ENZYMES
THAT THE PITCHER
ITSELF PRODUCES.
IT TAKES FOUR TO SIX DAYS FOR
AN INSECT THAT'S CAPTURED
TO BE BROKEN DOWN AND ITS NUTRIENTS
RELEASED TO THE PLANT.
Grisham: ONE DIFFERENCE BETWEEN A PITCHER
PLANT
AND A FOREST PLANT
IS THAT PITCHER PLANTS
HAVE THEIR DECOMPOSERS
IN THEIR LEAVES.
FOREST AND LAWN PLANTS HAVE THEIR
DECOMPOSERS IN THE SOIL.
Narrator: ONE OF THE WAYS HUMANS HAVE
SOLVED THE PROBLEM
OF OBTAINING NITROGEN WAS DEVELOPED BY
FRITZ HABER,
A GERMAN CHEMIST.
IN 1908, HE PERFECTED
A RELIABLE WAY
OF USING NITROGEN FROM THE AIR
TO MAKE AGRICULTURAL FERTILIZERS.
IF YOU'RE A FARMER,
YOU NEED A LOT OF NITROGEN.
WE ALL KNOW NOW WHAT WE DO IS
WE HAVE FERTILIZER.
FERTILIZER IS ACTUALLY MORE INTERESTING
THAN IT MAY SEEM,
BECAUSE WE HAVE LEARNED INDUSTRIALLY
HOW TO DO
WHAT THE BACTERIA DO,
HOW TO FIX NITROGEN.
AND THEREFORE,
WE CAN TAKE THE NITROGEN,
MAKE FERTILIZER,
AND PUT IT ON THE FIELDS,
AND NITROGEN IS NO LONGER
A LIMITING FACTOR.
Narrator: WHAT IS THE IMPACT OF HABER'S
DISCOVERY?
THIS FERTILIZER PLANT IS
A REPRESENTATIVE EXAMPLE.
IT CAPTURES 100 MILLION TONS
OF NITROGEN
FROM THE AIR EACH YEAR,
ENOUGH FIXED NITROGEN TO FEED
5 MILLION ACRES OF CORN.
MANMADE FERTILIZERS SUPPLEMENT THE
NATURAL FLOW OF MATERIALS,
ALLOWING FARMERS
TO PRODUCE MORE FOOD.
BY SOME ESTIMATES, AS MUCH AS 2/5 OF THE
WORLD'S POPULATION
ARE FED BY CROPS GROWN WITH THESE
MANMADE FERTILIZERS.
WE'LL LOOK AT THE EFFECTS OF THIS BOON ON
ECOSYSTEMS
LATER IN THE PROGRAM.
WE HAVE SEEN HOW CARBON
AND NITROGEN
ARE ESSENTIAL TO PHOTOSYNTHESIS AND
PLANT GROWTH.
THE PRODUCERS USE
FIXED CARBON AND NITROGEN,
AND OTHER ESSENTIAL ELEMENTS FOUND IN
SOIL, WATER, AND AIR,
TO BUILD THEIR BODIES.
WHAT ABOUT THE CONSUMERS?
WHERE DO THEY FIND
THE SPONCH CaFe IN ECOSYSTEMS?
WE SAW IN SESSION SEVEN
THAT CONSUMERS MEET THEIR
ENERGY NEEDS BY EATING FOOD,
WHICH IS ENERGY STORED
IN ORGANIC MATTER.
ORGANISMS ACQUIRE MATTER CONSTANTLY,
BUT HAVE YOU EVER WONDERED WHY?
IT'S EASY TO SEE HOW
GROWTH AND REPRODUCTION
REQUIRE AN INFLUX
OF MATTER INTO BODIES
BECAUSE WE CAN ACTUALLY SEE
THE BODIES GETTING BIGGER.
BUT WHY DO ORGANISMS THAT HAVE STOPPED
GROWING AND REPRODUCING
NEED NEW MATTER?
WE ASKED DR. SHEATS TO EXPLAIN WHY
CONSUMER ORGANISMS
NEED A CONSTANT SUPPLY
OF NITROGEN.
Sheats: WE EAT THE PLANTS
AND WE TAKE IN THE NITROGEN.
AND WE USE THE NITROGEN IN MANY OF THE
SAME WAYS THE PLANTS DO.
THERE'S A LOT OF PROTEIN
IN OUR BODY.
AND NITROGEN
IS ESSENTIAL IN PROTEIN.
SO THE NITROGEN THEN BECOMES THE
STRUCTURAL PART OF YOUR BODY.
AT SOME POINT, YOUR BODY WILL BREAK
DOWN PROTEINS
AND DNA AND ENZYMES.
THE NITROGEN THEN CAN BE
TOXIC TO YOUR BODY,
TOXIC TO
THE BODIES OF ANIMALS.
THEN YOU HAVE
TO GET RID OF THEM.
SO WE EAT PLANTS, INCORPORATE THE
NITROGEN INTO OUR BODY,
USE THE NITROGEN,

THEN WE BREAK IT DOWN.
AND WE EXCRETE IT OUT
OF OUR BODY.
CONSUMERS,
LIKE ALL ORGANISMS,
NEED A CONSTANT SUPPLY
OF NEW MATTER,
TO KEEP UP WITH THE MATERIAL NEEDS OF
CELL RENEWAL.
AND LIKE NITROGEN,
CARBON IS ALSO A STRUCTURAL
PART OF BODIES.
OVER TIME, THE ATOMS THAT
MAKE UP AN ORGANISM
ARE REPLACED AS ORGANIC MOLECULES ARE
BROKEN DOWN.
FOR INSTANCE, NEARLY
ALL OF THE ATOMS
IN A HUMAN BODY ARE
CONTINUOUSLY REPLACED.
CARBON WASTE IS RELEASED INTO THE AIR AS
CARBON DIOXIDE
WHEN WE EXHALE.
AND IT IS EXPELLED FROM THE BODY IN FECES
AND URINE.
Narrator:
IF LIFE-SUSTAINING MATERIALS
LIKE CARBON AND NITROGEN LEAVE BODIES
AS WASTE MATTER,
ARE CONSUMER ORGANISMS
IN DANGER
OF CONVERTING ALL OF THE EARTH'S MATTER
INTO WASTE?
WHEN WE LOOKED
AT ENERGY LAST TIME,
WE SAW THAT IT IS CONTINUOUSLY
CONVERTED TO HEAT,
AN UNUSABLE FORM OF ENERGY,
AND THEN RADIATED
BACK INTO SPACE.
IS THE SAME TRUE FOR MATTER
OR CAN LIFE USE WASTES?
TO FIND OUT, WE PAID A VISIT
TO CHARLES TYLER,
PLANT MANAGER AT THE DEER ISLAND
SEWAGE TREATMENT FACILITY.
Tyler: THE MATERIAL THAT IS
IN THE WASTEWATER
IS WASTE FROM HUMAN USE.
SO THERE'S ALL KINDS
OF ORGANIC MATERIAL IN IT.
FOR OUR DECOMPOSING BACTERIA, THIS STUFF
IS FOOD.
IT IS SOMETHING THAT CAN BE BROKEN DOWN
BY THEM.
IT'S SOMETHING THAT CAN BE CONSUMED BY
THEM
SO THAT THEY CAN LIVE
NATURAL LIVES,
THEN DIE AND BECOME FOOD THEMSELVES
FOR OTHER BACTERIA.
WE USE DECOMPOSING BACTERIA
BECAUSE IT'S VERY COMPLICATED
TO GET DISSOLVED SOLIDS
OUT OF WASTEWATER.
OUR PROCESS DOES,
IN FACT, MIMIC NATURE.
WHAT WE HAVE DONE IS CONCENTRATED IT
AND ACCELERATED IT IN
A SMALL PLACE,
WHICH WE HAVE TO DO
BECAUSE THE CONCENTRATION
OF WASTE FROM THESE LARGE POPULATION
AREAS IS SO GREAT
THAT WE MUST DO IT
IN THAT WAY.
WE TAKE A SAMPLE FROM
OUR TREATMENT PROCESS
TO SEE WHAT KIND
OF BACTERIA WE HAVE
AND TO SEE WHAT KIND
OF SHAPE THEY'RE IN.
DO THEY GET ENOUGH OXYGEN?
WHAT KIND OF BACTERIA
DO WE HAVE IN THERE?
AND WHAT OTHER KINDS OF MICROORGANISMS
ARE IN THE WATER SO THAT WE CAN TELL IF,
IN FACT, IT IS
A HEALTHY DECOMPOSING
BACTERIA POPULATION
THAT WE HAVE IN THE SYSTEM.
WHAT WE LOOK FOR ARE A CERTAIN TYPE OF
INDICATOR ORGANISMS
THAT ARE ACTIVE IN THIS SLUDGE
THAT, IN FACT, PROVE TO US THAT THERE ARE
ALSO HEALTHY BACTERIA
OPERATING IN THE SLUDGE AS WELL.
THERE'S A ROTIFER.
THE ROTIFERS ARE REALLY GOOD.
WE LIKE TO SEE A FEW OF THOSE BUT NOT TOO
MANY.
A NICE ROTIFER SHOWS THAT WE HAVE A
GOOD AGE OF SLUDGE.
IT'S A CONTINUAL
MONITORING PROCESS.
WE NEED TO WATCH IT EVERY DAY. WE NEED
TO LOOK AT IT EVERY DAY.
AND WE NEED TO MAKE CHANGES EVERY DAY
IN ORDER TO KEEP UP
WITH WHAT'S COMING IN.
HERE'S THE FINAL PRODUCT --
BAY STATE FERTILIZER.
THE OTHER PRODUCTS INCLUDE
TREATED WATER
PUMPED OUT TO SEA,
CARBON DIOXIDE,
AND NITROGEN GAS.
IT MAY SEEM
COUNTERINTUITIVE,
BUT THE TREATMENT
PLANT
IS A HIGHLY DESIGNED
ECOSYSTEM.
IN THE SETTLING POOLS,
THERE IS A STEADY FLOW
OF FOOD,
MATTER, AND ENERGY THAT
SUPPORTS
THE POPULATION OF
BACTERIAL DECOMPOSERS.
Zook: AND TO TAKE A LOOK AT
HOW THE REMAINS OF LIFE
ARE TREATED
IN MORE NATURAL SETTINGS,
LET'S RETURN TO THE WORM TANKS
IN MARY ANN BERNSTEIN'S CLASS.
THREE WEEKS HAVE PASSED
SINCE THE STUDENTS
PUT THE TANKS TOGETHER,
AND THEY'RE MONITORING THE WORK
OF DECOMPOSERS.
THINK ABOUT WHAT IT
LOOKED LIKE WHEN WE STARTED.
DO YOU NOTICE ANY CHANGES?
IN THE WORM TANK,
IT WAS QUITE OBVIOUS BY NOW
THAT SOMETHING WAS HAPPENING
TO THAT ORGANIC MATTER.
IT WAS JUST NOT THERE
ANYMORE.
OR...
IT STARTED TAKING ON A FORM

THAT LOOKED
A LITTLE BIT DIFFERENT.
Girl: MOST THINGS GOT EATEN
THAT WE PUT IN THERE.
Bernstein: OKAY, WHEN YOU SAY
"MOST THINGS GOT EATEN,"
WHAT THINGS DO YOU MEAN?
Girl: LIKE, ORGANIC STUFF GOT
EATEN BY WORMS AND MOLD.
Bernstein: OKAY,
IF THE WORMS ATE IT,
THEN WHAT HAPPENED?
WHERE IS IT?
THEY COULD HAVE MADE
SOIL OUT OF IT AND...
Bernstein: SO MAYBE SOME OF
THE WORMS
USED THIS FOR FOOD
AND THEN TURNED THE LEFTOVERS
BACK INTO SOME KIND OF SOIL.
WE WANT THEM TO BE ABLE
TO MAKE THE CONNECTION
AND TO BE ABLE TO QUESTION
AND SAY,
I KNOW THAT THE DECOMPOSITION
IN THE WORM TANK
WAS CAUSED BY THE WORMS.
I SEE DECOMPOSITION ALSO HAPPENING IN THE
OTHER TANK.
THERE ARE NO WORMS THERE
TO MAKE THAT HAPPEN.
I SEE THE EFFECT,
THERE'S GOT TO BE
A CAUSE THERE SOMEWHERE.
I WONDER WHAT THAT IS.
OKAY, LET'S TAKE A LOOK
AT THIS ONE.
DOES IT LOOK DIFFERENT
THAN WHEN WE SET IT UP?
RACHEL?
Rachel: IT DOESN'T LOOK
MUCH DIFFERENT TO ME
BECAUSE EVERYTHING'S JUST --
LIKE ALL THE ANIMAL CRACKERS
AND THE CAPS ARE JUST ALL
ON THE TOP,
LIKE WHEN WE PUT THEM THERE.
Bernstein: OKAY, WHAT ELSE?
COURTNEY.
Courtney: WELL,
I SORT OF KNOW THIS,
BUT REALLY NOTHING
IN THE WORM-FREE TIN
CAN EAT THE FOOD,
BECAUSE THERE'S LIKE NO,
UM...
THERE'S NO WORMS.
AH! WHAT DO YOU THINK
ABOUT THAT?
CARA.
Cara: MOLD COULD STILL
GROW ON IT,
AND THEN,
AFTER A LONG TIME,
IT MIGHT, LIKE, EAT IT,
INSTEAD OF WORMS.
SO, WHERE'S THE MOLD
COMING FROM?
WHEN YOU PUT
ALL THE STUFF IN,
THERE WAS LIKE
BACTERIA AND GERMS
ALL OVER IT,
SO THAT WAY,
JUST A LOT MORE
BACTERIA COMES TOGETHER
AND THAT'S WHAT FORMS
THE MOLD.
SO IT'S NOT THAT
IT JUST APPEARS.
IT'S THAT IT HAS TO
COME FROM SOMEWHERE.
AH! EXACTLY.
LADIES AND GENTLEMEN,
IN THE WORM-FREE TANK,
WE STILL HAVE SOME

DECOMPOSERS.
AND THOSE ARE
THE VERY TINY
LITTLE ORGANISMS
THAT WE CALL
MICROBES.
Bernstein: WHAT I WANTED
THE STUDENTS
TO NOTICE OR RECOGNIZE
IS THAT THERE ARE
OTHER DECOMPOSERS
THAT ARE NOT
SO OBVIOUS,
THAT THERE ARE THINGS
GOING ON THAT AID
THE DECOMPOSITION PROCESS
ALL THE TIME
THAT MAY NOT BE SO READILY
RECOGNIZABLE TO US.
WE'VE GOT DECOMPOSERS
AT WORK.
THE STUDENTS ARE VERY
USED TO EVENTS
THAT HAVE CAUSES
AND EFFECTS
THAT THEY CAN SEE
DIRECTLY.
BUT THEY HAVE
A HARD TIME
WITH MICROSCOPIC
LIFE FORMS
THAT ONLY LEAVE
TRACE EVIDENCE
OF BEING THERE
THROUGH THEIR ACTIVITY.
EVEN WHEN PRESENTED
WITH THE EVIDENCE
OF DECOMPOSITION,
CHILDREN OFTEN HAVE
DIFFICULTY
UNDERSTANDING
THE PROCESS.
WE ASKED PJ AND MICHAEL
TO SHARE THEIR IDEAS
ABOUT DECOMPOSITION.
SO IF I TOOK THAT BREAD OUT
AND I STUCK IT RIGHT HERE
ON THE TABLE,
HOW WOULD IT DECOMPOSE?
UM, I DON'T THINK IT
COULD BE DECOMPOSED
BECAUSE IT'S NOT NEAR OR AROUND WHERE
FUNGUS COULD GROW.
IT DOESN'T JUST DECOMPOSE
ON ITS OWN.
IT HAS TO HAVE FUNGUS.
IF YOU LEAVE A SANDWICH OUT
ON A TABLE FOR TWO WEEKS,
IT WOULD ROT.
BUT THERE'S NO SOIL
AROUND IT,
SO IT WOULD DECOMPOSE.
FUNGUS GROWS ON IT.
FUNGUS GROWS
ON DEAD STUFF.

Abrams: BUT HOW DOES
THE FUNGUS FIND IT?
IT JUST GROWS
BECAUSE IT PROVIDES
THE NUTRIENTS AND...
I HAVE NO IDEA
HOW FUNGUS GROWS.
FUNGUS IS A LOT
DIFFERENT
THAN MANY THINGS
ON THIS PLANET.
Narrator: LIKE MANY CHILDREN,
PJ AND MICHAEL
HAVE HEARD OF BACTERIA
AND FUNGI,
BUT THEY ARE VERY UNCLEAR
ABOUT WHERE
THESE ORGANISMS COME FROM
AND HOW THEY GROW.
DECOMPOSER ORGANISMS THRIVE
ON WASTES
AND DEAD PLANTS AND ANIMALS.
WE TAPED THE DECOMPOSITION
OF THIS RAT
OVER A SIX-WEEK PERIOD.
THE RAT'S MATERIAL BODY
IS SLOWLY BEING CONSUMED
BY BACTERIA AND FUNGI
THAT LANDED ON IT
AND HAVE GROWN THERE.
THEN WE TOOK A SAMPLE
FROM THE RAT
AND PUT IT UNDER
A MICROSCOPE
TO GET A GLIMPSE
OF THE BACTERIA AT WORK.
HERE THEY ARE.
Zook: MARY ANN BERNSTEIN'S
CLASS
CONTINUES ITS STUDY
OF DECOMPOSERS.
NOW THEY'RE EXPERIMENTING
WITH BREAD MOLD,
A TYPE OF FUNGUS.
YOU'RE GOING TO TAKE
THE PIECE OF BREAD,
NICE, FRESH, SOFT BREAD.
YOU'RE GOING
TO GENTLY RUB
ONE SIDE OF THE BREAD
SOMEPLACE
IN THIS BUILDING.
I WOULD LIKE YOU
TO CHOOSE A PLACE
THAT GETS
LOTS OF TRAFFIC,
A PLACE WHERE PEOPLE
FREQUENTLY GO.
THE MICROBES ARE
PROBLEMATIC FOR KIDS
BECAUSE YOU CAN'T
SEE THEM.
SO IT CREATES
A SITUATION WHERE
THEY'RE FORCED TO RECOGNIZE
THAT THERE ARE
OTHER THINGS AT WORK
THAT ARE NOT VISIBLE.
THE BREAD HAS BEEN
SEALED IN THE BAG,
BUT SOMETHING IS AT WORK
CAUSING THE DECOMPOSITION.
WHAT DO YOU THINK
WOULD HAPPEN
IF WE LEFT THEM UP HERE
EXACTLY THE WAY THEY ARE
UNTIL YOU CAME BACK TO SCHOOL
IN SEPTEMBER?
UH...
WE WON'T DO THAT,
BUT IF WE DID,
I WOULD LIKE YOU TO PREDICT
WHAT YOU THINK MIGHT HAPPEN.
IT WOULDN'T BE, LIKE, STILL
A PIECE OF BREAD.
LIKE THERE WILL
BE SOME MOLD ON IT.
I THINK IT WILL BE
VERY MOLDY.
YEAH.
I THINK IT WILL BE
LIKE ALL GONE.
Bernstein: SO, WHAT DID YOU PREDICT WOULD
HAPPEN?
I PREDICTED THAT
MY BREAD WOULD BE
STALE AND MOLDY
'CAUSE IT WOULD HAVE
BEEN SITTING THERE SO LONG.
Bernstein: OKAY, AND WHEN
YOU SAY "STALE,"
WHAT DID YOU EXPECT IT
TO LOOK LIKE?
UM...
MAYBE IT WOULD HAVE
LIKE FUZZ
OR IT WOULD BE KIND OF
HARD IF YOU TOUCHED IT.
Bernstein: OKAY.
WHO ELSE? CONNOR?
UM, IT WOULDN'T BE
THE ORIGINAL COLOR,
IT WOULD KIND OF LIKE
BE A BIT GREENISH.
OKAY.
I THOUGHT THAT IT WOULD
START BREAKING IN PIECES.
YOU THOUGHT IT WOULD
START BREAKING IN PIECES?
YEAH, BUT STILL STAY MOLDY.
OKAY. NICKY?
LIKE IT WOULD BE ALL GREEN
AND LIKE FUZZY.
I PICTURED IT IN MY MIND
LIKE IT WAS GOING TO BE
ALL LIKE YELLOW
AND THERE WAS GOING TO BE
LIKE FUZZ SHOOTING FROM IT.
OKAY.
RYAN, HOW ABOUT YOU?
I THOUGHT LIKE SOME OF IT
WOULD BE GONE.
SINCE LIKE SOME OF IT,
LIKE, THE FUZZ,
AND THEN SOME OF IT,
IT WAS LIKE,
BEING GONE,
I DON'T KNOW.
WHEN YOU SAY "GONE,"
WHAT DO YOU MEAN?
LIKE SOME OF THE BREAD
WOULD BE EATEN.
IT WOULD BE EATEN?
SO YOU THOUGHT THERE
WOULD BE
LESS IN THE BAG THAN
YOU STARTED OUT WITH?
OKAY.
OH, MY GOSH!
OH, MY GOSH!
NICKY, LOOK AT MINE!
LOOK AT IT!

OH, MY GOSH, CONNOR!
[CHILDREN TALKING
EXCITEDLY]
Bernstein: WE'LL TAKE A COUPLE OF THESE
SAMPLES INSIDE,
WE'LL PUT THEM ON
THE MICROSCOPE,
AND YOU'LL BE ABLE TO TAKE
A CLOSER LOOK AT THEM
ON THE SCREEN.
Children: OOH!
Boy: THAT IS LIKE FUZZ!
Girl: IT LOOKS
LIKE JELLY!
Girl #2: NO, IT DOESN'T.
[CHILDREN DISCUSSING
IMAGES]
Narrator: MICROBES ARE EVERYWHERE.
MICROSCOPIC MOLD SPORES
ARE ABUNDANT
IN SCHOOLS AND HOMES.
THEY'RE FLOATING IN THE AIR
AND LIVE ON MOST SURFACES.
ON CONTACT WITH A FOOD SUPPLY,
THEY GROW TO THE POINT
WHERE THEY'RE OFTEN VISIBLE
TO THE NAKED EYE.
WITH DECOMPOSERS AROUND,
NOTHING GOES TO WASTE.
THEY USE FOOD TO GROW
AND REPRODUCE,
LIKE ALL ORGANISMS.
DECOMPOSERS OCCUPY THE NICHE
AT THE END OF THE FOOD CHAIN.
BUT WHAT DOES THAT MEAN
FOR MATTER?
WHAT HAPPENS TO ALL THE MATTER
AFTER DEATH AND DECAY?
WE ASKED THE CHILDREN
IN OUR SCIENCE STUDIO,
CAN THE MATTER IN DEAD THINGS EVER BE
LIVING MATTER AGAIN?
NONLIVING CANNOT
BECOME ALIVE.
BUT, UH...
NONLIVING
CANNOT --
AND NONLIVING
CANNOT BECOME DEAD,
BECAUSE DEAD,
YOU HAVE TO BE
ONCE LIVING
TO BECOME DEAD.
AND LIVING CAN BECOME
DEAD,
AND DEAD CAN BECOME
NONLIVING.
LIVING BECOMES DEAD
AND DEAD BECOMES
NONLIVING, EVENTUALLY.
BUT THERE'S NO WAY
THE NONLIVING
CAN BECOME
LIVING AGAIN?
NO.
SO IT'S
A ONE-WAY STREET?
IT'S LIVING, DEAD,
NONLIVING --
IT'S ONE-WAY.
THE CHILDREN DESCRIBE
INTERACTIONS
BETWEEN LIVING,
NONLIVING,
AND DEAD THINGS
WITH CONFIDENCE.
THEY THINK THAT THE PATH
LIVING THINGS TAKE
IS LINEAR -- LIVING,
DEAD, NONLIVING --
AND THAT THAT'S
THE END OF THE LINE.
WE NOW KNOW MATTER
IS NEITHER CREATED
NOR DESTROYED.
SO IF PJ AND MICHAEL
ARE RIGHT,
WE SHOULD EXPECT
TO SEE
AN ACCUMULATION
OF NONLIVING MATTER
PILING UP
ALL OVER THE WORLD.
LET'S SEE WHAT GREG
AND MAGGY THINK
ABOUT THE ONE-WAY
STREET.
SO THE DIRT'S
IN THE GROUND,
AND HOW IS IT
USED?
CAN YOU KIND OF
EXPLAIN USING
ANY OF THESE ANIMALS
AND PLANTS IN HERE?
WORMS EAT DIRT,
I THINK.
Greg: YEAH,
WORMS EAT DIRT.
THEN THEY GO
TO THE BATHROOM.
AND THEN THERE'S
MORE DIRT.
WELL, IT'S THE SAME
AMOUNT OF DIRT, BUT --
AND THEN THERE'S DIRT
AGAIN,
AND THEN IT JUST KEEPS
GETTING REUSED
BY THE WORMS, OR ANYTHING
ELSE THAT USES DIRT.
CAN YOU THINK OF ANYTHING
ELSE IN THE PICTURE
THAT EATS DIRT?
MUSHROOMS, 'CAUSE THEY'RE
CONNECTED TO THE GROUND,
WHICH MEANS --
AND TO THE TREES.
THAT'S WHERE THEY GET
THEIR NUTRIENTS,
TO MAKE,
TO KEEP THEM ALIVE.
IN THIS CONVERSATION,
GREG AND MAGGY HINT AT CYCLING
WHEN THEY SAY THAT THE SOIL
KEEPS GETTING REUSED OVER AGAIN
AS A SOURCE OF NUTRIENTS,
ALTHOUGH THEY SEEM
TO THINK THAT
SOILS ONLY WERE USED
BY WORMS.
WHICH EXPLANATION
FITS THE FACTS?
IS THE PATH TAKEN BY MATERIALS
A ONE-WAY STREET,
AS PJ AND MICHAEL BELIEVE?
OR IS IT A CYCLE,
AS GREG AND MAGGY SUGGEST?
Narrator: CONSIDER THE SIGNATURE ELEMENT
OF THE LIVING WORLD --
CARBON.
WHAT PATH DOES IT TAKE?

IN SESSION SEVEN,
WE SAW PART OF THIS PATHWAY
WITH DR. ELLISON
AND HIS CARNIVOROUS PLANTS.
PRODUCERS USE THE CARBON DIOXIDE
THEY TAKE IN FROM THE AIR
TO MAKE SUGARS.
AS THEY USE THAT SUGAR
IN RESPIRATION,
THE CARBON IS RELEASED
BACK INTO THE AIR.
THIS IMPLIES THAT CARBON CYCLES BACK AND FORTH
BETWEEN PLANTS
AND THE AIR,
BUT IN ACTUAL FACT,
IT DOES MUCH MORE.
EVERY LIVING THING PLAYS
A ROLE IN CARBON CYCLING.
NEARLY EVERY ORGANISM
RESPIRES,
FROM THE BACTERIA AT WORK
IN COMPOST PILES
TO GREEN, LEAFY PLANTS.
LET'S TAKE A LOOK AT
THE REST OF THE CARBON CYCLE
WITH DR. FINZI.
THE AMOUNT OF TIME THAT CARBON
RESIDES IN AN ECOSYSTEM
DEPENDS UPON WHERE
THAT CARBON ATOM IS FOUND.
IF CARBON ENTERS
INTO A LEAF,
IT WILL ONLY STAY
IN THE ECOSYSTEM
FOR A PERIOD
OF MONTHS TO YEARS
AS A RESULT OF
THE PROCESS OF DECOMPOSITION.
YOU CAN SEE
ALL THESE LEAVES
ON THE GROUND HERE, AND AS SOON AS THEY
HIT THE GROUND,
BACTERIA AND FUNGI BEGIN
TO DECOMPOSE THOSE LEAVES,
AND A PRODUCT, A BY-PRODUCT OF
THE PROCESS OF DECOMPOSITION,
IS THE RETURN OF CARBON
TO THE ATMOSPHERE
IN THE FORM OF CO2.
IF THAT CARBON ATOM WERE
TO ENTER, SAY,
INTO THE TRUNK OF A TREE,
IT WOULD RESIDE IN THAT
POOL OF CARBON
FOR AS LONG AS
THAT TREE IS ALIVE.
AND THAT TREE MAY BE
ALIVE FOR 20 YEARS,
IT MAY BE ALIVE FOR 50 YEARS,
OR SEVERAL HUNDRED YEARS,
DEPENDING UPON THE ECOLOGICAL
PROCESSES THAT TAKE PLACE HERE.
IF THAT CARBON ATOM ENTERS
INTO THE SOIL,
IT'S LIKELY TO STAY
IN THE SOIL
FOR A PERIOD
OF THOUSANDS OF YEARS.
THE MAJOR MECHANISM BY WHICH
CARBON EXITS SOILS
AND LEAVES THE ECOSYSTEM
IS THROUGH THE PROCESS
OF DECOMPOSITION,
JUST LIKE THESE FRESH LEAVES
ON THE GROUND HERE
BEING CONSUMED BY
SOIL MICROORGANISMS
AND RETURN TO THE ATMOSPHERE
AS CO2,
OR LOST FROM THE SOIL ECOSYSTEM
AS A RESULT OF WATER
MOVING THROUGH THE SOIL
AND DELIVERING THAT CARBON ATOM
INTO STREAMS AND LAKES.
THERE ARE LARGE VARIATIONS
IN THE AMOUNT OF CARBON
THAT ENTER AND EXIT
AN ECOSYSTEM
WITHIN THE COURSE
OF A DAY.
PHOTOSYNTHESIS ONLY OCCURS
DURING DAYLIGHT HOURS,
WHEREAS RESPIRATION OCCURS
ALL DAY LONG.
WE CAN ESTIMATE THE AMOUNT OF CARBON
THAT'S BEING ACCUMULATED
OR BEING LOST FROM AN ECOSYSTEM
ON A DAILY BASIS,
OR ON AN ANNUAL BASIS,
BY MEASURING THE TOTAL AMOUNT
OF CARBON
THAT ENTERS
INTO THE ECOSYSTEM
THROUGH THE PROCESS
OF PHOTOSYNTHESIS
AND THE TOTAL AMOUNT OF CARBON
THAT LEAVES THE ECOSYSTEM
THROUGH THE PROCESS
OF RESPIRATION.
DURING OUR MEASUREMENT PERIODS,
IF THE RATE OF PHOTOSYNTHESIS
IS GREATER
THAN THE RATE OF RESPIRATION,
THE ECOSYSTEM IS
ACCUMULATING CARBON.
ON THE OTHER HAND,
IF, DURING
OUR MEASUREMENT PERIODS,
RESPIRATION RATES ARE GREATER THAN THE
RATE OF PHOTOSYNTHESIS,
THEN THE ECOSYSTEM
HAS LOST CARBON.
THE METHOD SCIENTISTS USE
TO TEST FOR THE PRESENCE
OF CYCLING ELEMENTS
ARE CONDUCTED WITH
SOPHISTICATED EQUIPMENT
THAT YIELDS VERY PRECISE
MEASUREMENTS.
THIS SOIL SAMPLE KIT
IS LESS PRECISE,
BUT IT DOES HELP TO ILLUSTRATE
HOW WE KNOW
THAT A CERTAIN ELEMENT
IS PRESENT OR NOT.
WE PUT A SAMPLE OF SOIL
IN TWO CONTAINERS
TO SEE WHICH ELEMENTS
WE COULD DETECT.
WE FOUND NITROGEN
AND PHOSPHOROUS IN OUR SAMPLE.
NOW LET'S RETURN
TO DR. SHEATS
TO EXPLORE THE PATH
NITROGEN TAKES
THROUGH ECOSYSTEMS.
Sheats: LET'S TALK ABOUT
HOW NITROGEN CAN BE CYCLED.
THERE'S A LOT
OF NITROGEN IN THE AIR.
THE PROBLEM WITH RESPECT

TO LIVING ORGANISMS
IS THAT THE NITROGEN
IN THE AIR,
IT'S NOT IN A FORM
THAT WE CAN USE.
BUT TO THE RESCUE COME
OUR NITROGEN-FIXING
BACTERIA.
THEY FIX NITROGEN.
THEY CAN PASS
THE NITROGEN TO A PLANT,
AND THE PLANT WILL THEN
TAKE NITROGEN
AND INCORPORATE IT INTO
ITS BODY TISSUES.
EVENTUALLY, LIKE ALL OTHER
LIVING ORGANISMS,
THE PLANT DIES.
ONCE THE PLANT DIES,
WE GO BACK TO BACTERIA.
BACTERIA TAKE THE PLANT TISSUES AND
BREAK THEM DOWN.
SOME OTHER BACTERIA
CAN COME ALONG
AND USE THIS NITROGEN THAT'S
NOW IN A DIFFERENT FORM
AND CONVERT IT BACK
TO A GAS.
SO NOW THE NITROGEN IS
BACK INTO THE ATMOSPHERE.
AND THEN THE CYCLE
CAN BE REPEATED AGAIN.
AND AGAIN.
AND AGAIN.
WE ASKED,
WHERE DOES THE MATTER GO?
AND WE CAN NOW SEE
THAT CARBON AND NITROGEN,
OUR REPRESENTATIVE EXAMPLES,
CYCLE FROM THE NONLIVING
TO THE LIVING WORLD, AND BACK.
THE PATHS AND RATES
MAY VARY,
BUT ALL MATERIALS CYCLE
THROUGH ECOSYSTEMS
OVER AND OVER AGAIN.
PLEASE VISIT OUR WEBSITE
TO LEARN
ABOUT OTHER MATERIAL
CYCLES.
IT'S TIME TO CATCH UP
WITH BOTTLE BIOLOGY TO SEE
HOW PAUL WILLIAMS' INVENTIVE ECOSYSTEMS
ARE PROGRESSING.
HI, FOLKS, IT'S BEEN QUITE
A JOURNEY WITH BOTTLE BIOLOGY.
IT'S HARD TO BELIEVE THAT THIS IS OUR LAST
SESSION TOGETHER.
THE GOOD NEWS IS THAT YOU CAN KEEP YOUR
BOTTLE SYSTEM GOING
AND MAYBE EVEN TRY
ANOTHER ONE.
EACH SYSTEM IS DESIGNED
TO BRING
OUR ESSENTIAL SCIENCE TOPICS
TO LIFE.
YOU CAN USE THE TERRAQUA
COLUMN
TO HELP YOUR STUDENTS ANSWER
THE QUESTION, "WHAT IS LIFE?"
IT ALSO PROVIDES LIVING EXAMPLES FOR
CLASSIFICATION
OF PLANTS, ANIMALS, FUNGI,
PROTEASE, AND EVEN TINY
LIFE FORMS LIKE BACTERIA.
THE BRASSICA AND BUTTERFLY
SYSTEM
COMBINES TWO LIFE CYCLES
THAT ARE INTERTWINED,
AN ANIMAL AND A PLANT
WORKING TOGETHER TO REPRODUCE.
THE FUNDAMENTALS
OF EVOLUTION --
VARIATION, ADAPTATION,
AND NATURAL SELECTION --
CAN BE INTRODUCED IN
AN ELEGANT EXPERIMENT
USING THE FIELD POPULATION.
THE ECOCOLUMN PROVIDES
MANY EXAMPLES
OF HOW ENERGY FLOWS
AND MATERIALS CYCLE
THROUGH AN ECOSYSTEM.
THROUGH BOTTLE BIOLOGY,
I HOPE YOU AND YOUR STUDENTS
WILL BE CONVINCED
OF THE INTERDEPENDENCE
BETWEEN LIVING THINGS
AND THEIR ENVIRONMENT.
REMEMBER, MATERIALS ARE
EASY TO FIND
AND THE POSSIBILITIES
ARE LIMITLESS.
THIS IS PAUL WILLIAMS
SIGNING OFF FOR BOTTLE BIOLOGY.
THANKS, PAUL.
ECOSYSTEMS NATURALLY GROW
AND CHANGE WITH TIME.
BOTTLE BIOLOGY IS ONE WAY
TO SEE THIS IN ACTION.
ECOSYSTEMS ARE IN DYNAMIC BALANCE
WHEN THE FLOW
OF MATERIALS IS STEADY.
BECAUSE THE PARTS OF ECOSYSTEMS
ARE SO INTERCONNECTED,
CHANGES TO THE WAY
MATERIALS CYCLE
CAN HAVE CASCADING CONSEQUENCES
TO THE ENVIRONMENT.
IN THE LAST PART
OF TODAY'S SESSION,
WE'LL BRIEFLY CONSIDER
THE EFFECTS OF CYCLES
THAT ARE *OUT* OF BALANCE.
WHEN APPLIED
IN LARGE QUANTITIES,
MANMADE FERTILIZERS PROVIDE
MORE AVAILABLE NITROGEN
THAN THE CROPS CAN USE.
WHAT HAPPENS
TO THE EXCESS NITROGEN?
DR. NICKY SHEATS EXPLAINS
HOW NITROGEN FERTILIZER
CAN IMPACT
AN AQUATIC ECOSYSTEM.
Sheats: WE HAVE A PROBLEM
IN THIS COUNTRY
AND OTHER PLACES
IN THE WORLD
WHERE RIVERS, ESTUARIES
NEAR HUMAN POPULATIONS,
SOMETIMES THEY HAVE TOO MUCH
NITROGEN IN THEM.
AND PART OF THIS IS DUE
TO FERTILIZER
THAT'S RUN OFF FROM
ADJACENT FIELDS.
SO, THE PROBLEM WITH
TOO MUCH NITROGEN
IS THAT IT CAN CAUSE
MORE LIFE IN ESTUARY,
IN PARTICULAR, MORE LIFE

IN THE FORM OF THE PLANTS
THAT ARE IN THE WATER,
BACTERIA IN THE WATER,
AND THAT LIFE,
LIKE OTHER LIFE, USES OXYGEN.
THEY'LL USE UP
THE OXYGEN IN THE WATER.
AND THAT'S NOT GOOD
FOR THE ANIMALS IN THE WATER.
SO THEN IF YOU HAVE
FISH IN THE WATER,
THEY MAY NOT HAVE
ENOUGH OXYGEN.
SO, PRETTY SOON ALL YOU HAVE
IN THE RIVER
ARE PLANTS AND BACTERIA.
Narrator: DISRUPTIONS
IN THE CARBON CYCLE
CAN BE EQUALLY HARMFUL
TO ECOSYSTEMS.
DR. FINZI STUDIES THE EFFECTS
OF EXCESS CARBON
IN FOREST ECOSYSTEMS.
THERE ARE THREE PROCESSES
BY WHICH HUMAN ACTIVITY
MODIFIES THE AMOUNT OF CARBON IN
TERRESTRIAL ECOSYSTEMS.
THAT INCLUDES THE HARVEST
OF FOREST TREES,
AGRICULTURE,
AND THE COMBUSTION
OF FOSSIL FUELS.
THE COMBUSTION OF FOSSIL FUELS
REPRESENTS
A TRANSFER OF CARBON
THAT HAS BEEN STORED
FOR TENS TO HUNDREDS
OF MILLIONS OF YEARS
IN GEOLOGICAL DEPOSITS
AND DELIVERS IT
TO THE EARTH'S ATMOSPHERE.
THE RECENT RISE
IN THE CONCENTRATION
OF CARBON DIOXIDE
IN THE EARTH'S ATMOSPHERE
IS NOW KNOWN TO HAVE CAUSED
AN INCREASE
IN THE EARTH'S SURFACE
TEMPERATURE.
NATURAL ECOSYSTEMS,
LIKE FORESTLANDS
AND GRASSLANDS,
HAVE AN ABILITY TO ASSIMILATE
CARBON DIOXIDE
FROM THE ATMOSPHERE
THROUGH THE PROCESS
OF PHOTOSYNTHESIS.
AND RECENT STUDIES SHOW
THAT THE RISE IN ATMOSPHERIC CARBON
DIOXIDE CONCENTRATIONS
THAT'S ASSOCIATED WITH
THE COMBUSTION OF FOSSIL FUELS
HAS INCREASED THE AMOUNT
OF CARBON BEING STORED
IN TERRESTRIAL ECOSYSTEMS.
SOME HAVE ARGUED THAT
THE STIMULATION IN PLANT GROWTH
AS A RESULT OF HIGH
CARBON DIOXIDE CONCENTRATIONS
WILL SOLVE GLOBAL WARMING.
THAT IS, NATURAL ECOSYSTEMS
WILL ABSORB EXCESS CO2
THAT'S DELIVERED INTO
THE EARTH'S ATMOSPHERE
AS A RESULT
OF FOSSIL FUEL COMBUSTION.
HOWEVER, THE PROJECTED
AMOUNT OF CARBON
IN THE EARTH'S ATMOSPHERE
ASSOCIATED WITH
FOSSIL FUEL COMBUSTION
OVER THE NEXT 100 YEARS
FAR EXCEEDS THE CAPACITY
OF NATURAL ECOSYSTEMS
TO ABSORB CARBON DIOXIDE.
LIFE IN TERRESTRIAL
AND AQUATIC ECOSYSTEMS
ARE LINKED BY MATTER.
A CLOSE LOOK
AT MATERIAL CYCLES
REMINDS US
HOW INTERDEPENDENT
THE LIVING AND
NONLIVING WORLDS ARE.
Grisham: THERE IS A FINITE AMOUNT OF MATTER
ON EARTH.
THIS MATTER FORMS
THE BUILDING BLOCKS OF LIFE
AND IS FOUND IN SOIL, ROCKS,
AND AIR.
THE MATTER IMPORTANT TO ALL LIFE
IS REPRESENTED IN
THE SPONCH CaFe MNEMONIC.
Zook: THE MATTER CYCLES
THROUGH FOOD CHAINS
AND RETURNS
TO THE NONLIVING WORLD
AND THEN CYCLES BACK INTO
NEW FOOD CHAINS.
THE HEALTH OF ECOSYSTEMS,
WHICH INCLUDES ALL OF US,
ULTIMATELY DEPENDS
ON THE CYCLING OF MATTER.
WELL, WE'VE COME
A LONG WAY TOGETHER.
LET'S LOOK BACK AT
SOME OF THE BIG IDEAS
THAT WE'VE EXPLORED
THROUGHOUT THE COURSE.
Narrator: IN SESSION ONE,
WE ASKED "WHAT IS LIFE?"
AND DISCOVERED THAT
FIVE CHARACTERISTICS
UNITE ALL LIVING
ORGANISMS.
LIFE IS BUILT FROM CELLS.
SINGLE OR MULTICELLED,
ALL ORGANISMS HAVE LIFE SPANS,
WHICH START
WITH A LIVE BEGINNING
AND END IN DEATH --
WITH GROWTH,
DEVELOPMENT,
AND REPRODUCTION
IN BETWEEN.
LIFE REQUIRES A CONSTANT SUPPLY OF
MATTER AND ENERGY
TO RESPOND TO CHANGING
ENVIRONMENTS,
BOTH INSIDE AND OUTSIDE
THE ORGANISM.
ALL OF THESE BIOLOGICAL RESPONSES
ARE ULTIMATELY CONTROLLED
BY THE HEREDITARY MATERIAL
DNA.
DESPITE THE UNIFYING
CHARACTERISTICS OF LIFE,
WE INHABIT A WORLD OF DIVERSITY,
WHERE WIDELY DIFFERENT LANDSCAPES
ARE INHABITED BY
AN ARRAY OF PLANTS, ANIMALS,
AND OTHER ORGANISMS.

IN OUR SECOND SESSION,
WE EXPLORED WAYS TO MAKE SENSE
OF DIVERSITY
BY LOOKING AT
CLASSIFICATION SYSTEMS
BASED ON CELL FEATURES.
CURRENTLY THREE DOMAINS ARE USED TO
CLASSIFY ALL LIFE FORMS,
WITH THOSE MOST FAMILIAR TO US GROUPED
INTO FOUR KINGDOMS.
SESSIONS THREE AND FOUR LOOKED
MORE CLOSELY
AT THE LIFE CYCLES
OF ANIMALS AND PLANTS.
WE LEARNED HOW SEXUAL REPRODUCTION
INVOLVES DNA
CONTRIBUTED BY TWO PARENTS,
EACH PASSING EXACTLY HALF
OF THEIR CHROMOSOMES
TO A FERTILIZED EGG.
OUR STUDY OF PLANTS SHOWS THAT THEY
REPRODUCE SEXUALLY, TOO,
WITH FLOWERS, FRUITS, AND SEEDS.
LIFE CYCLES
OF INDIVIDUAL ORGANISMS
BROUGHT US TO THE LEVEL
OF POPULATIONS.
IN SESSION FIVE, WE CONSIDERED THE
FUNDAMENTALS OF EVOLUTION --
WE OBSERVED THAT
ALL POPULATIONS --
PLANTS AND ANIMALS --
VARY TREMENDOUSLY
IN THEIR TRAITS
AS A RESULT OF
VARIATION IN GENES.
ADAPTATION
THROUGH NATURAL SELECTION
IS THE RESULT OF VARIATION
THAT PROVIDES SURVIVAL
AND REPRODUCTIVE ADVANTAGE
TO CERTAIN INDIVIDUALS
IN A POPULATION.
IN SESSION SIX,
WE STUDIED HOW NEW SPECIES
COME INTO BEING,
AS POPULATIONS ADAPT TO NEW
AND CHANGING ENVIRONMENTS.
THE TREE OF LIFE IS A MODEL
USED TO DESCRIBE
HOW MILLIONS OF SPECIES
EVOLVED ON EARTH
AND HOW THEY ARE RELATED
TO EACH OTHER
THROUGH COMMON ANCESTORS.
WE MOVED TO THE LEVEL
OF COMMUNITIES IN SESSION SEVEN,
WHERE PHOTOSYNTHESIS
AND CELL RESPIRATION
EMERGED AS THE TWO PROCESSES
THAT HARNESS ENERGY
THAT SUPPORTS ALMOST ALL
LIFE ON EARTH.
IN THIS, OUR FINAL SESSION,
WE LOOKED AT THE MATTER
THAT MAKES UP LIFE,
AND HOW INTERLINKED LIFE
AND MATTER ARE TO ECOSYSTEMS.
MATTER CYCLES FROM THE NONLIVING TO THE
LIVING WORLD, AND BACK,
AGAIN AND AGAIN.
WE REALLY HAVE COME
A LONG WAY.
AND WE HOPE THAT
THE CONTENT
YOU'VE EXPLORED
WITH US
WILL HELP YOU BECOME
MORE COMFORTABLE
AND CONFIDENT
IN BRINGING
THE EXCITEMENT
OF LIFE SCIENCE
TO YOUR STUDENTS.
THANK YOU FOR
PARTICIPATING
IN THIS COURSE.
Both: GOODBYE.
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