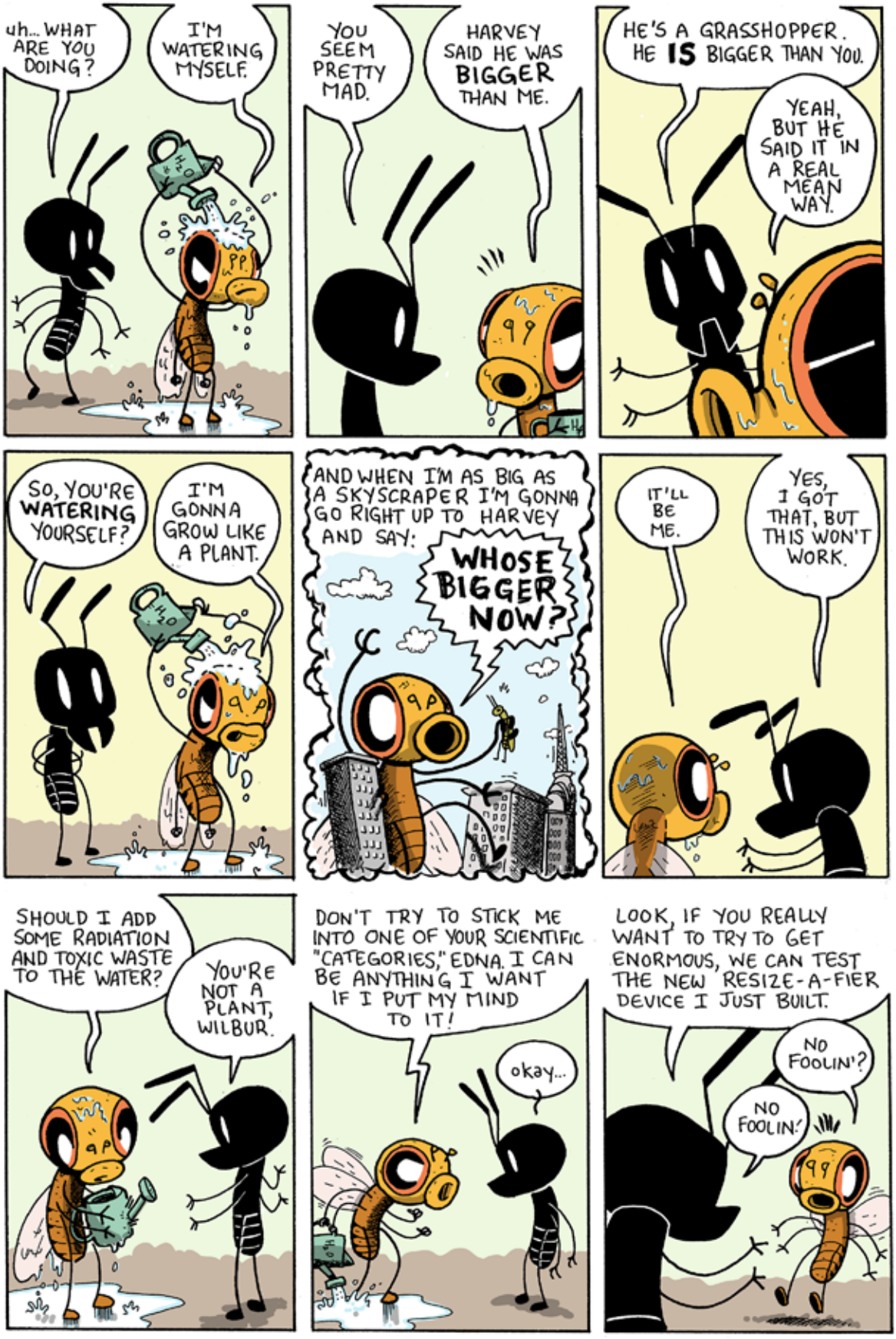
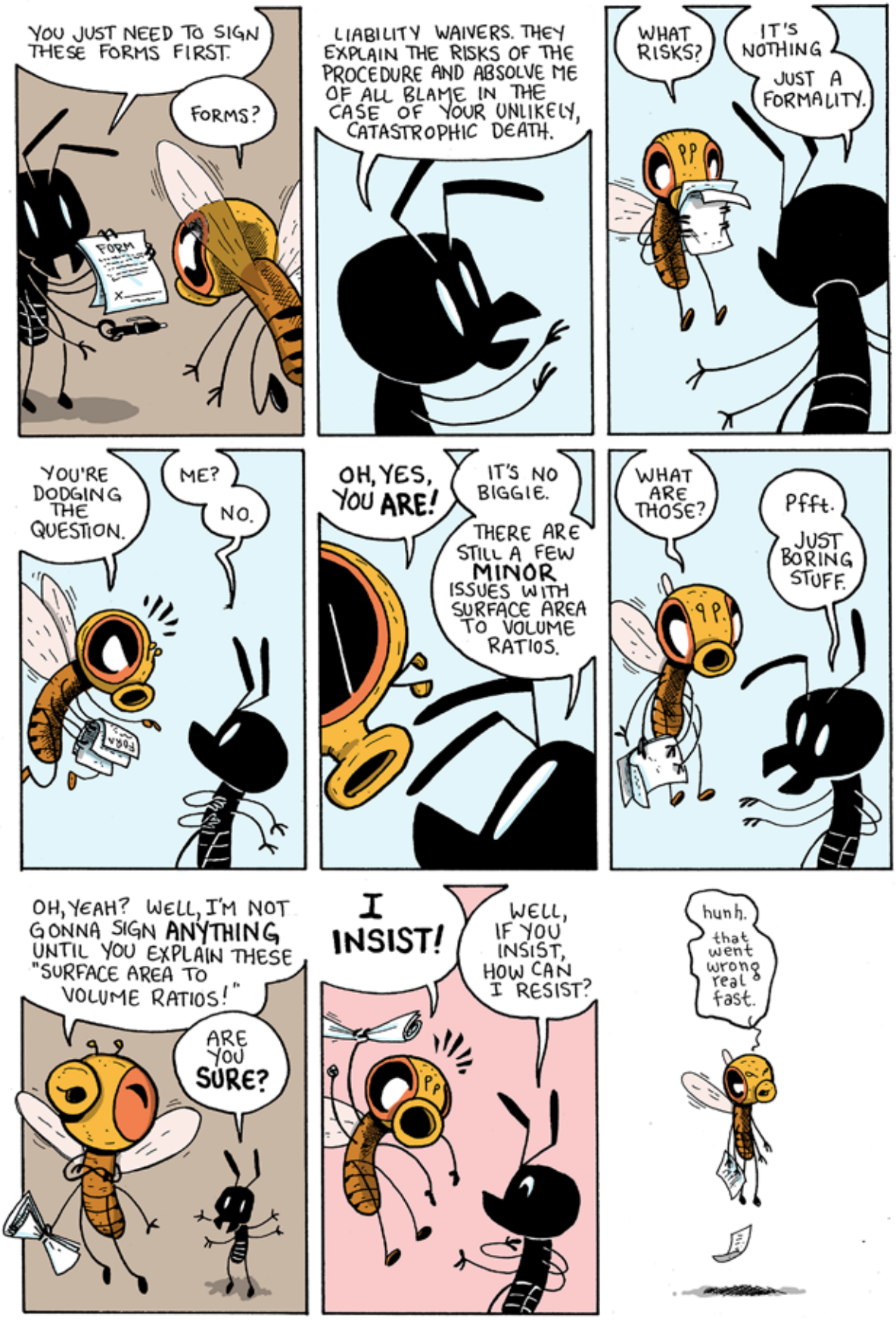
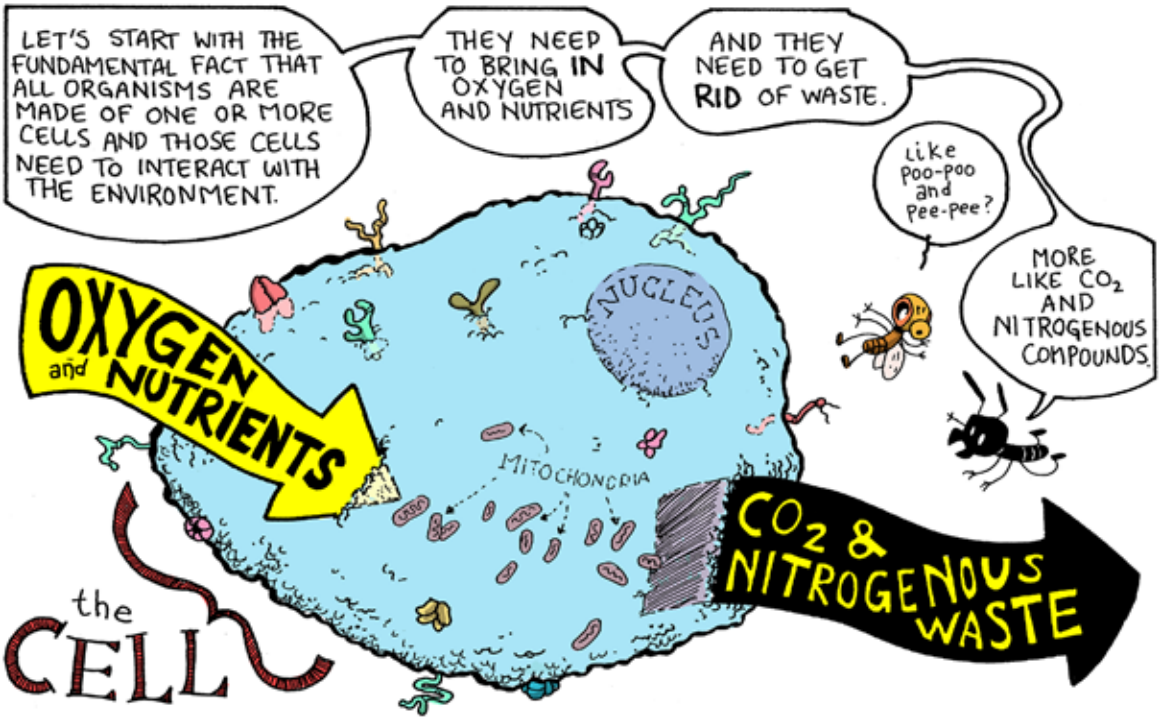
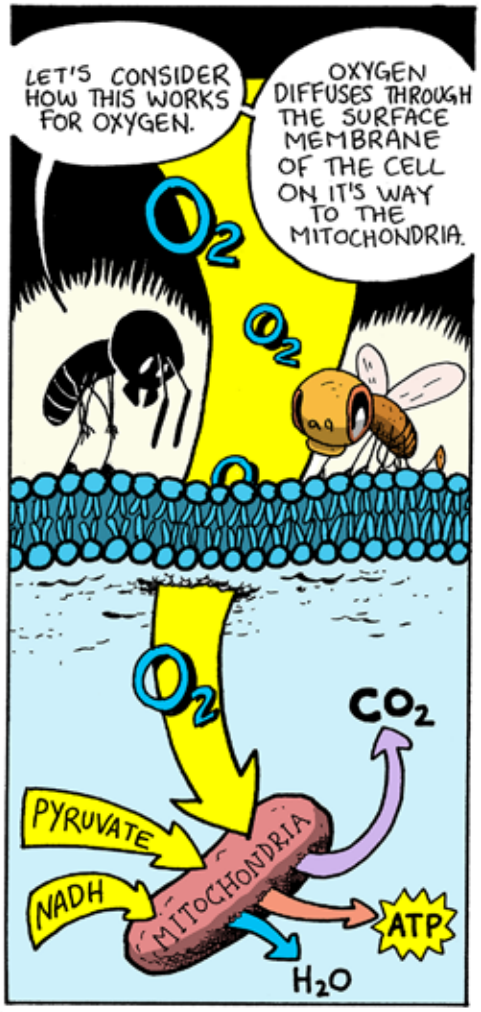
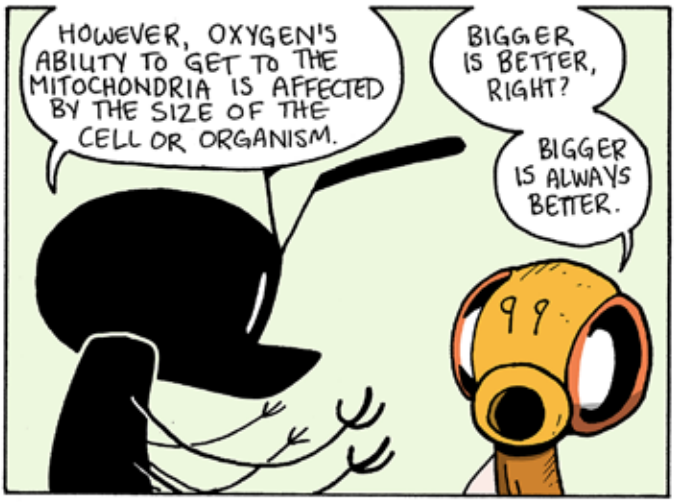
BIG IDEAS ABOUT SURFACE AREA AND VOLUME by Jay Hosler (c)




YOU JUST NEED TO SIGN THESE FORMS FIRST.
FORMS?
FORM
LIABILITY WAIVERS. THEY EXPLAIN THE RISKS OF THE PROCEDURE AND ABSOLVE ME OF ALL BLAME IN THE CASE OF YOUR UNLIKELY, CATASTROPHIC DEATH.
WHAT RISKS?
IT'S NOTHING JUST A FORMALITY.
YOU'RE DODGING THE QUESTION.
ME? NO.
OH, YES, YOU ARE!
IT'S NO BIGGIE.
THERE ARE STILL A FEW MINOR ISSUES WITH SURFACE AREA TO VOLUME RATIOS.
WHAT ARE THOSE?
Pfft. JUST BORING STUFF.
OH, YEAH? WELL, I'M NOT GONNA SIGN ANYTHING UNTIL YOU EXPLAIN THESE "SURFACE AREA TO VOLUME RATIOS!"
ARE YOU SURE?
I INSIST!
WELL, IF YOU INSIST, HOW CAN I RESIST?
hunh. that went wrong real fast.

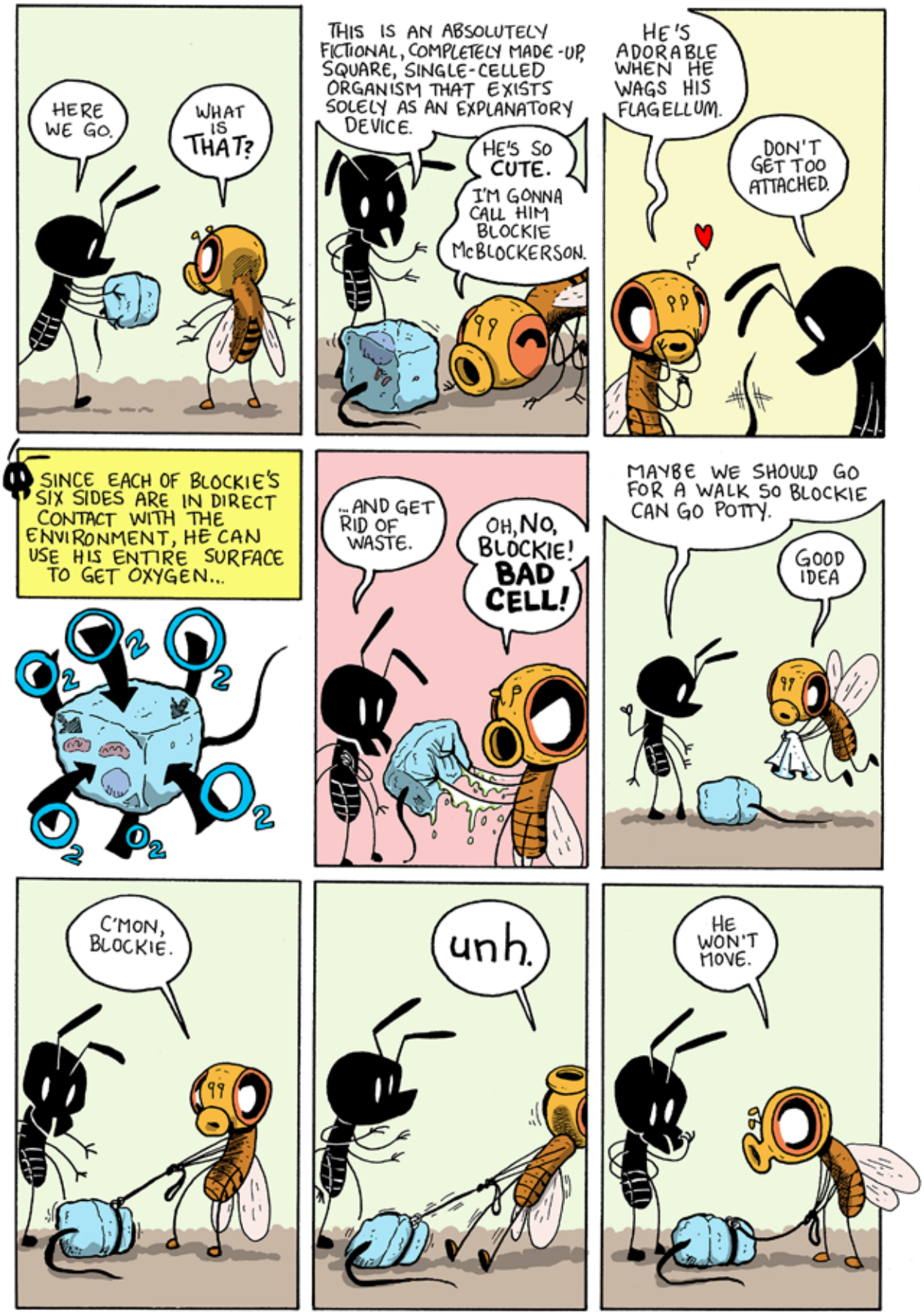

LET'S START WITH THE FUNDAMENTAL FACT THAT ALL ORGANISMS ARE MADE OF ONE OR MORE CELLS AND THOSE CELLS NEED TO INTERACT WITH THE ENVIRONMENT.
THEY NEED TO BRING IN OXYGEN AND NUTRIENTS
AND THEY NEED TO GET RID OF WASTE.
like Poo-poo and Pee-pee?
MORE LIKE CO_2 AND NITROGENOUS COMPOUNDS.
OXYGEN and NUTRIENTS
NUCLEUS
MITOCHONDRIA
CO_2 & NITROGENOUS WASTE
the CELL

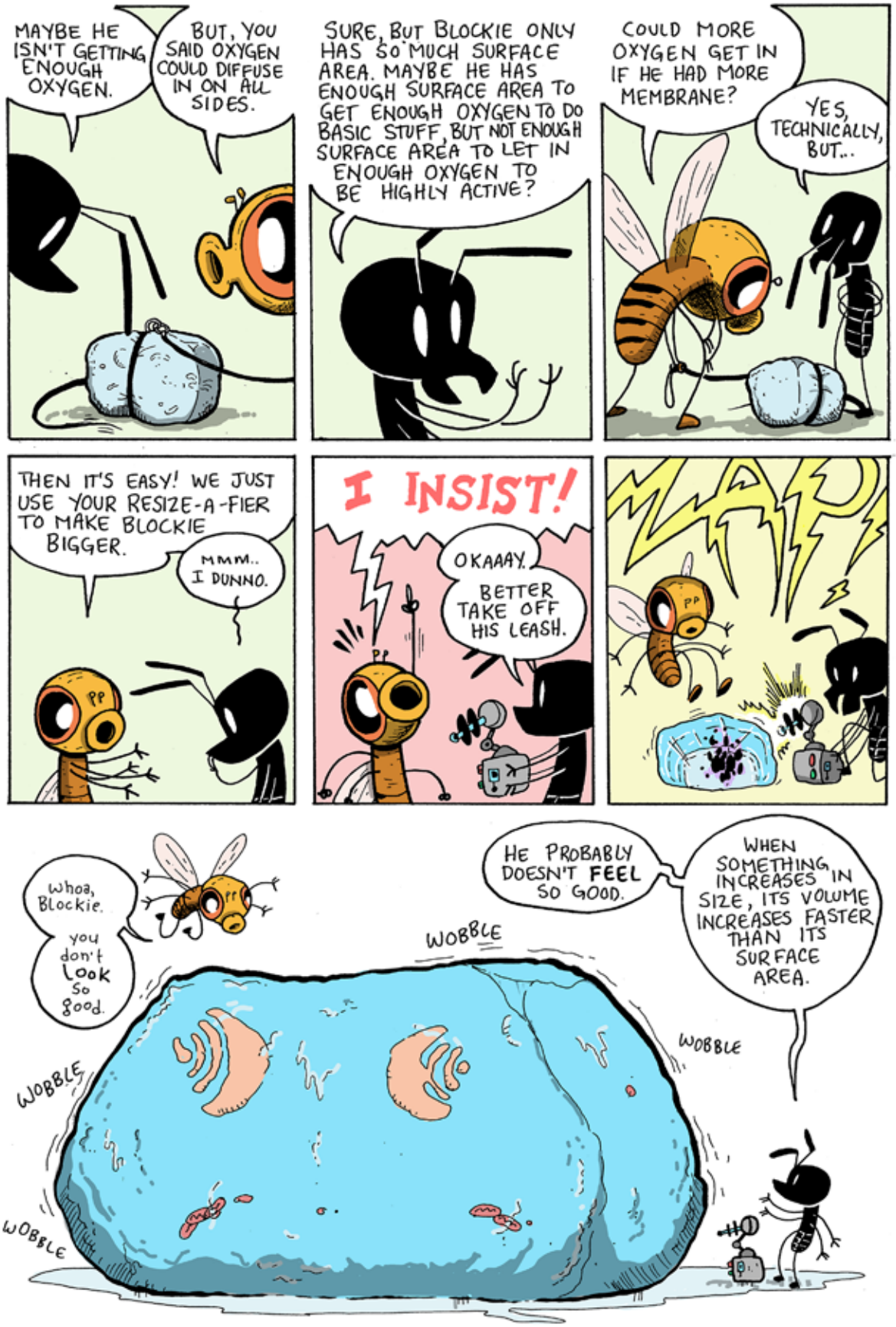

LET'S CONSIDER HOW THIS WORKS FOR OXYGEN.
OXYGEN DIFFUSES THROUGH THE SURFACE MEMBRANE OF THE CELL ON IT'S WAY TO THE MITOCHONDRIA.
O_2
O_2
O_2
CO_2
PYRUVATE
NADH
MITOCHONDRIA
ATP
H_2O


HOWEVER, OXYGEN'S ABILITY TO GET TO THE MITOCHONDRIA IS AFFECTED BY THE SIZE OF THE CELL OR ORGANISM.
BIGGER IS BETTER, RIGHT?
BIGGER IS ALWAYS BETTER.


uh, not exactly
how can i explain?
hmm. ...that might work...


BE RIGHT BACK!


HERE WE GO.
WHAT IS THAT?
THIS IS AN ABSOLUTELY FICTIONAL, COMPLETELY MADE-UP, SQUARE, SINGLE-CELLED ORGANISM THAT EXISTS SOLELY AS AN EXPLANATORY DEVICE.
HE'S SO CUTE.
I'M GONNA CALL HIM BLOCKIE McBLOCKERSON.
HE'S ADORABLE WHEN HE WAGS HIS FLAGELLUM.
DON'T GET TOO ATTACHED.
SINCE EACH OF BLOCKIE'S SIX SIDES ARE IN DIRECT CONTACT WITH THE ENVIRONMENT, HE CAN USE HIS ENTIRE SURFACE TO GET OXYGEN...
O2
...AND GET RID OF WASTE.
OH, NO, BLOCKIE! BAD CELL!
MAYBE WE SHOULD GO FOR A WALK SO BLOCKIE CAN GO POTTY.
GOOD IDEA
C'MON, BLOCKIE.
unh.
HE WON'T MOVE.


MAYBE HE ISN'T GETTING ENOUGH OXYGEN.
BUT, YOU SAID OXYGEN COULD DIFFUSE IN ON ALL SIDES.
SURE, BUT BLOCKIE ONLY HAS SO MUCH SURFACE AREA. MAYBE HE HAS ENOUGH SURFACE AREA TO GET ENOUGH OXYGEN TO DO BASIC STUFF, BUT NOT ENOUGH SURFACE AREA TO LET IN ENOUGH OXYGEN TO BE HIGHLY ACTIVE?
COULD MORE OXYGEN GET IN IF HE HAD MORE MEMBRANE?
YES, TECHNICALLY, BUT...
THEN IT'S EASY! WE JUST USE YOUR RESIZE-A-FIER TO MAKE BLOCKIE BIGGER.
MMM.. I DUNNO.
I INSIST!
OKAAAY.
BETTER TAKE OFF HIS LEASH.
ZAP!
Whoa, Blockie.
you don't look so good.
HE PROBABLY DOESN'T FEEL SO GOOD.
WHEN SOMETHING INCREASES IN SIZE, ITS VOLUME INCREASES FASTER THAN ITS SURFACE AREA.
WOBBLE
WOBBLE
WOBBLE
WOBBLE

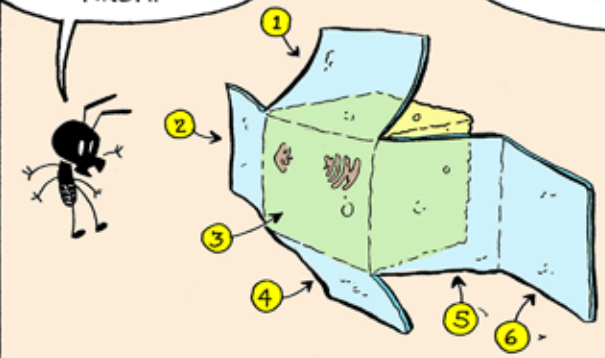
YOU'RE GONNA NEED TO EXPLAIN THAT.

IT WILL REQUIRE MATH AND GRAPHING

I CAN HANDLE IT.

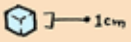
OKAY, FIRST, LET'S CONSIDER BLOCKIE'S SURFACE AREA.

AS A CUBE, HE HAS SIX SIDES AND EACH SIDE IS A SQUARE.



LET'S IMAGINE THAT THE LENGTH OF ONE SIDE IS **1cm**. THAT MEANS THE AREA OF **ONE SIDE** IS:

$1\,cm \times 1\,cm = 1\,cm^2$



TOTAL SURFACE AREA

TO GET BLOCKIE'S TOTAL SURFACE AREA, WE NEED TO MULTIPLY THE AREA OF ONE SIDE BY SIX:

$= 1\,cm^2 \times 6 =$

$6\,cm^2$

VOLUME

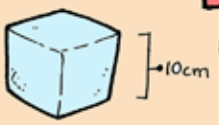
TO FIND BLOCKIE'S VOLUME, WE MULTIPLY HIS LENGTH BY WIDTH BY HEIGHT

$= 1cm \times 1cm \times 1cm =$

$1\,cm^3$

WHEN THE LENGTH OF A SIDE IS **10cm** WE GET:

$10\,cm \times 10\,cm = 100\,cm^2$



TOTAL SURFACE AREA

$= 100\,cm^2 \times 6 =$

$600\,cm^2$

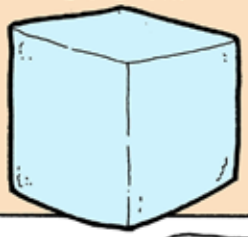
VOLUME

$= 10cm \times 10cm \times 10cm =$

$1000\,cm^3$

WHEN THE LENGTH IS **20cm**, THE AREA OF ONE SIDE IS:

$20\,cm \times 20\,cm = 400\,cm^2$



TOTAL SURFACE AREA

$= 400\,cm^2 \times 6 =$

$2400\,cm^2$

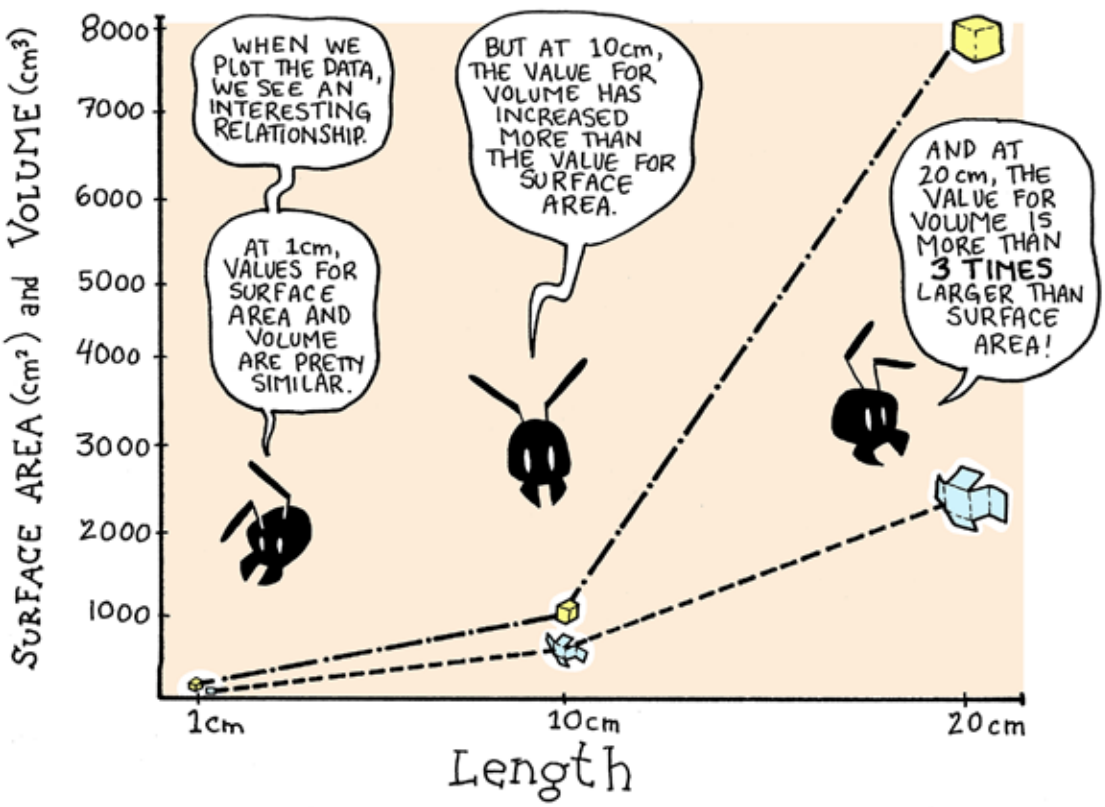
VOLUME

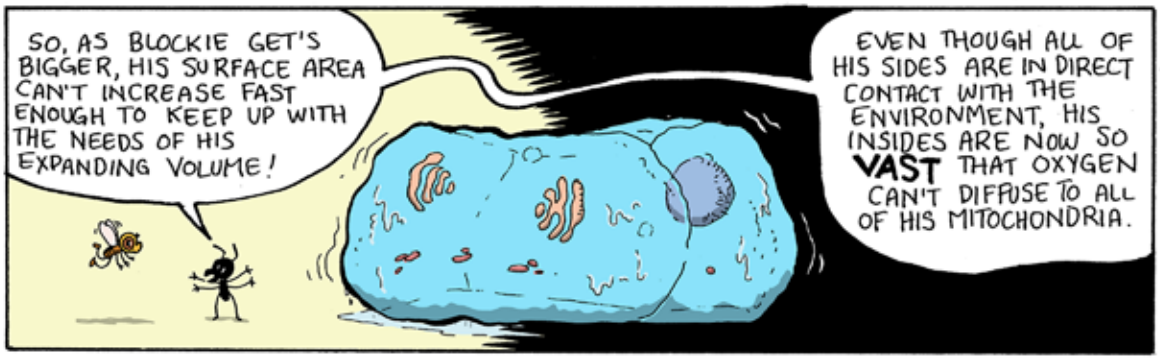
$= 20cm \times 20cm \times 20cm =$

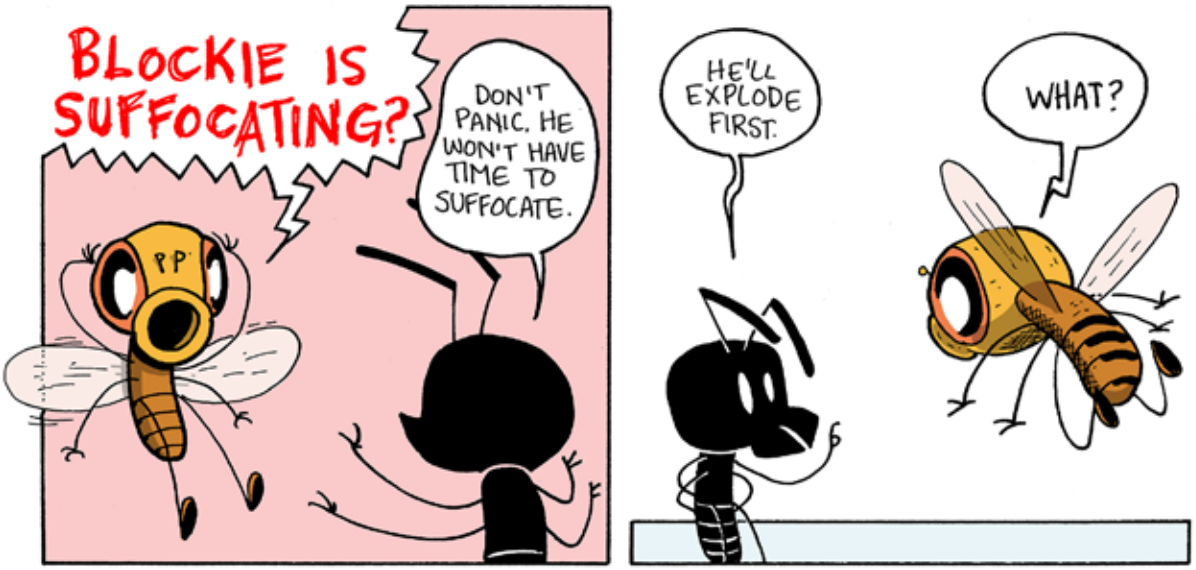
$8000\,cm^3$

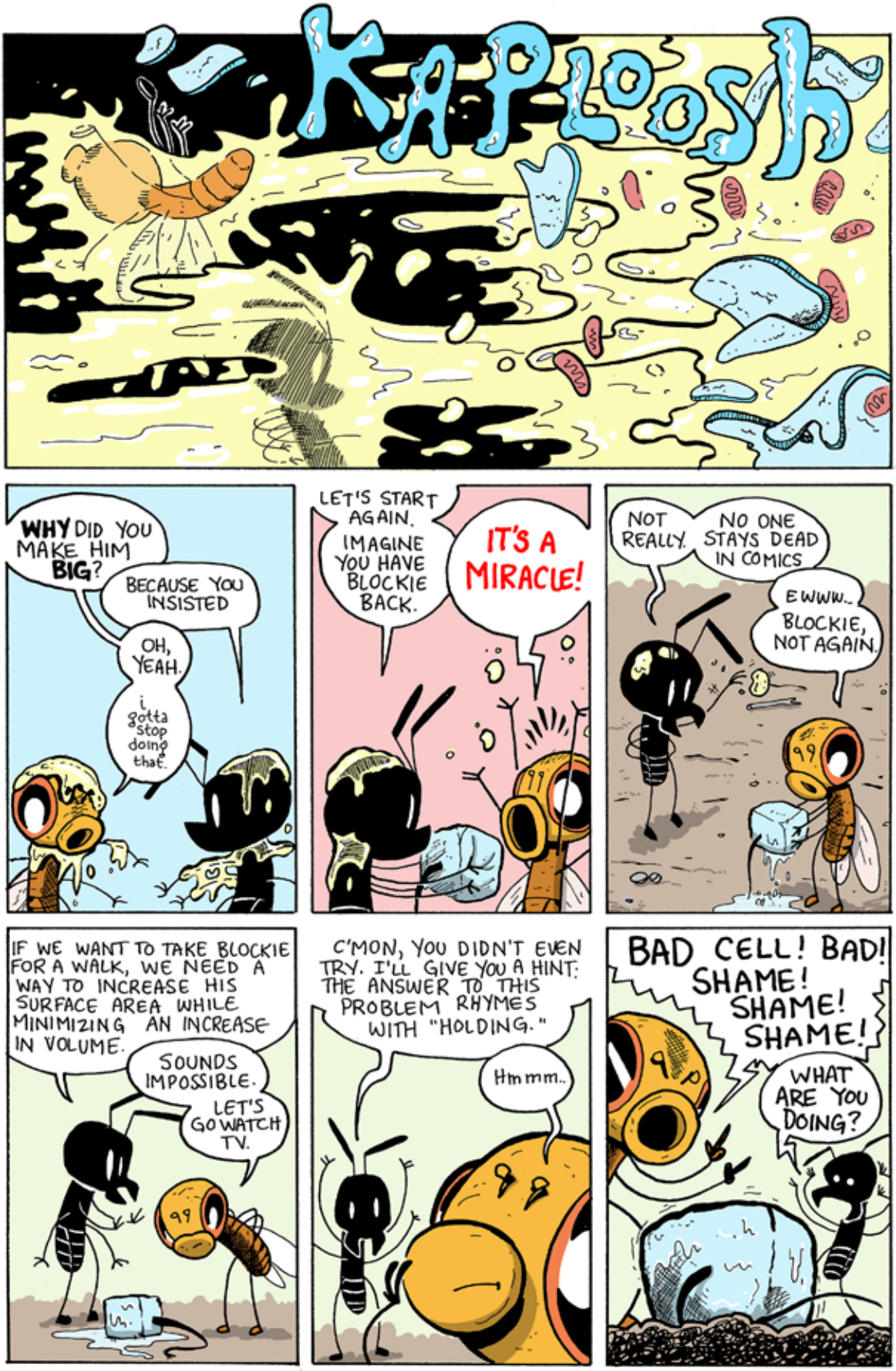
uh... **ALL** OF THE NUMBERS ARE INCREASING, EDNA.

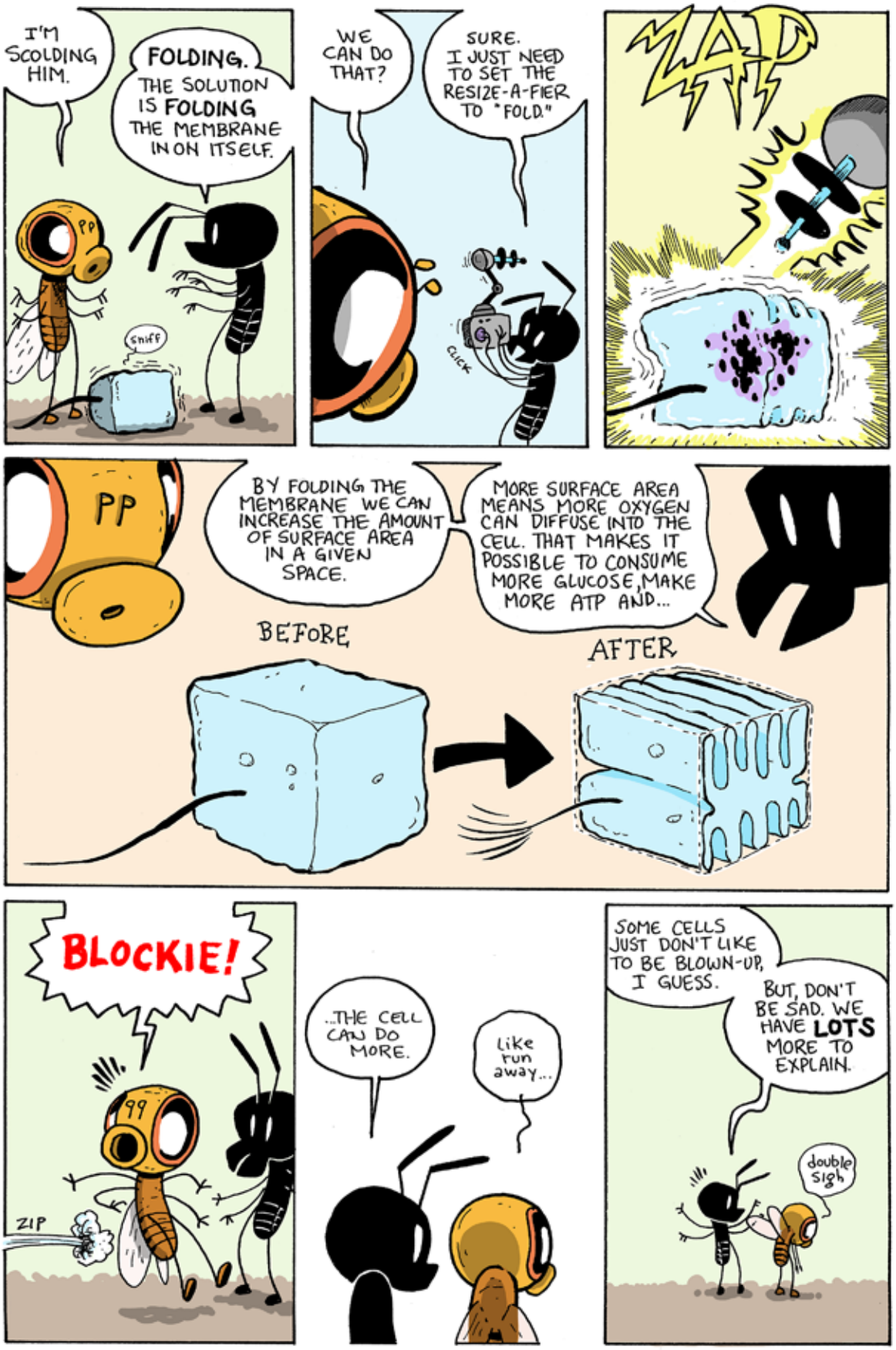
OF COURSE, **BUT** VOLUME IS GETTING BIGGER FASTER.

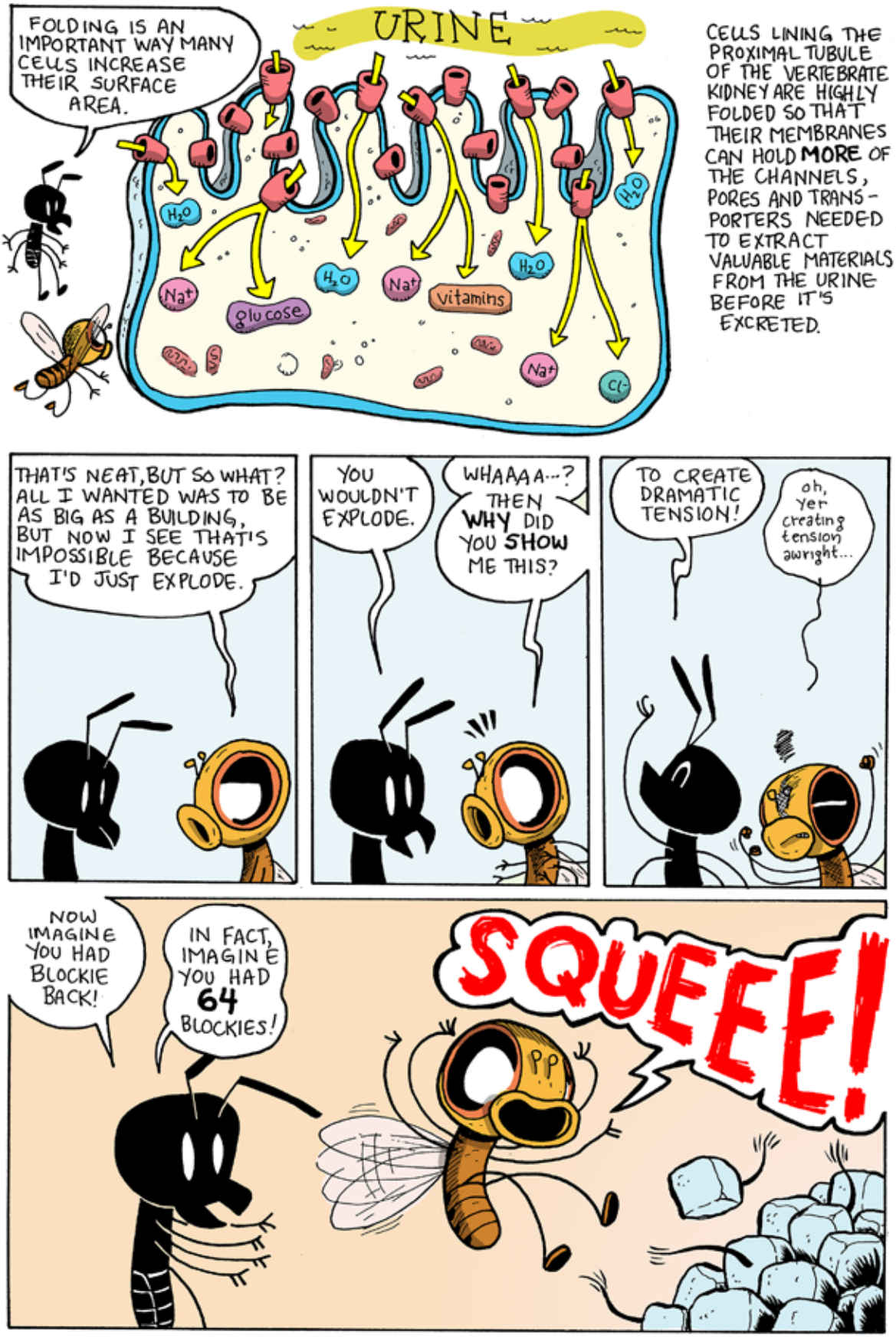

SURFACE AREA (cm²) and VOLUME (cm³)
8000
7000
6000
5000
4000
3000
2000
1000
1cm
10cm
20cm
Length
WHEN WE PLOT THE DATA, WE SEE AN INTERESTING RELATIONSHIP.
AT 1cm, VALUES FOR SURFACE AREA AND VOLUME ARE PRETTY SIMILAR.
BUT AT 10cm, THE VALUE FOR VOLUME HAS INCREASED MORE THAN THE VALUE FOR SURFACE AREA.
AND AT 20 cm, THE VALUE FOR VOLUME IS MORE THAN 3 TIMES LARGER THAN SURFACE AREA!

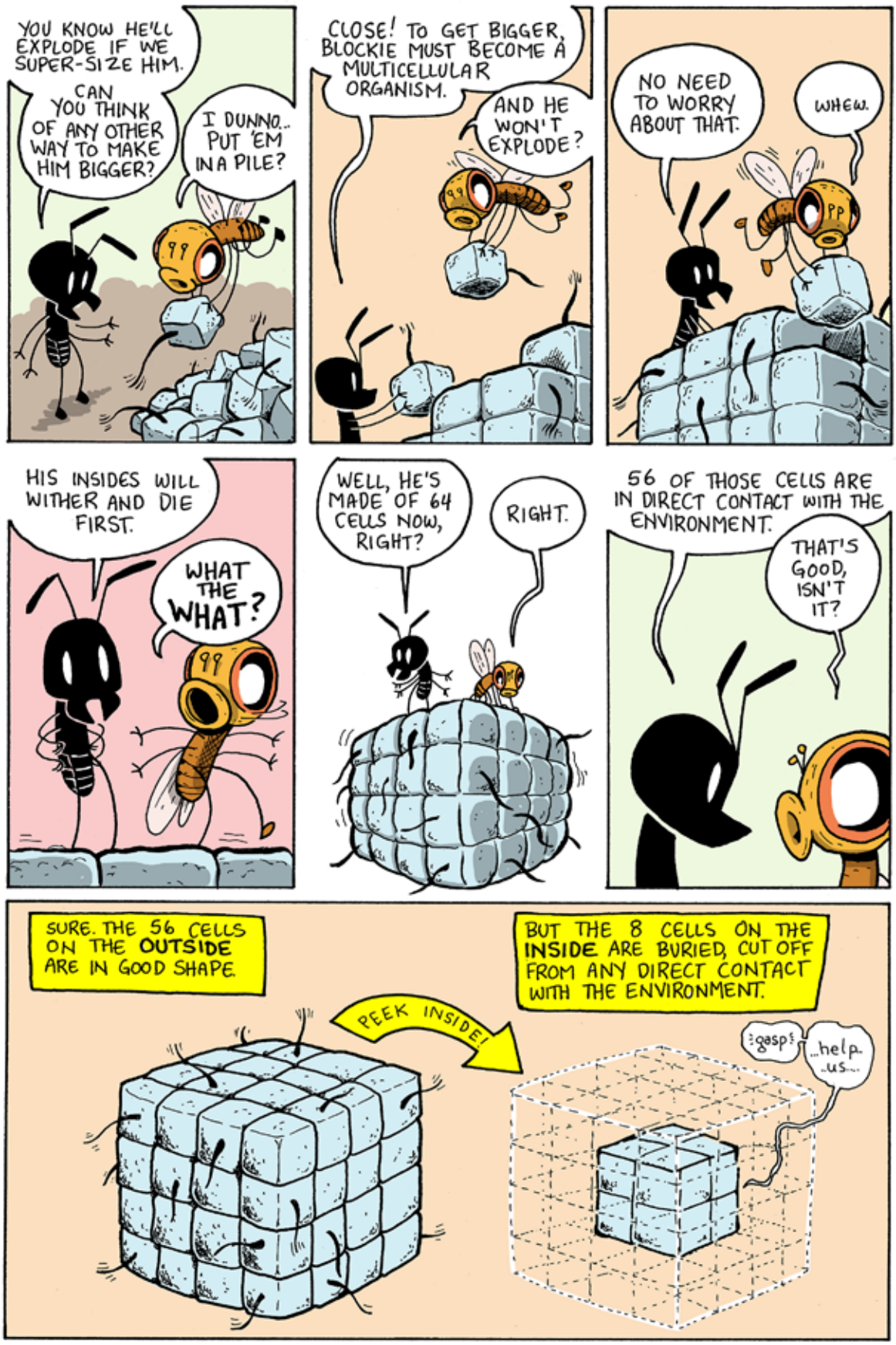

SO, AS BLOCKIE GET'S BIGGER, HIS SURFACE AREA CAN'T INCREASE FAST ENOUGH TO KEEP UP WITH THE NEEDS OF HIS EXPANDING VOLUME!
EVEN THOUGH ALL OF HIS SIDES ARE IN DIRECT CONTACT WITH THE ENVIRONMENT, HIS INSIDES ARE NOW SO VAST THAT OXYGEN CAN'T DIFFUSE TO ALL OF HIS MITOCHONDRIA.

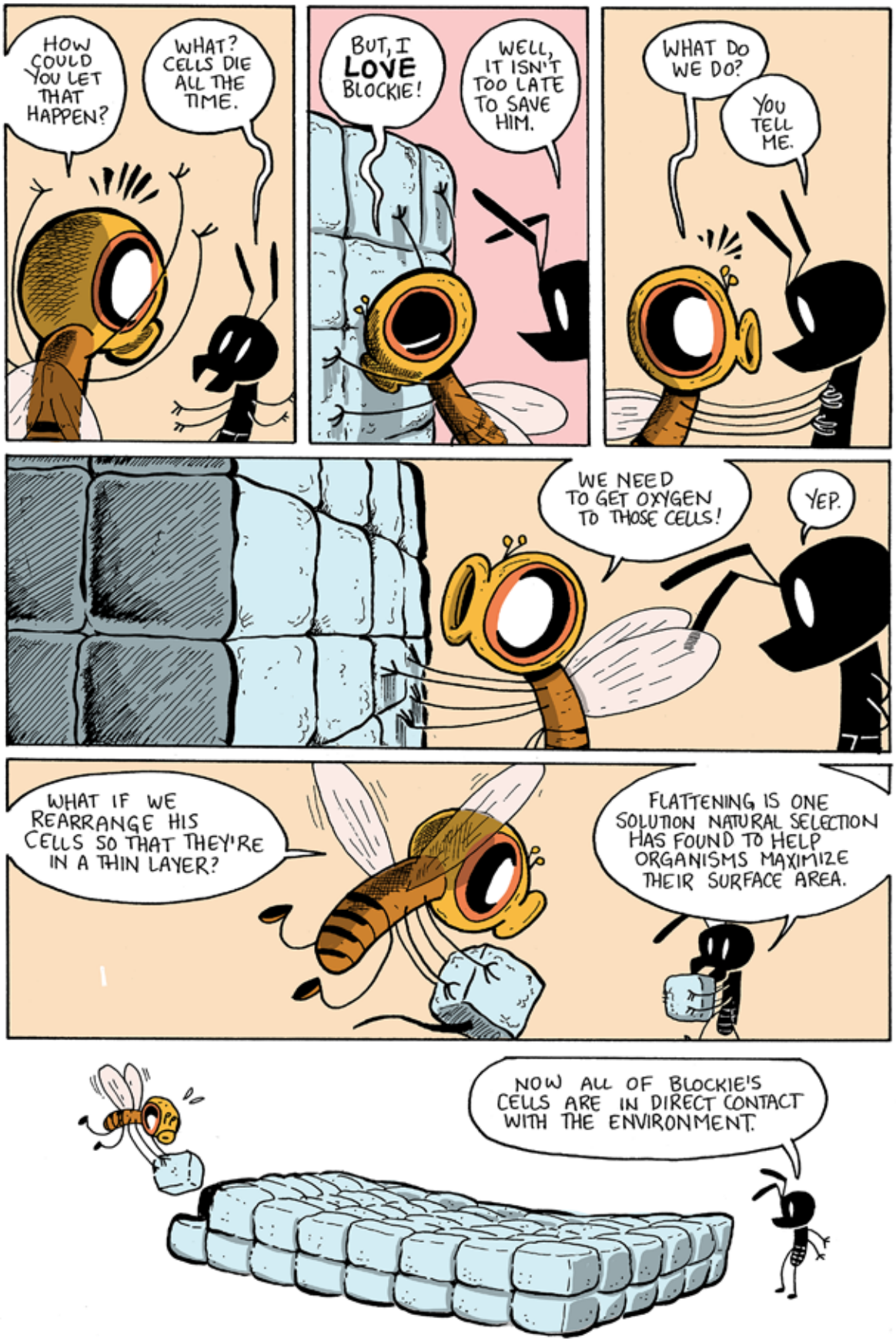

BLOCKIE IS SUFFOCATING?
DON'T PANIC. HE WON'T HAVE TIME TO SUFFOCATE.
HE'LL EXPLODE FIRST.
WHAT?

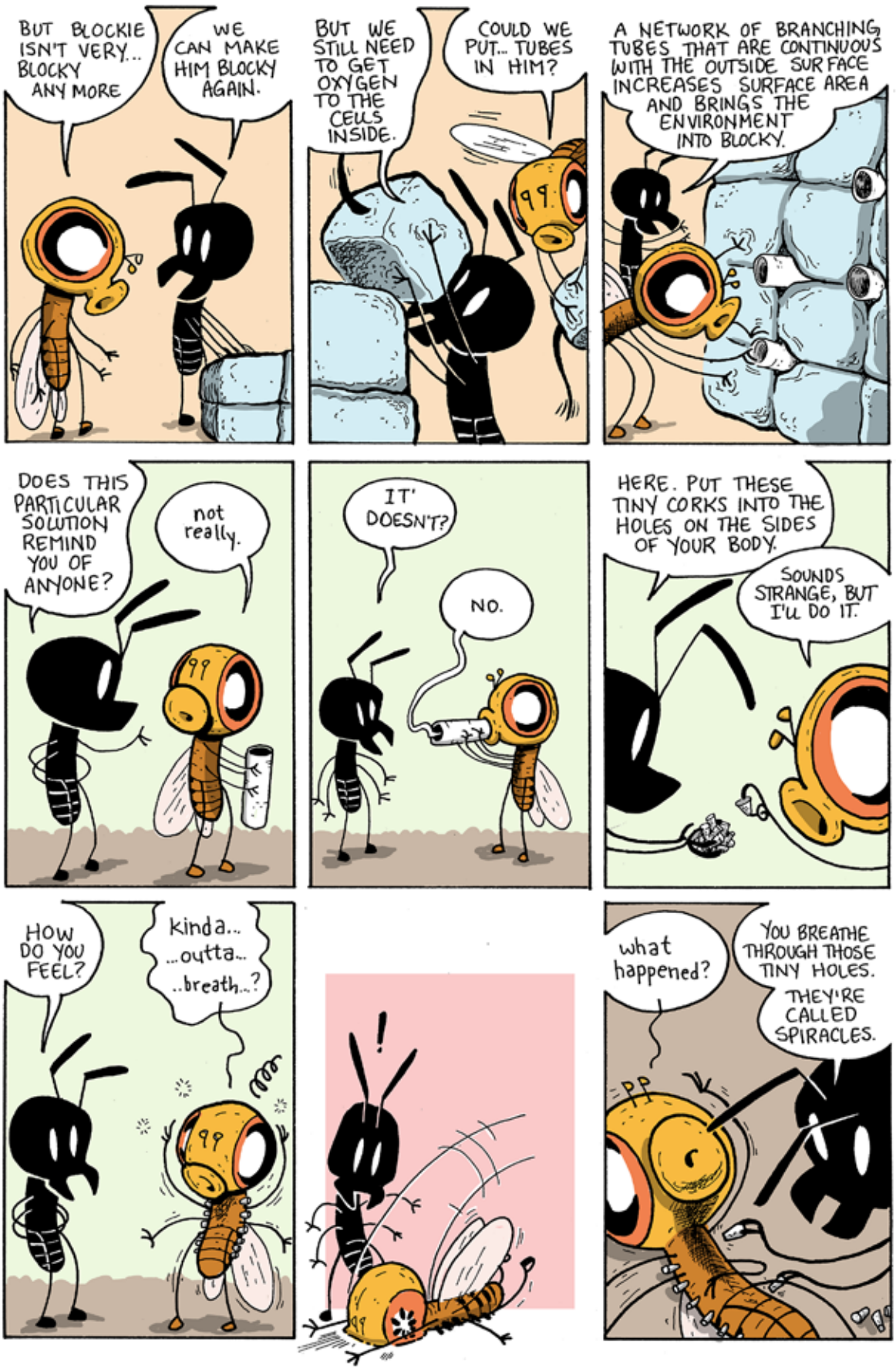

KAPLOOSH
WHY DID YOU MAKE HIM BIG?
BECAUSE YOU INSISTED
OH, YEAH.
i gotta stop doing that.
LET'S START AGAIN.
IMAGINE YOU HAVE BLOCKIE BACK.
IT'S A MIRACLE!
NOT REALLY.
NO ONE STAYS DEAD IN COMICS
EWWW.. BLOCKIE, NOT AGAIN.
IF WE WANT TO TAKE BLOCKIE FOR A WALK, WE NEED A WAY TO INCREASE HIS SURFACE AREA WHILE MINIMIZING AN INCREASE IN VOLUME.
SOUNDS IMPOSSIBLE.
LET'S GO WATCH TV.
C'MON, YOU DIDN'T EVEN TRY. I'LL GIVE YOU A HINT: THE ANSWER TO THIS PROBLEM RHYMES WITH "HOLDING."
Hmmm..
BAD CELL! BAD! SHAME! SHAME! SHAME!
WHAT ARE YOU DOING?

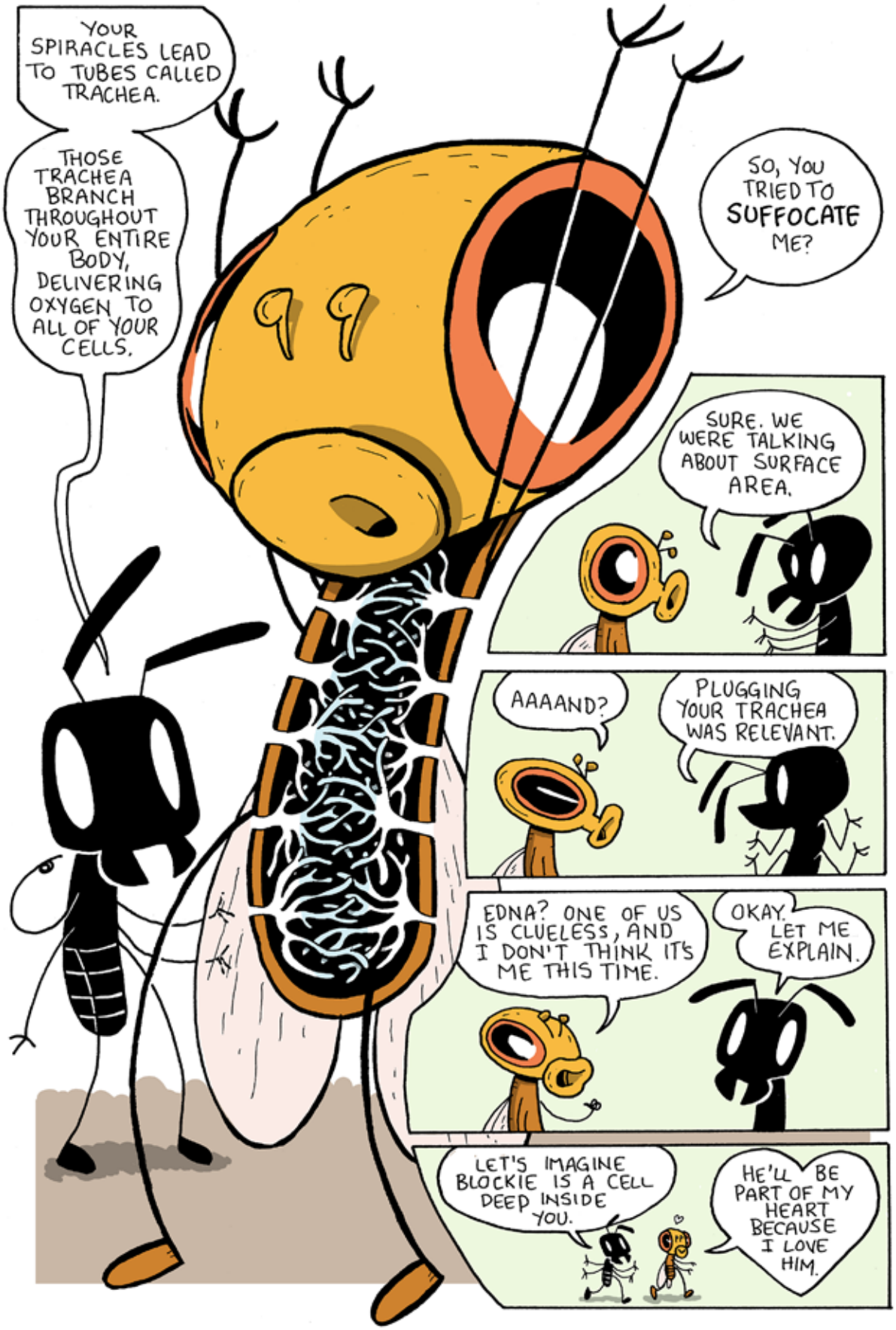

I'M SCOLDING HIM.
FOLDING. THE SOLUTION IS FOLDING THE MEMBRANE IN ON ITSELF.
PP
sniff
WE CAN DO THAT?
SURE. I JUST NEED TO SET THE RESIZE-A-FIER TO "FOLD."
CLICK
ZAP
PP
BY FOLDING THE MEMBRANE WE CAN INCREASE THE AMOUNT OF SURFACE AREA IN A GIVEN SPACE.
MORE SURFACE AREA MEANS MORE OXYGEN CAN DIFFUSE INTO THE CELL. THAT MAKES IT POSSIBLE TO CONSUME MORE GLUCOSE, MAKE MORE ATP AND...
BEFORE
AFTER
BLOCKIE!
99
ZIP
...THE CELL CAN DO MORE.
Like run away...
SOME CELLS JUST DON'T LIKE TO BE BLOWN-UP, I GUESS.
BUT, DON'T BE SAD. WE HAVE LOTS MORE TO EXPLAIN.
double sigh

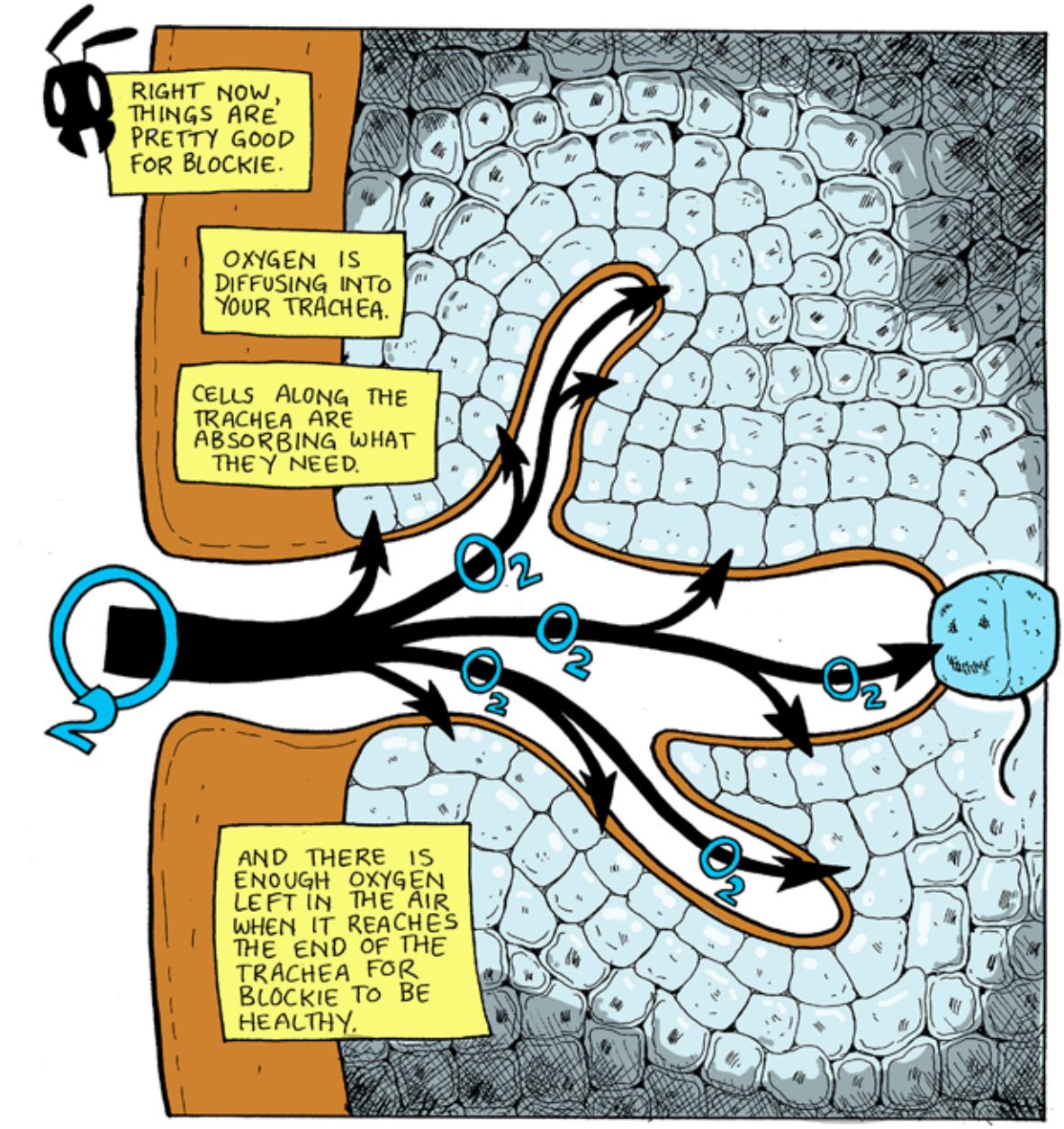

FOLDING IS AN IMPORTANT WAY MANY CELLS INCREASE THEIR SURFACE AREA.
URINE
H_2O
Na^+
glucose
vitamins
Cl^-
CELLS LINING THE PROXIMAL TUBULE OF THE VERTEBRATE KIDNEY ARE HIGHLY FOLDED SO THAT THEIR MEMBRANES CAN HOLD MORE OF THE CHANNELS, PORES AND TRANSPORTERS NEEDED TO EXTRACT VALUABLE MATERIALS FROM THE URINE BEFORE IT'S EXCRETED.
THAT'S NEAT, BUT SO WHAT? ALL I WANTED WAS TO BE AS BIG AS A BUILDING, BUT NOW I SEE THAT'S IMPOSSIBLE BECAUSE I'D JUST EXPLODE.
YOU WOULDN'T EXPLODE.
WHAAAA...? THEN WHY DID YOU SHOW ME THIS?
TO CREATE DRAMATIC TENSION!
oh, yer creating tension awright...
NOW IMAGINE YOU HAD BLOCKIE BACK!
IN FACT, IMAGINE YOU HAD 64 BLOCKIES!
SQUEEE!

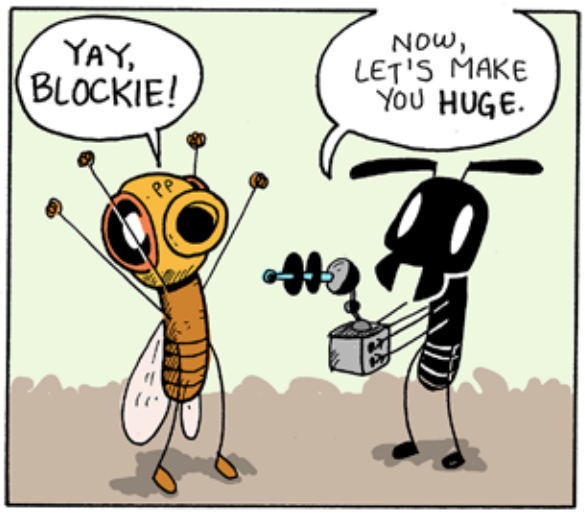

YOU KNOW HE'LL EXPLODE IF WE SUPER-SIZE HIM.
CAN YOU THINK OF ANY OTHER WAY TO MAKE HIM BIGGER?
I DUNNO... PUT 'EM IN A PILE?
CLOSE! TO GET BIGGER, BLOCKIE MUST BECOME A MULTICELLULAR ORGANISM.
AND HE WON'T EXPLODE?
NO NEED TO WORRY ABOUT THAT.
WHEW.
HIS INSIDES WILL WITHER AND DIE FIRST.
WHAT THE WHAT?
WELL, HE'S MADE OF 64 CELLS NOW, RIGHT?
RIGHT.
56 OF THOSE CELLS ARE IN DIRECT CONTACT WITH THE ENVIRONMENT.
THAT'S GOOD, ISN'T IT?
SURE. THE 56 CELLS ON THE OUTSIDE ARE IN GOOD SHAPE.
BUT THE 8 CELLS ON THE INSIDE ARE BURIED, CUT OFF FROM ANY DIRECT CONTACT WITH THE ENVIRONMENT.
PEEK INSIDE!
:gasp:
...help. ...us...

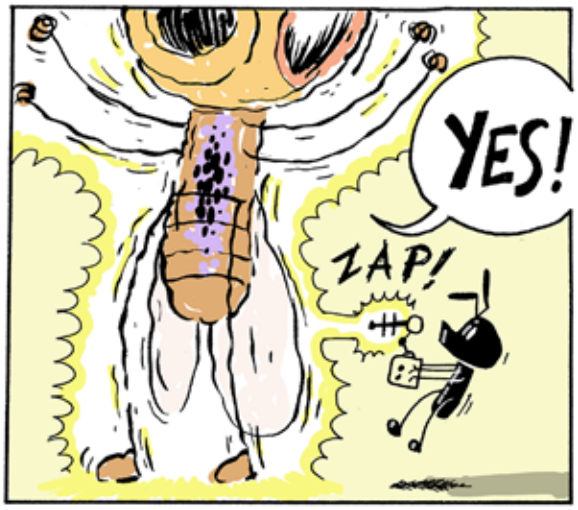

HOW COULD YOU LET THAT HAPPEN?
WHAT? CELLS DIE ALL THE TIME.
BUT, I LOVE BLOCKIE!
WELL, IT ISN'T TOO LATE TO SAVE HIM.
WHAT DO WE DO?
YOU TELL ME.
WE NEED TO GET OXYGEN TO THOSE CELLS!
YEP.
WHAT IF WE REARRANGE HIS CELLS SO THAT THEY'RE IN A THIN LAYER?
FLATTENING IS ONE SOLUTION NATURAL SELECTION HAS FOUND TO HELP ORGANISMS MAXIMIZE THEIR SURFACE AREA.
NOW ALL OF BLOCKIE'S CELLS ARE IN DIRECT CONTACT WITH THE ENVIRONMENT.

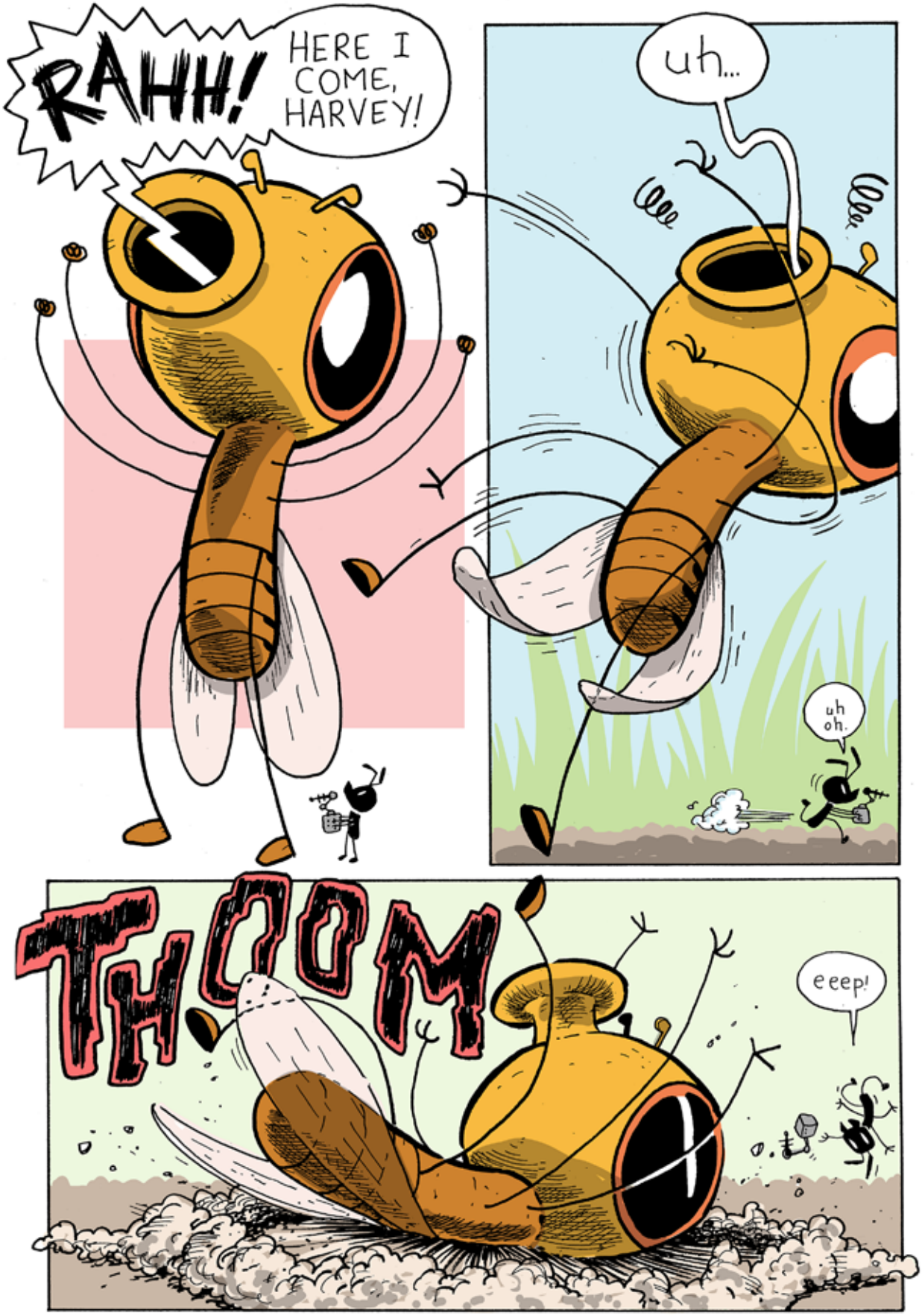

BUT BLOCKIE ISN'T VERY... BLOCKY ANY MORE
WE CAN MAKE HIM BLOCKY AGAIN.
BUT WE STILL NEED TO GET OXYGEN TO THE CELLS INSIDE.
COULD WE PUT... TUBES IN HIM?
A NETWORK OF BRANCHING TUBES THAT ARE CONTINUOUS WITH THE OUTSIDE SURFACE INCREASES SURFACE AREA AND BRINGS THE ENVIRONMENT INTO BLOCKY.
DOES THIS PARTICULAR SOLUTION REMIND YOU OF ANYONE?
not really.
IT' DOESN'T?
NO.
HERE. PUT THESE TINY CORKS INTO THE HOLES ON THE SIDES OF YOUR BODY.
SOUNDS STRANGE, BUT I'll DO IT.
HOW DO YOU FEEL?
kinda... ...outta... ..breath...?
!
what happened?
YOU BREATHE THROUGH THOSE TINY HOLES.
THEY'RE CALLED SPIRACLES.

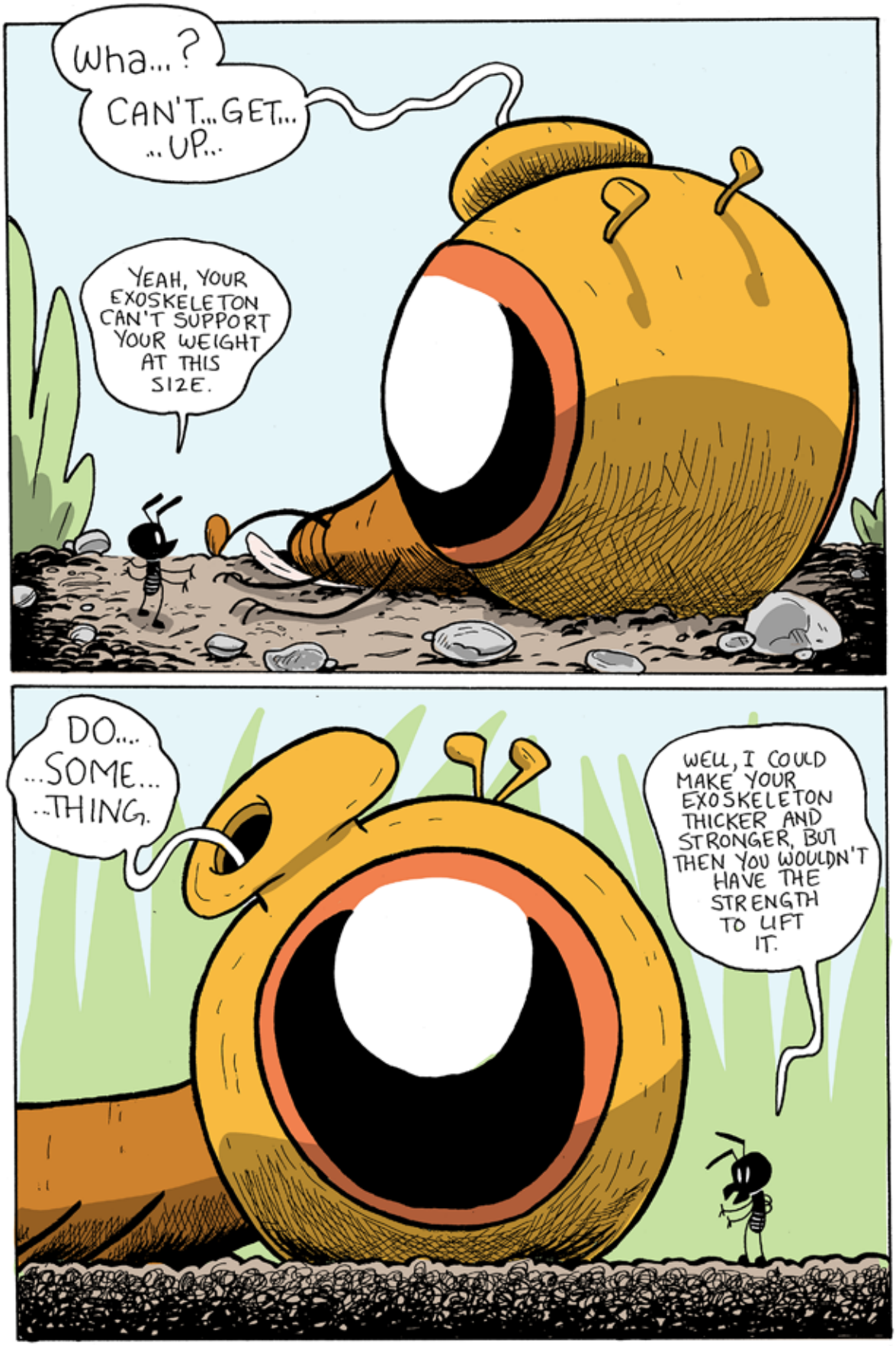

YOUR SPIRACLES LEAD TO TUBES CALLED TRACHEA.
THOSE TRACHEA BRANCH THROUGHOUT YOUR ENTIRE BODY, DELIVERING OXYGEN TO ALL OF YOUR CELLS.
SO, YOU TRIED TO SUFFOCATE ME?
SURE. WE WERE TALKING ABOUT SURFACE AREA.
AAAAND?
PLUGGING YOUR TRACHEA WAS RELEVANT.
EDNA? ONE OF US IS CLUELESS, AND I DON'T THINK IT'S ME THIS TIME.
OKAY. LET ME EXPLAIN.
LET'S IMAGINE BLOCKIE IS A CELL DEEP INSIDE YOU.
HE'LL BE PART OF MY HEART BECAUSE I LOVE HIM.

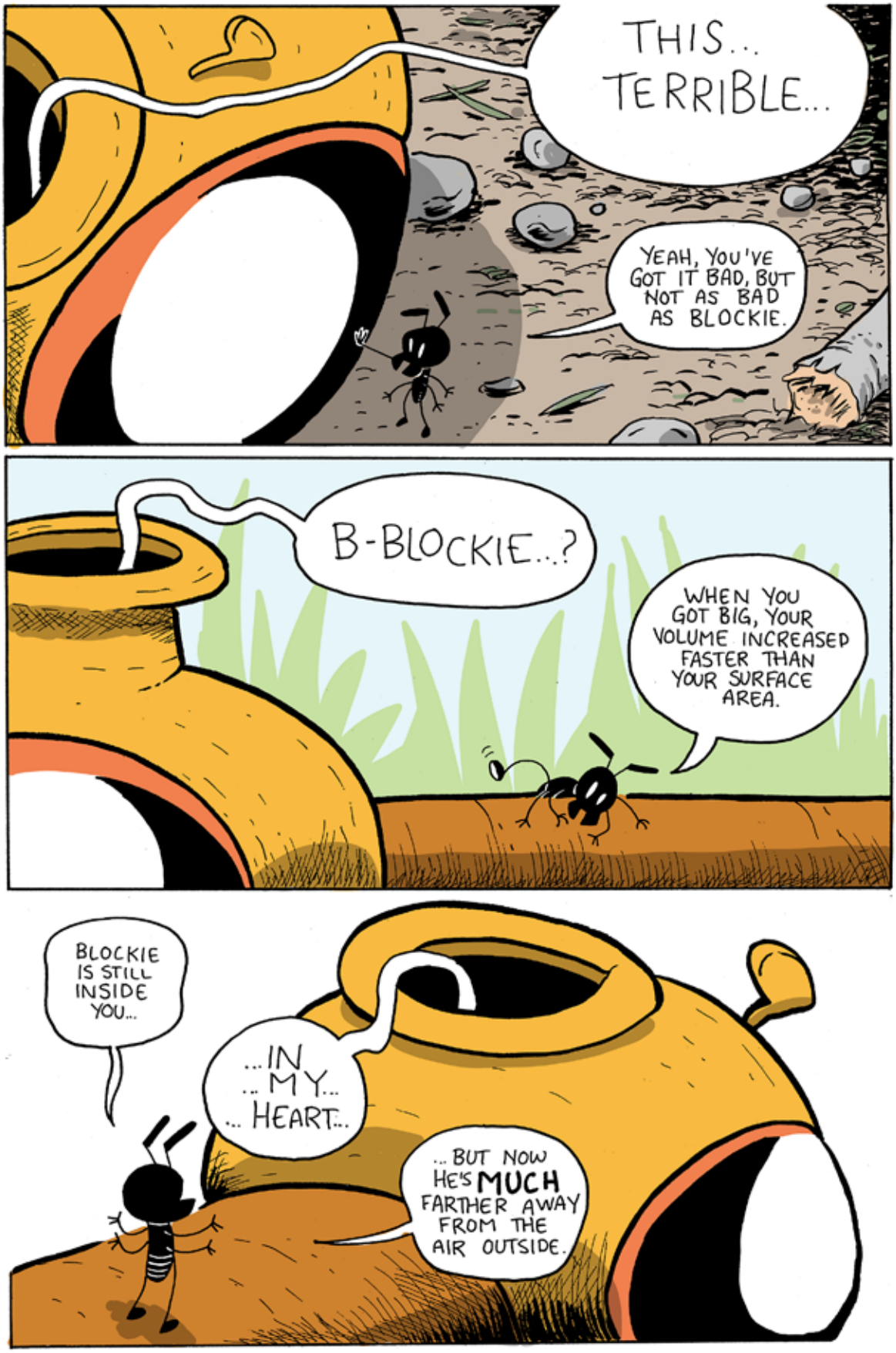

RIGHT NOW, THINGS ARE PRETTY GOOD FOR BLOCKIE.
OXYGEN IS DIFFUSING INTO YOUR TRACHEA.
CELLS ALONG THE TRACHEA ARE ABSORBING WHAT THEY NEED.
AND THERE IS ENOUGH OXYGEN LEFT IN THE AIR WHEN IT REACHES THE END OF THE TRACHEA FOR BLOCKIE TO BE HEALTHY.
O2
O2
O2
O2
O2
2

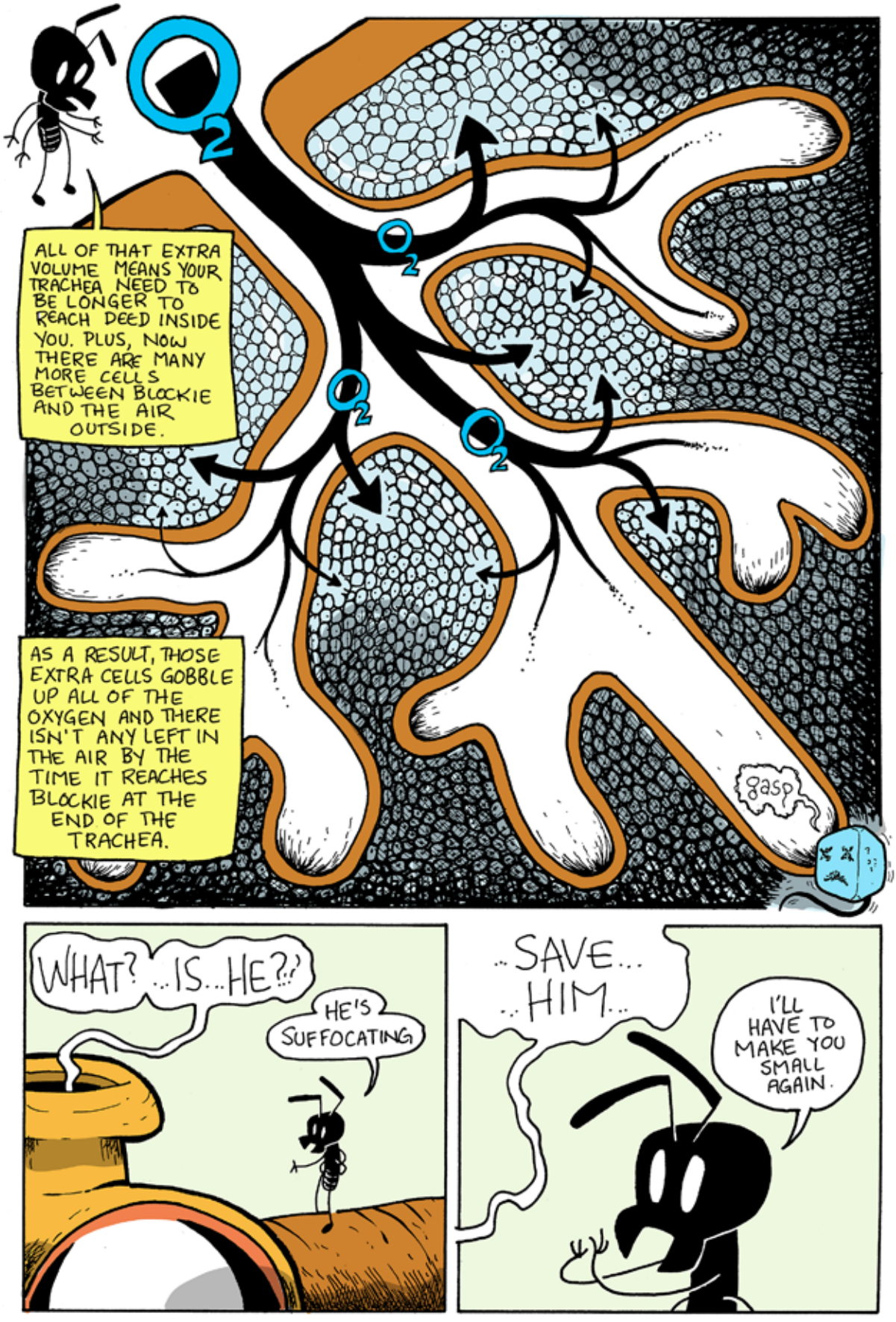

YAY, BLOCKIE!
NOW, LET'S MAKE YOU HUGE.


YES!
ZAP!

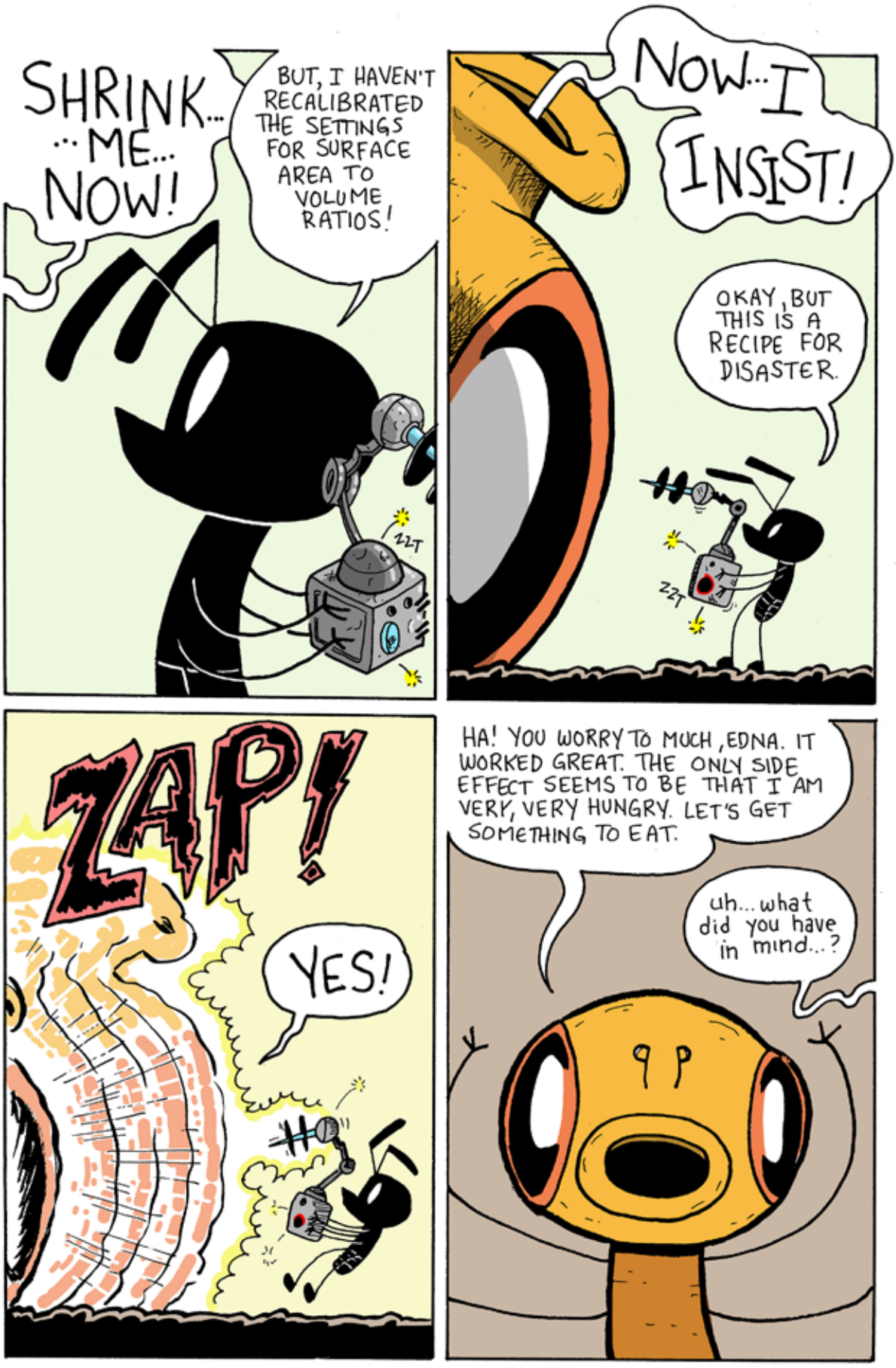

RAHH!
HERE I COME, HARVEY!
uh...
uh oh.
THOOM
eeep!

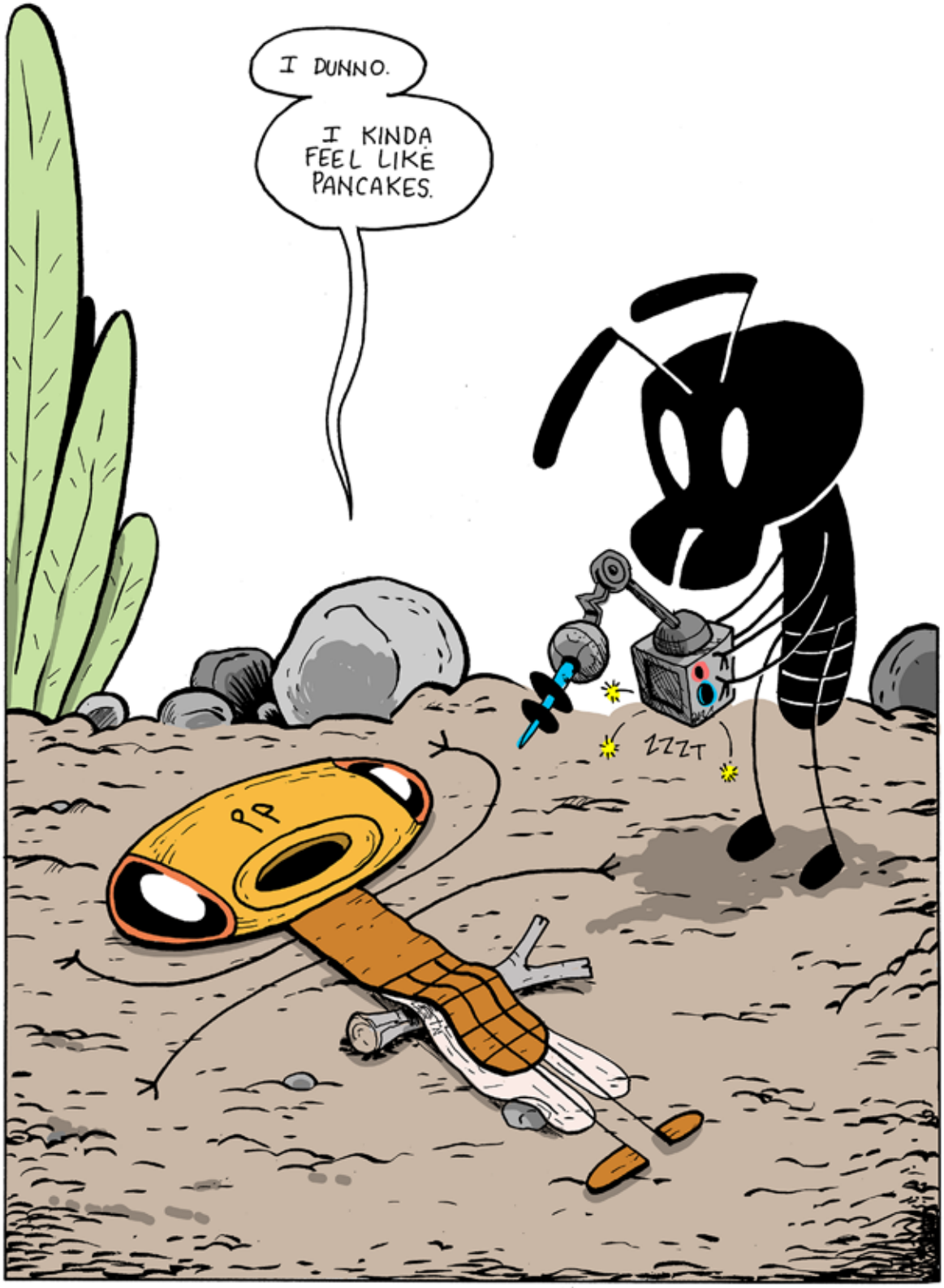

Wha...?
CAN'T...GET...
...UP...
YEAH, YOUR EXOSKELETON CAN'T SUPPORT YOUR WEIGHT AT THIS SIZE.
DO...
...SOME...
...THING.
WELL, I COULD MAKE YOUR EXOSKELETON THICKER AND STRONGER, BUT THEN YOU WOULDN'T HAVE THE STRENGTH TO LIFT IT.


THIS... TERRIBLE...
YEAH, YOU'VE GOT IT BAD, BUT NOT AS BAD AS BLOCKIE.
B-BLOCKIE..?
WHEN YOU GOT BIG, YOUR VOLUME INCREASED FASTER THAN YOUR SURFACE AREA.
BLOCKIE IS STILL INSIDE YOU...
...IN ...MY... ...HEART...
...BUT NOW HE'S MUCH FARTHER AWAY FROM THE AIR OUTSIDE.


O_2
O_2
O_2
O_2
ALL OF THAT EXTRA VOLUME MEANS YOUR TRACHEA NEED TO BE LONGER TO REACH DEED INSIDE YOU. PLUS, NOW THERE ARE MANY MORE CELLS BETWEEN BLOCKIE AND THE AIR OUTSIDE.
AS A RESULT, THOSE EXTRA CELLS GOBBLE UP ALL OF THE OXYGEN AND THERE ISN'T ANY LEFT IN THE AIR BY THE TIME IT REACHES BLOCKIE AT THE END OF THE TRACHEA.
gasp
WHAT? ..IS..HE?!
HE'S SUFFOCATING
..SAVE..
..HIM..
I'LL HAVE TO MAKE YOU SMALL AGAIN.


DO... IT..
ARE YOU SURE?
YOU REALLY WANTED TO BE BIG.
YES.. HURRY...
OKAY, GIMME A MINUTE.
I DROPPED THE RESIZE-A-FIER WHEN YOU GOT BIG AND IT BROKE.
FIX... IT...
I'M WORKING AS FAST AS I CAN.


SHRINK... ...ME... NOW!
BUT, I HAVEN'T RECALIBRATED THE SETTINGS FOR SURFACE AREA TO VOLUME RATIOS!
ZZT
NOW... I INSIST!
OKAY, BUT THIS IS A RECIPE FOR DISASTER.
ZZT
ZAP!
YES!
HA! YOU WORRY TO MUCH, EDNA. IT WORKED GREAT. THE ONLY SIDE EFFECT SEEMS TO BE THAT I AM VERY, VERY HUNGRY. LET'S GET SOMETHING TO EAT.
uh... what did you have in mind...?


I DUNNO.
I KINDA FEEL LIKE PANCAKES.
ZZZT
RP