Cartoon Physics

A Graphic Novel Guide to Solving Physics Problems

By

Scott Calvin

Kirin Emlet Furst

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A GRAPHIC NOVEL GUIDE TO SOLVING PHYSICS PROBLEMS

BY SCOTT CALVIN AND KIRIN EMLET FURST

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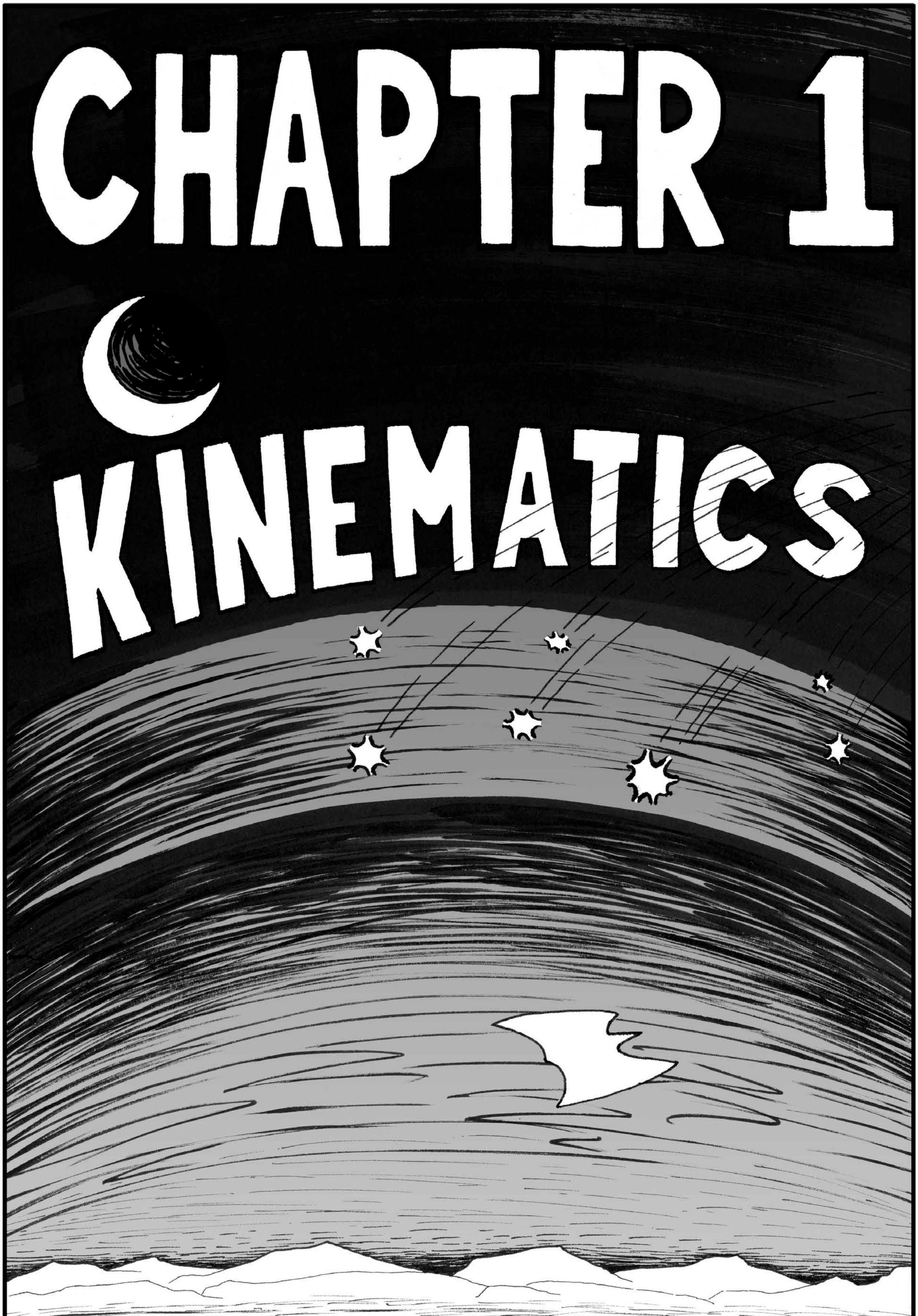
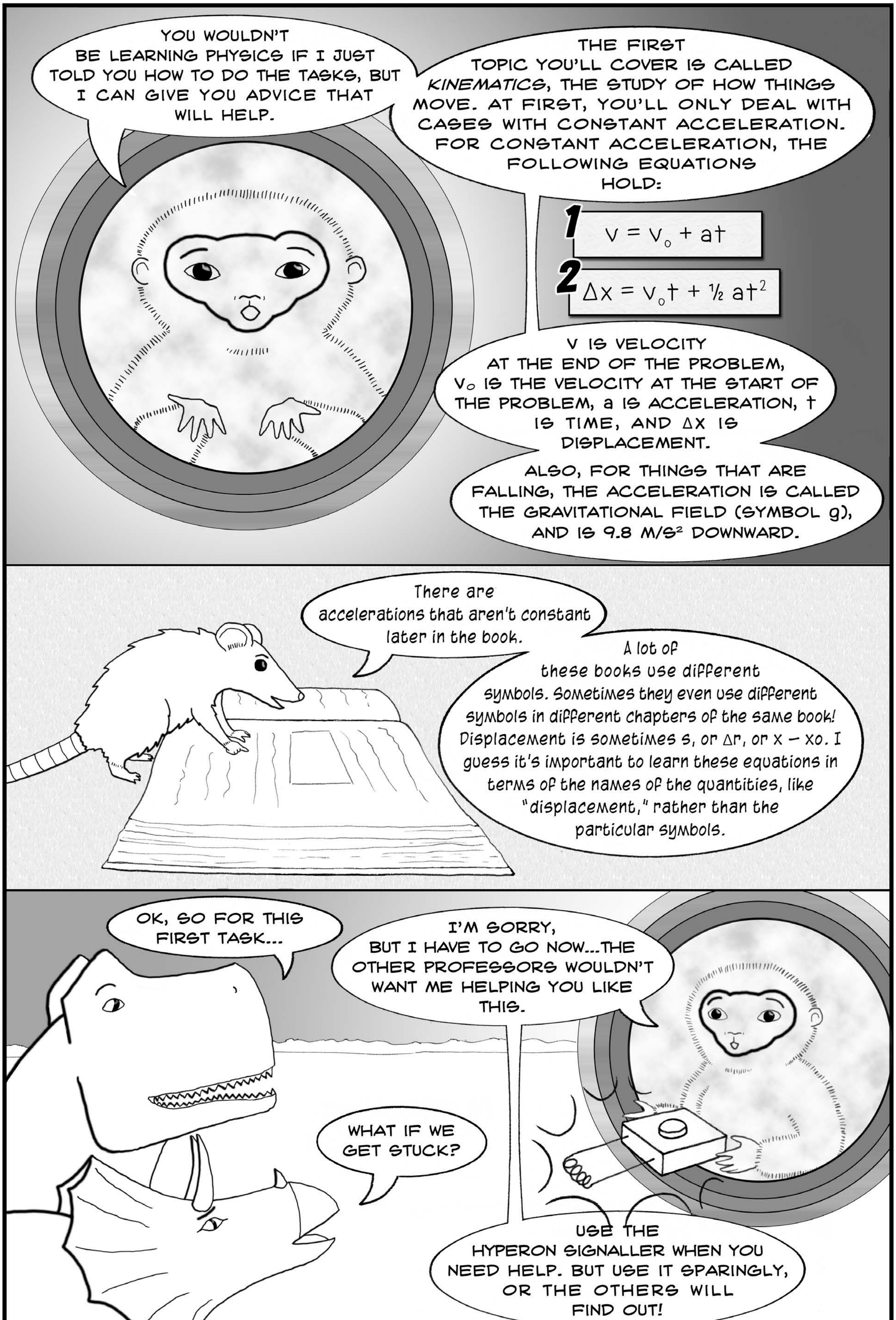

CHAPTER 1
KINEMATICS

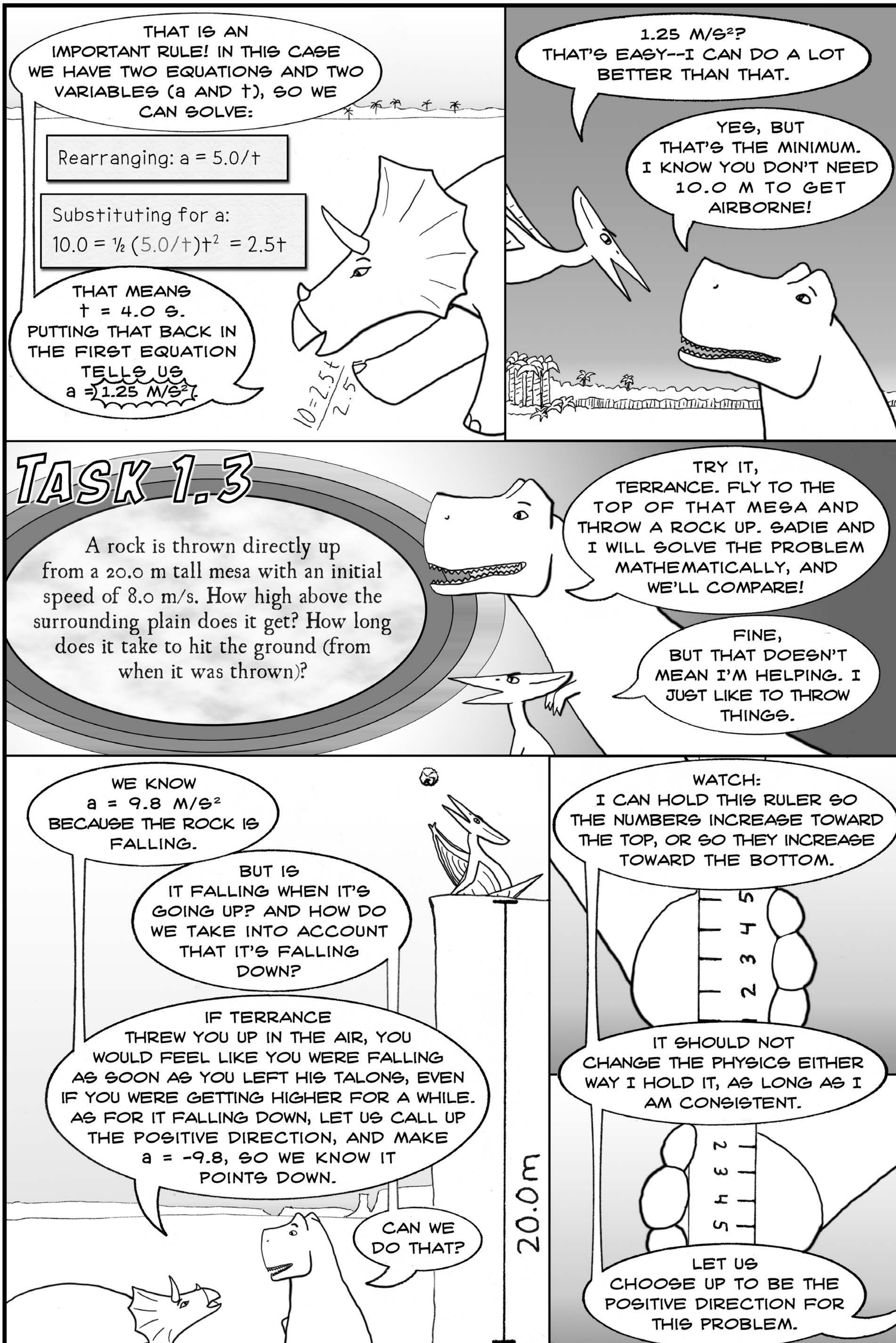

One day in the late Cretaceous...
GO HIGH, TERRANCE!
GOT IT, SADIE! CATCH THIS, SIMPLICIO!
HE-HE! I CAUGHT THE RAT-THING!
I don't like this game!
You hear that, dinosaurs? Maia doesn't like this game!
I wish they understood me. I understand Dinosaur, but I can't speak it.
WHAT'S THAT?


WE ARE THE PROFESSORS. WE ARE FROM THE FUTURE. WE WILL ATTEMPT TO TEACH YOU PHYSICS.
YOU WILL PROBABLY FAIL, BECAUSE I THINK IT HIGHLY UNLIKELY THAT DINOSAURS ARE CAPABLE OF LEARNING PHYSICS.
WHY SHOULD WE EVEN BOTHER? WHAT'S IN IT FOR US?
IF YOU FAIL, THE OUTCOME FOR YOU WILL BE GRIM.
IS THAT A THREAT?
NO. IT IS A FACT.
AND IF YOU THINK WE'RE GOING TO FAIL ANYWAY, WHAT'S IN IT FOR YOU?
WE HAVE RECEIVED A LUCRATIVE GRANT TO TRY TO TEACH DINOSAURS PHYSICS.
WE ARE WELL KNOWN TO BE BRILLIANT SCIENTISTS.
IF YOU FAIL UNDER OUR INSTRUCTION, THEN SURELY IT CAN'T BE DONE.
BUT IN THE MEANTIME, WE'VE USED THE MONEY TO BUY SOME VERY NICE TOYS, LIKE THE TACHYON GENERATOR WHICH ALLOWS US TO SEE EACH OTHER AT THIS MOMENT.
FORGET IT. WE'RE NOT PLAYING YOUR GAME.
TO HELP YOU, WE ARE PROVIDING SEVERAL RESOURCES.

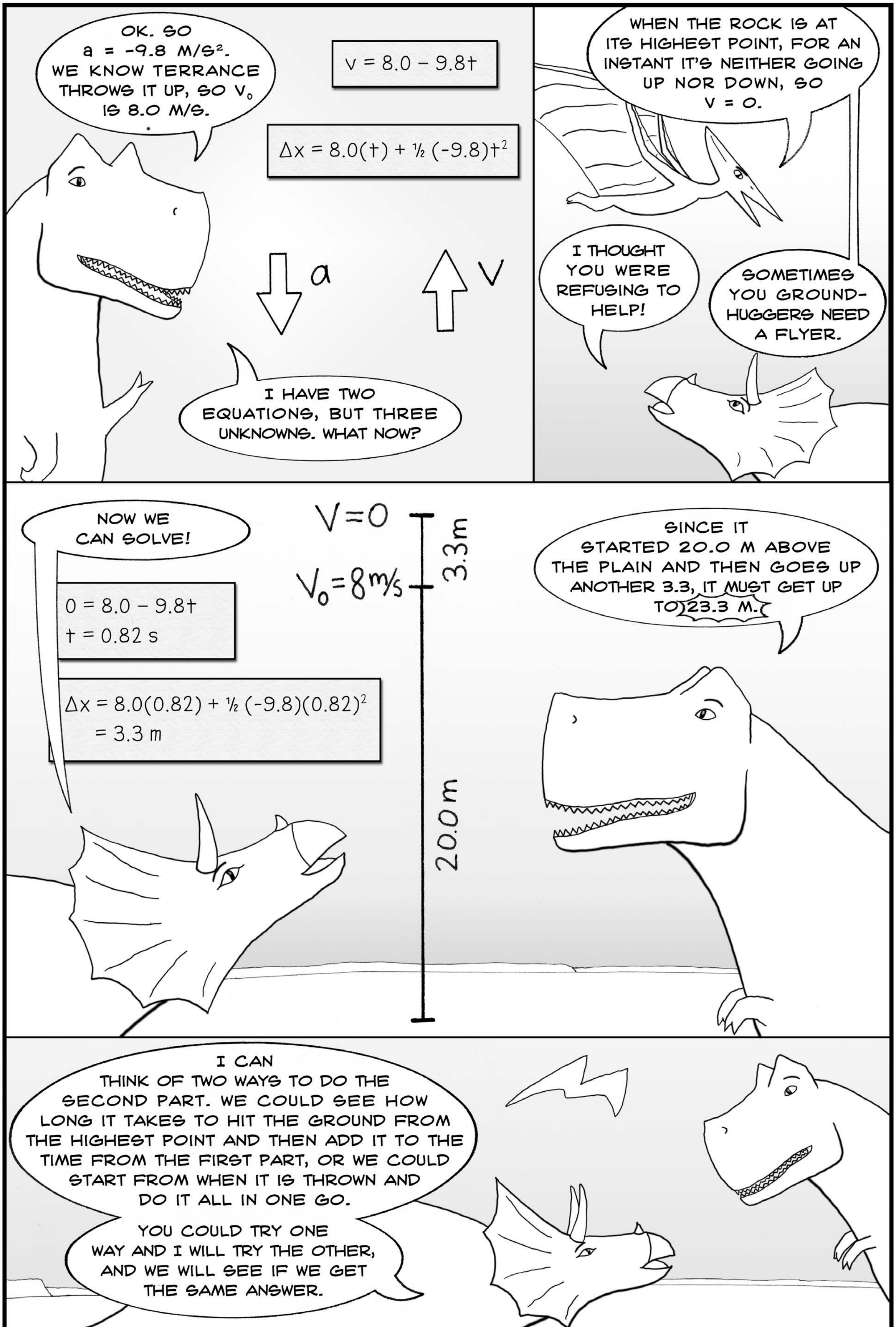

I CANNOT READ THESE--THEY ARE NOT IN A LANGUAGE I UNDERSTAND.
I can! Maia can help!
PHYSICS
Oh, but the dinosaurs can't understand Maia. Poor dinosaurs. I will read the books anyway.
PHYSICS
WE WILL ALSO PROVIDE YOU A LECTURE ON THE MATERIAL. PROFESSOR J?
VELOCITY IS THE RATE OF CHANGE OF POSITION. ACCELERATION IS THE RATE OF CHANGE OF VELOCITY. END OF LECTURE.
BRILLIANT! YOU WILL NOW RECEIVE YOUR FIRST TASK, TO SEE HOW WELL YOU HAVE ABSORBED THE MATERIAL.
TASK 1.1
Simplicio can go from rest to 9.0 m/s in 2.0 seconds. What is his acceleration? How far does he go during that time? Assume constant acceleration.
C'MON, LET'S GO. THESE PROFESSORS ARE LOOPY.
OK. BUT I WONDER HOW FAR I *COULD* GO DURING THAT TIME?
WAIT!
I KNOW THAT PROBABLY SOUNDED BAD. AND I KNOW PROFESSOR J'S LECTURE AND OUR BOOKS MIGHT NOT HAVE HELPED MUCH. BUT I CAN HELP! MY NAME IS KITSUNE, AND I'M PLEASED TO MAKE YOUR ACQUAINTANCE.
LOOK, KITSUNE, YOU SEEM LIKE A NICE PROFESSOR. BUT WE'RE NOT INTERESTED IN LEARNING PHYSICS.
OH! BUT YOU HAVE TO! OTHERWISE...
OTHERWISE, WHAT?
I CAN'T TELL YOU. BUT REALLY, YOU NEED TO TRY. IT'S FOR YOUR OWN GOOD!
FINE. YOU WANT TO HELP? TELL US HOW TO DO THE FIRST TASK.

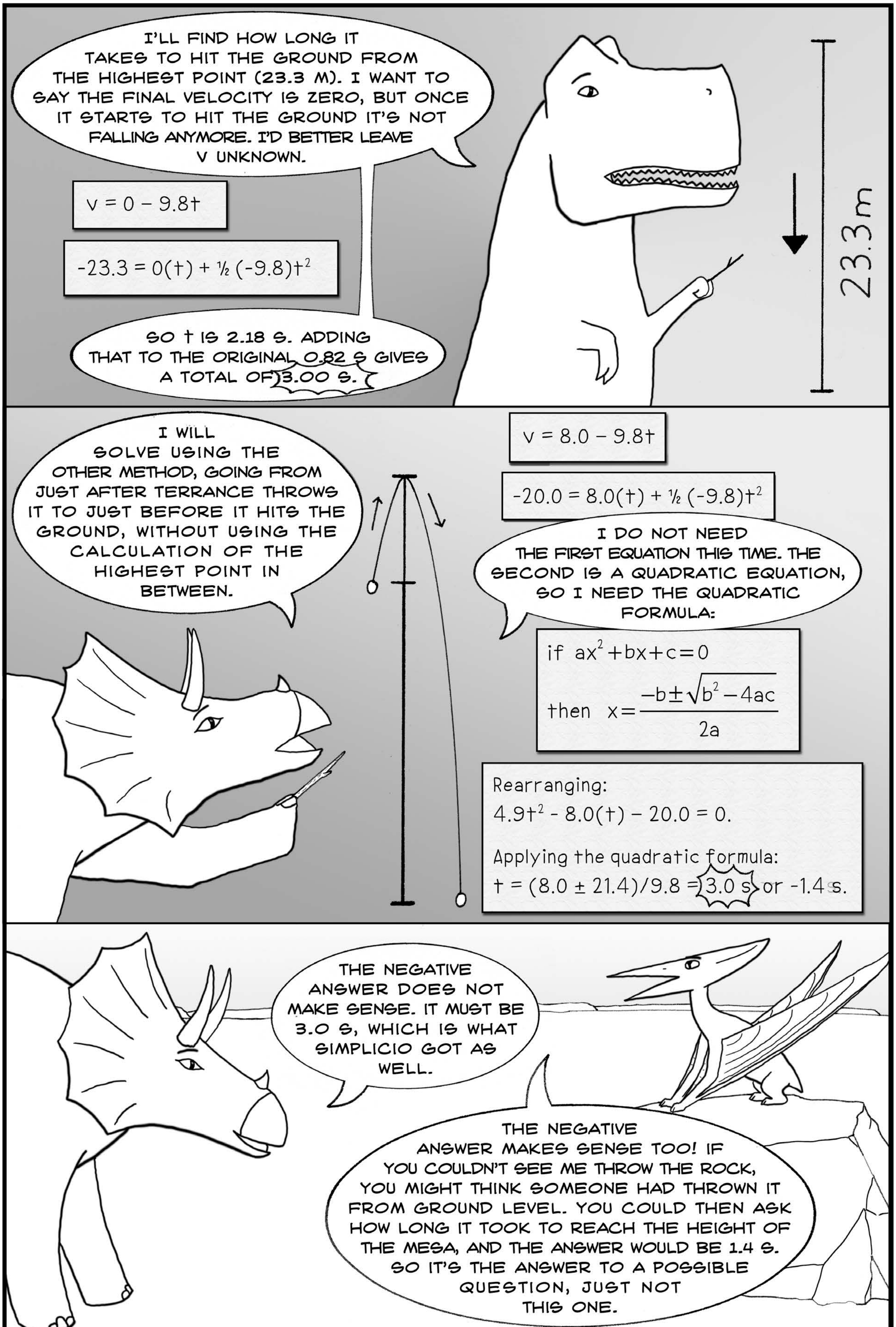

YOU WOULDN'T BE LEARNING PHYSICS IF I JUST TOLD YOU HOW TO DO THE TASKS, BUT I CAN GIVE YOU ADVICE THAT WILL HELP.
THE FIRST TOPIC YOU'LL COVER IS CALLED *KINEMATICS*, THE STUDY OF HOW THINGS MOVE. AT FIRST, YOU'LL ONLY DEAL WITH CASES WITH CONSTANT ACCELERATION. FOR CONSTANT ACCELERATION, THE FOLLOWING EQUATIONS HOLD:
1 $v = v_0 + at$
2 $\Delta x = v_0 t + \frac{1}{2} a t^2$
V IS VELOCITY AT THE END OF THE PROBLEM, V_0 IS THE VELOCITY AT THE START OF THE PROBLEM, a IS ACCELERATION, t IS TIME, AND Δx IS DISPLACEMENT.
ALSO, FOR THINGS THAT ARE FALLING, THE ACCELERATION IS CALLED THE GRAVITATIONAL FIELD (SYMBOL g), AND IS 9.8 M/S^2 DOWNWARD.
There are accelerations that aren't constant later in the book.
A lot of these books use different symbols. Sometimes they even use different symbols in different chapters of the same book! Displacement is sometimes s, or Δr, or $x - x_0$. I guess it's important to learn these equations in terms of the names of the quantities, like "displacement," rather than the particular symbols.
OK, SO FOR THIS FIRST TASK...
I'M SORRY, BUT I HAVE TO GO NOW...THE OTHER PROFESSORS WOULDN'T WANT ME HELPING YOU LIKE THIS.
WHAT IF WE GET STUCK?
USE THE HYPERON SIGNALLER WHEN YOU NEED HELP. BUT USE IT SPARINGLY, OR THE OTHERS WILL FIND OUT!

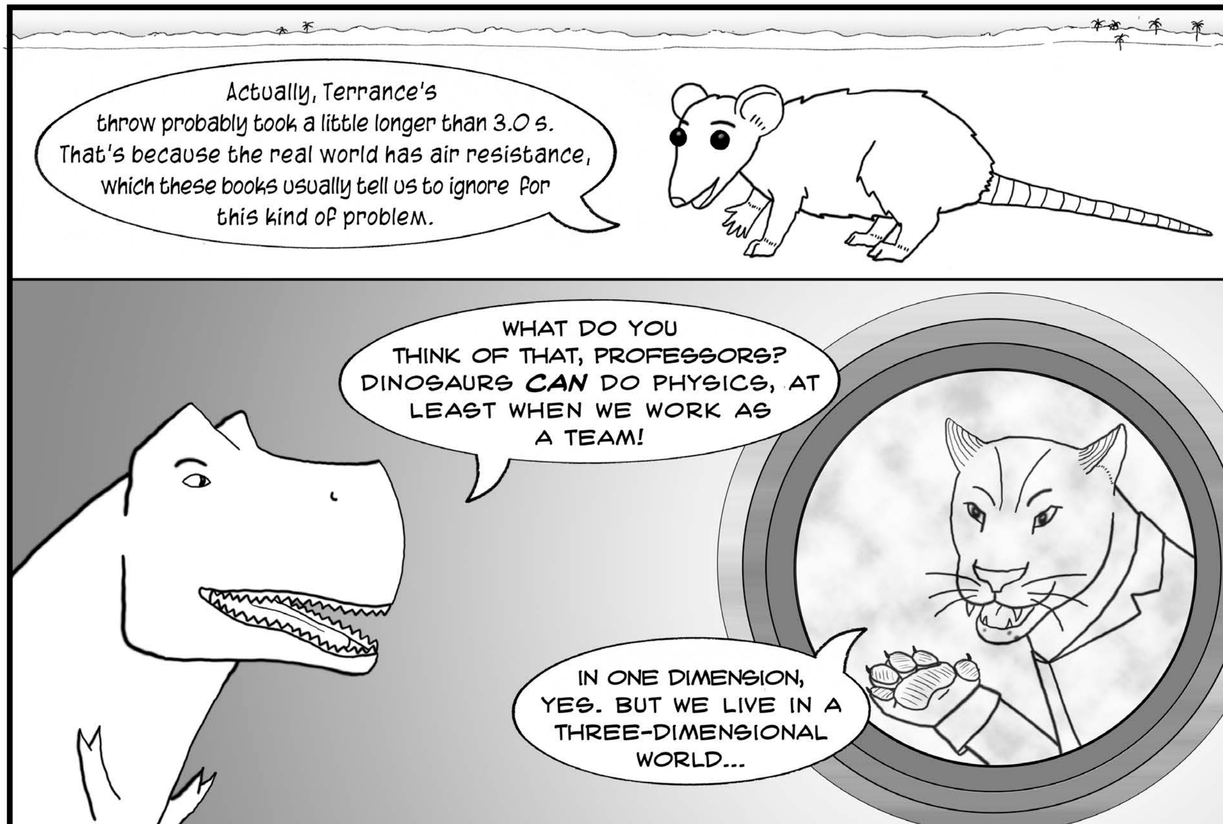

SOLUTION 1.1
IN THIS TASK, SIMPLICIO STARTS AT REST, MEANING V_0 IS ZERO. HE ENDS AT 9.0 M/S, SO THAT IS V. t IS 2.0 S. THE FIRST EQUATION IS THUS 9.0 = 0 + a(2.0), WHICH MEANS THAT a = 4.5 M/S^2.
9m
AND THE SECOND EQUATION SAYS Δx = 0(2.0) + ½ (4.5) (2.0)^2 = 9.0 M. THAT'S HOW FAR I CAN RUN IN 2.0 S!
YAY! WE DID A TASK!
TASK 1.2
WHO IS THIS "WE"? I DON'T REMEMBER AGREEING TO THIS.
Terrance is on a mesa 10.0 m across. If Terrance has to reach a horizontal speed of 5.0 m/s in order to take off, what minimum sustained acceleration must he have?
IF TERRANCE USES THE WHOLE MESA, THEN Δx IS 10.0 M.
NICE TRY, BUT I'M LEAVING.
V_0=0
V=5m/s
10m
HE NEEDS 5.0 M/S TO TAKE OFF. DOES THAT MEAN THAT IS THE INITIAL SPEED?
I DON'T THINK SO. I THINK "INITIAL" AND "FINAL" REFER TO THE PROBLEM--SORT OF WHEN WE START AND STOP PAYING ATTENTION. I THINK WE START PAYING ATTENTION WHEN TERRANCE IS AT REST, SO V_0 IS ZERO, AND V IS 5.0 M/S.
THE TWO EQUATIONS ARE:
5.0 = 0 + at
10.0 = 0(t) + ½ at^2
NEITHER ONE GIVES US THE ANSWER. LET'S CALL KITSUNE.
YOU DON'T NEED TO DO THAT! IF YOU HAVE AS MANY EQUATIONS AS UNKNOWN VARIABLES, IT'S POSSIBLE TO SOLVE.
YOINK!



THAT IS AN IMPORTANT RULE! IN THIS CASE WE HAVE TWO EQUATIONS AND TWO VARIABLES (a AND t), SO WE CAN SOLVE:
Rearranging: a = 5.0/t
Substituting for a:
10.0 = ½ (5.0/t)t² = 2.5t
THAT MEANS t = 4.0 s. PUTTING THAT BACK IN THE FIRST EQUATION TELLS US a = 1.25 M/S²
10=2.5t
2.5
1.25 M/S²? THAT'S EASY--I CAN DO A LOT BETTER THAN THAT.
YES, BUT THAT'S THE MINIMUM. I KNOW YOU DON'T NEED 10.0 M TO GET AIRBORNE!
TASK 1.3
A rock is thrown directly up from a 20.0 m tall mesa with an initial speed of 8.0 m/s. How high above the surrounding plain does it get? How long does it take to hit the ground (from when it was thrown)?
TRY IT, TERRANCE. FLY TO THE TOP OF THAT MESA AND THROW A ROCK UP. SADIE AND I WILL SOLVE THE PROBLEM MATHEMATICALLY, AND WE'LL COMPARE!
FINE, BUT THAT DOESN'T MEAN I'M HELPING. I JUST LIKE TO THROW THINGS.
WE KNOW a = 9.8 M/S² BECAUSE THE ROCK IS FALLING.
BUT IS IT FALLING WHEN IT'S GOING UP? AND HOW DO WE TAKE INTO ACCOUNT THAT IT'S FALLING DOWN?
IF TERRANCE THREW YOU UP IN THE AIR, YOU WOULD FEEL LIKE YOU WERE FALLING AS SOON AS YOU LEFT HIS TALONS, EVEN IF YOU WERE GETTING HIGHER FOR A WHILE. AS FOR IT FALLING DOWN, LET US CALL UP THE POSITIVE DIRECTION, AND MAKE a = -9.8, SO WE KNOW IT POINTS DOWN.
CAN WE DO THAT?
20.0m
WATCH: I CAN HOLD THIS RULER SO THE NUMBERS INCREASE TOWARD THE TOP, OR SO THEY INCREASE TOWARD THE BOTTOM.
1 2 3 4 5
IT SHOULD NOT CHANGE THE PHYSICS EITHER WAY I HOLD IT, AS LONG AS I AM CONSISTENT.
2 3 4 5
LET US CHOOSE UP TO BE THE POSITIVE DIRECTION FOR THIS PROBLEM.


OK. SO a = -9.8 M/S². WE KNOW TERRANCE THROWS IT UP, SO V_0 IS 8.0 M/S.
v = 8.0 – 9.8t
Δx = 8.0(t) + ½ (-9.8)t²
a
V
I HAVE TWO EQUATIONS, BUT THREE UNKNOWNS. WHAT NOW?
WHEN THE ROCK IS AT ITS HIGHEST POINT, FOR AN INSTANT IT'S NEITHER GOING UP NOR DOWN, SO V = 0.
I THOUGHT YOU WERE REFUSING TO HELP!
SOMETIMES YOU GROUND-HUGGERS NEED A FLYER.
NOW WE CAN SOLVE!
V=0
V_0=8m/s
3.3m
20.0m
0 = 8.0 – 9.8t
t = 0.82 s
Δx = 8.0(0.82) + ½ (-9.8)(0.82)²
= 3.3 m
SINCE IT STARTED 20.0 M ABOVE THE PLAIN AND THEN GOES UP ANOTHER 3.3, IT MUST GET UP TO 23.3 M.
I CAN THINK OF TWO WAYS TO DO THE SECOND PART. WE COULD SEE HOW LONG IT TAKES TO HIT THE GROUND FROM THE HIGHEST POINT AND THEN ADD IT TO THE TIME FROM THE FIRST PART, OR WE COULD START FROM WHEN IT IS THROWN AND DO IT ALL IN ONE GO.
YOU COULD TRY ONE WAY AND I WILL TRY THE OTHER, AND WE WILL SEE IF WE GET THE SAME ANSWER.


I'LL FIND HOW LONG IT TAKES TO HIT THE GROUND FROM THE HIGHEST POINT (23.3 M). I WANT TO SAY THE FINAL VELOCITY IS ZERO, BUT ONCE IT STARTS TO HIT THE GROUND IT'S NOT FALLING ANYMORE. I'D BETTER LEAVE V UNKNOWN.
$v = 0 - 9.8t$
$-23.3 = 0(t) + ½(-9.8)t^2$
SO t IS 2.18 S. ADDING THAT TO THE ORIGINAL 0.82 S GIVES A TOTAL OF 3.00 S.
23.3m
I WILL SOLVE USING THE OTHER METHOD, GOING FROM JUST AFTER TERRANCE THROWS IT TO JUST BEFORE IT HITS THE GROUND, WITHOUT USING THE CALCULATION OF THE HIGHEST POINT IN BETWEEN.
$v = 8.0 - 9.8t$
$-20.0 = 8.0(t) + ½(-9.8)t^2$
I DO NOT NEED THE FIRST EQUATION THIS TIME. THE SECOND IS A QUADRATIC EQUATION, SO I NEED THE QUADRATIC FORMULA:
if $ax^2+bx+c=0$ then $x=\dfrac{-b\pm\sqrt{b^2-4ac}}{2a}$
Rearranging:
$4.9t^2 - 8.0(t) - 20.0 = 0.$
Applying the quadratic formula:
$t = (8.0 \pm 21.4)/9.8 = 3.0$ s or -1.4 s.
THE NEGATIVE ANSWER DOES NOT MAKE SENSE. IT MUST BE 3.0 S, WHICH IS WHAT SIMPLICIO GOT AS WELL.
THE NEGATIVE ANSWER MAKES SENSE TOO! IF YOU COULDN'T SEE ME THROW THE ROCK, YOU MIGHT THINK SOMEONE HAD THROWN IT FROM GROUND LEVEL. YOU COULD THEN ASK HOW LONG IT TOOK TO REACH THE HEIGHT OF THE MESA, AND THE ANSWER WOULD BE 1.4 S. SO IT'S THE ANSWER TO A POSSIBLE QUESTION, JUST NOT THIS ONE.



EQUATIONS IN THIS CHAPTER

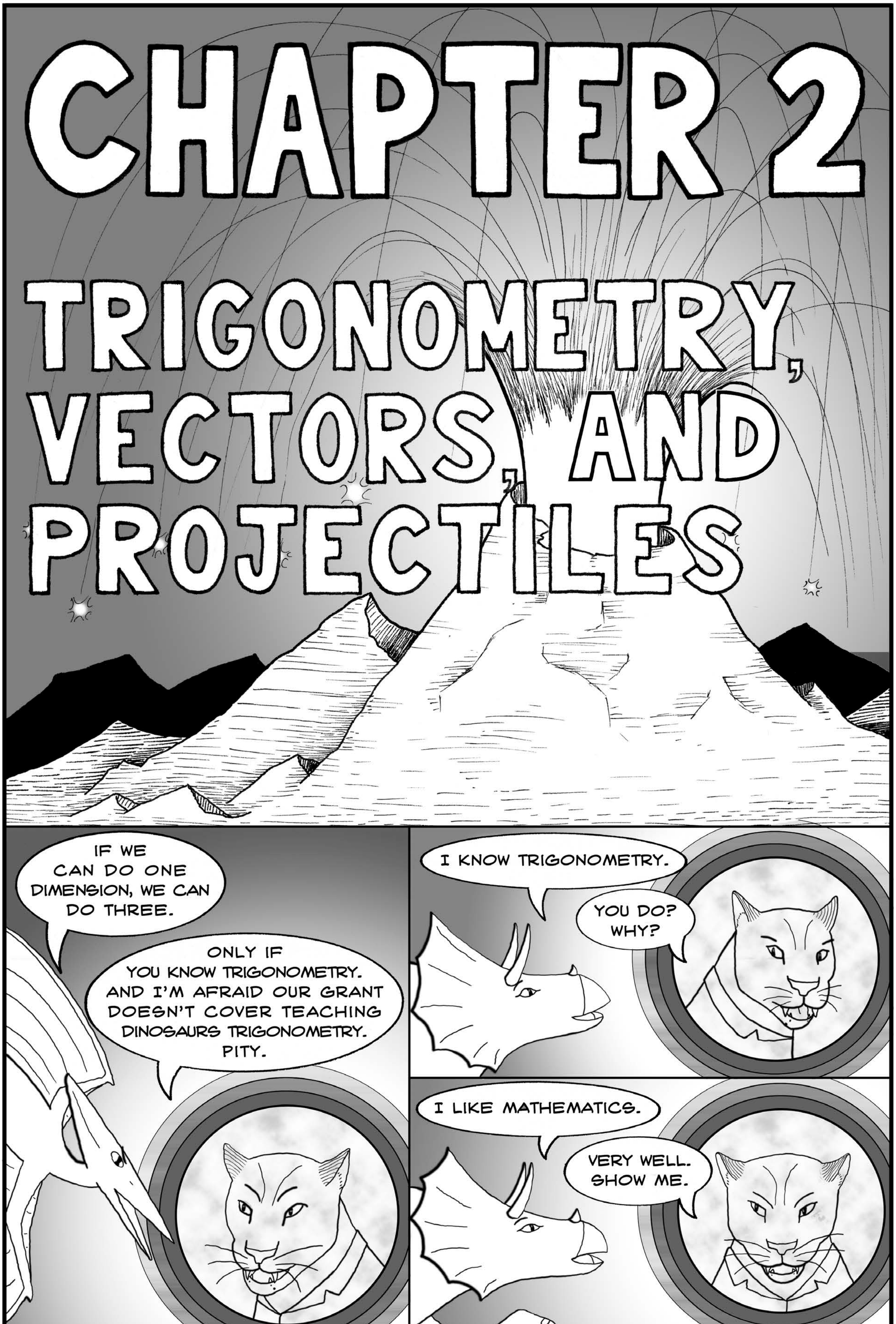
$$v = v_0 + at$$

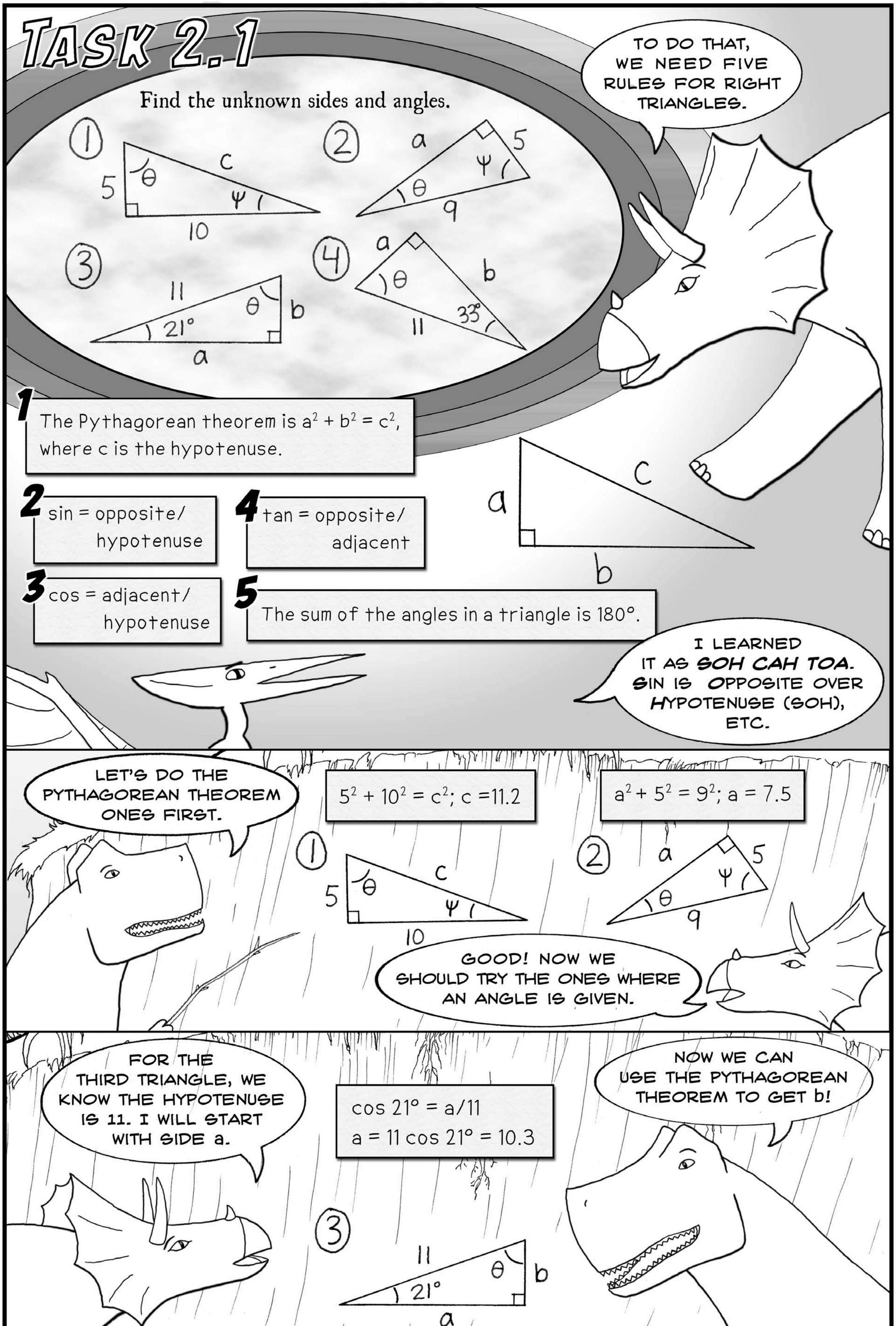
$$\Delta x = v_0 t + \tfrac{1}{2} at^2$$

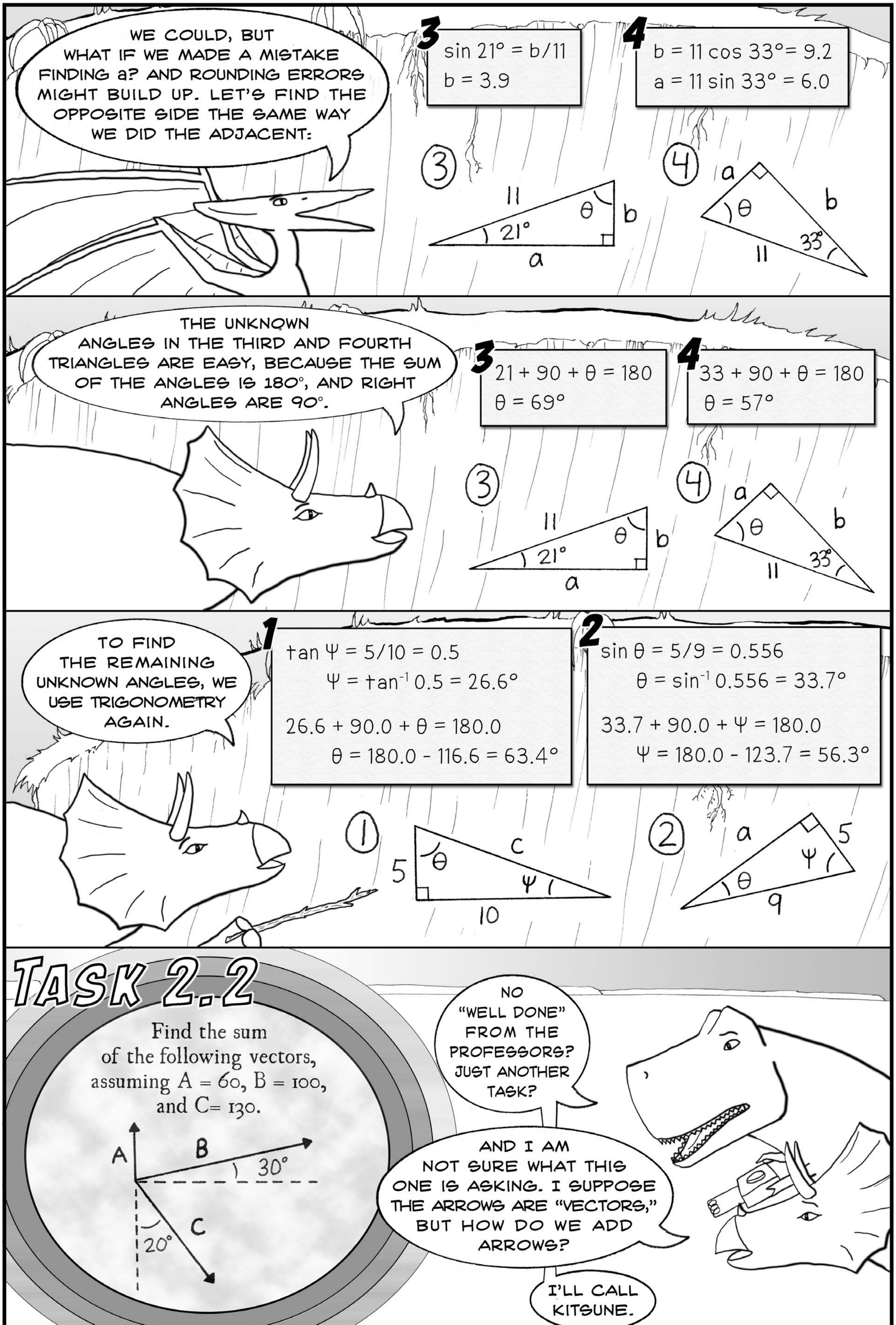
WORDS OF WISDOM

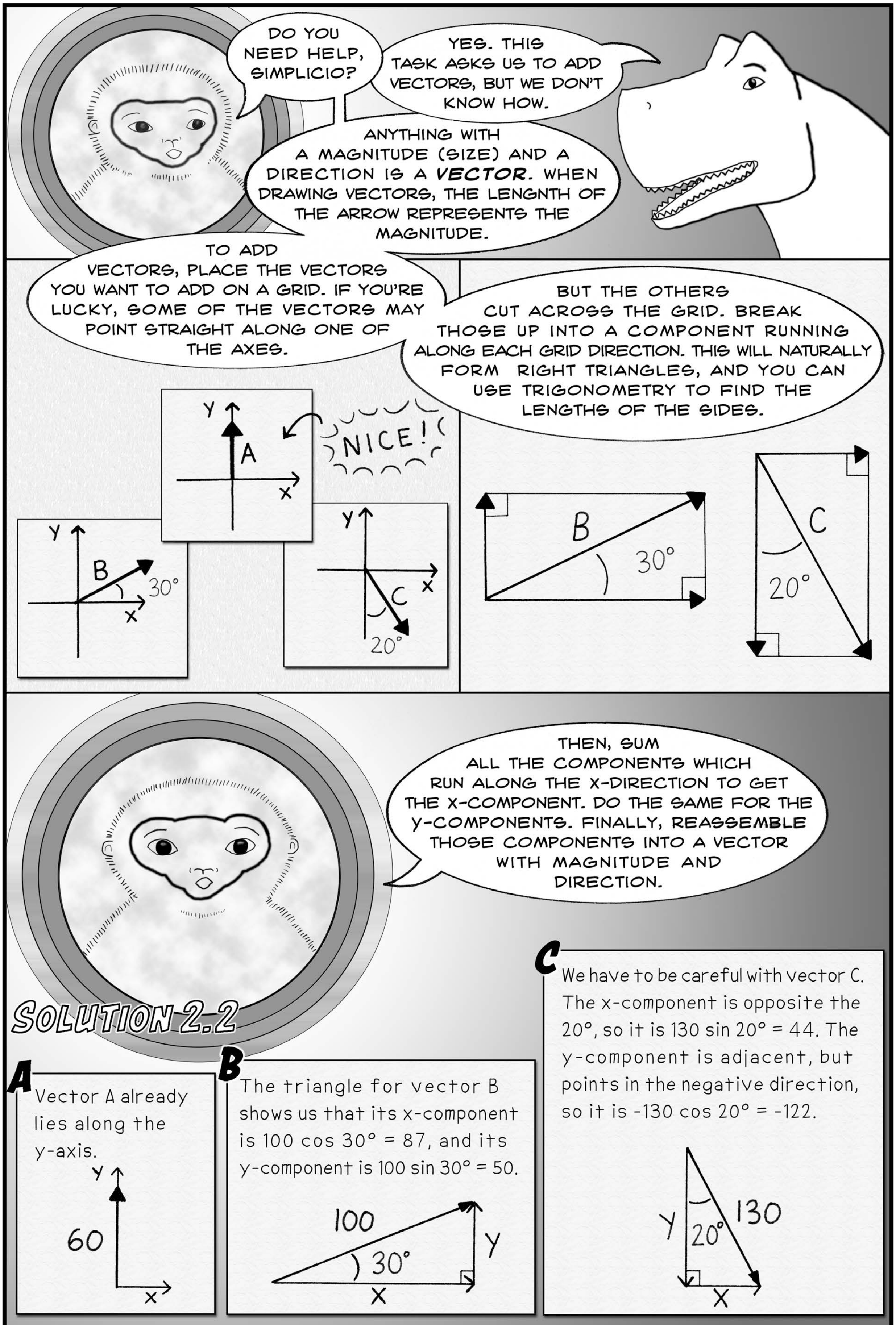
"Initial" and "Final" are when you start and stop paying attention

If you have as many equations as unknown variables, it's possible to solve

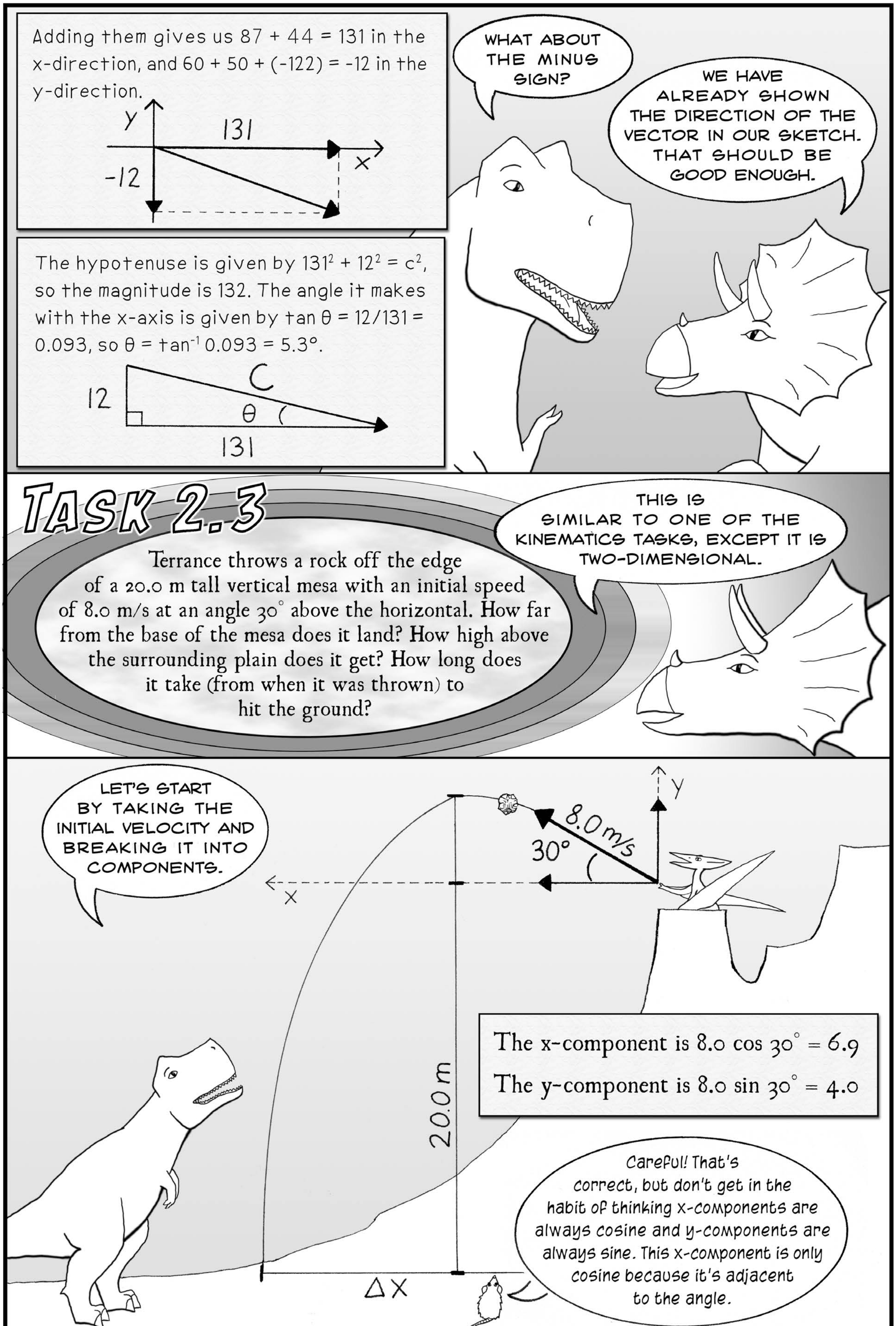

CHAPTER 2
TRIGONOMETRY, VECTORS, AND PROJECTILES
IF WE CAN DO ONE DIMENSION, WE CAN DO THREE.
ONLY IF YOU KNOW TRIGONOMETRY. AND I'M AFRAID OUR GRANT DOESN'T COVER TEACHING DINOSAURS TRIGONOMETRY. PITY.
I KNOW TRIGONOMETRY.
YOU DO? WHY?
I LIKE MATHEMATICS.
VERY WELL. SHOW ME.


TASK 2.1
Find the unknown sides and angles.
1 5 c θ ψ 10
2 a 5 ψ θ 9
3 11 θ b 21° a
4 a θ b 33° 11
TO DO THAT, WE NEED FIVE RULES FOR RIGHT TRIANGLES.
1 The Pythagorean theorem is $a^2 + b^2 = c^2$, where c is the hypotenuse.
2 sin = opposite/ hypotenuse
3 cos = adjacent/ hypotenuse
4 tan = opposite/ adjacent
5 The sum of the angles in a triangle is 180°.
a c b
I LEARNED IT AS SOH CAH TOA. SIN IS OPPOSITE OVER HYPOTENUSE (SOH), ETC.
LET'S DO THE PYTHAGOREAN THEOREM ONES FIRST.
$5^2 + 10^2 = c^2$; c =11.2
$a^2 + 5^2 = 9^2$; a = 7.5
1 5 c θ ψ 10
2 a 5 ψ θ 9
GOOD! NOW WE SHOULD TRY THE ONES WHERE AN ANGLE IS GIVEN.
FOR THE THIRD TRIANGLE, WE KNOW THE HYPOTENUSE IS 11. I WILL START WITH SIDE a.
cos 21° = a/11
a = 11 cos 21° = 10.3
NOW WE CAN USE THE PYTHAGOREAN THEOREM TO GET b!
3 11 θ b 21° a

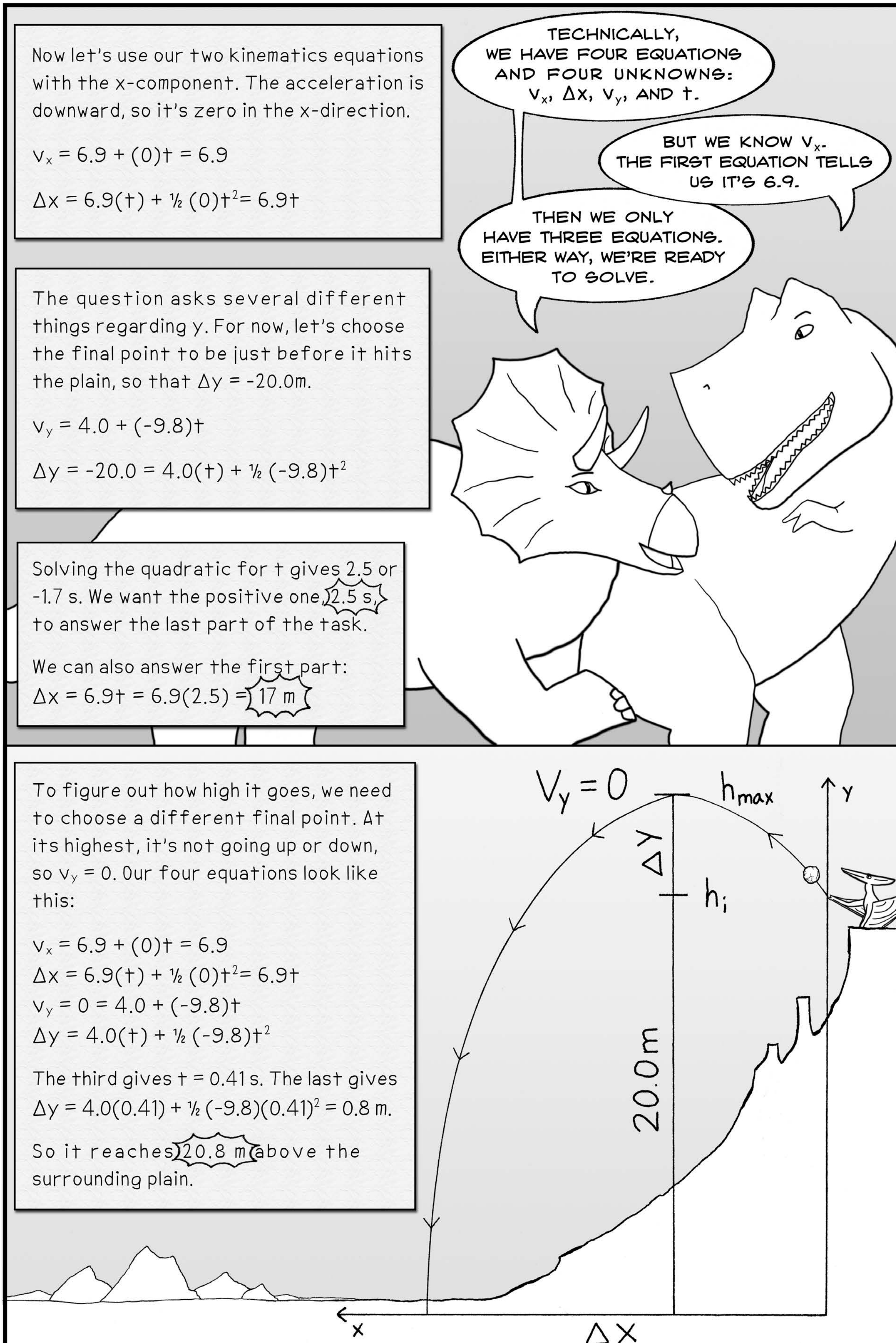

WE COULD, BUT WHAT IF WE MADE A MISTAKE FINDING a? AND ROUNDING ERRORS MIGHT BUILD UP. LET'S FIND THE OPPOSITE SIDE THE SAME WAY WE DID THE ADJACENT:
3
sin 21° = b/11
b = 3.9
4
b = 11 cos 33°= 9.2
a = 11 sin 33° = 6.0
3
11
θ
b
21°
a
4
a
θ
b
11
33°
THE UNKNOWN ANGLES IN THE THIRD AND FOURTH TRIANGLES ARE EASY, BECAUSE THE SUM OF THE ANGLES IS 180°, AND RIGHT ANGLES ARE 90°.
3
21 + 90 + θ = 180
θ = 69°
4
33 + 90 + θ = 180
θ = 57°
3
11
θ
b
21°
a
4
a
θ
b
11
33°
TO FIND THE REMAINING UNKNOWN ANGLES, WE USE TRIGONOMETRY AGAIN.
1
tan Ψ = 5/10 = 0.5
Ψ = tan⁻¹ 0.5 = 26.6°
26.6 + 90.0 + θ = 180.0
θ = 180.0 - 116.6 = 63.4°
2
sin θ = 5/9 = 0.556
θ = sin⁻¹ 0.556 = 33.7°
33.7 + 90.0 + Ψ = 180.0
Ψ = 180.0 - 123.7 = 56.3°
1
5
θ
c
Ψ
10
2
a
5
Ψ
θ
9
TASK 2.2
Find the sum of the following vectors, assuming A = 60, B = 100, and C= 130.
A
B
30°
20°
C
NO "WELL DONE" FROM THE PROFESSORS? JUST ANOTHER TASK?
AND I AM NOT SURE WHAT THIS ONE IS ASKING. I SUPPOSE THE ARROWS ARE "VECTORS," BUT HOW DO WE ADD ARROWS?
I'LL CALL KITSUNE.



DO YOU NEED HELP, SIMPLICIO?
YES. THIS TASK ASKS US TO ADD VECTORS, BUT WE DON'T KNOW HOW.
ANYTHING WITH A MAGNITUDE (SIZE) AND A DIRECTION IS A VECTOR. WHEN DRAWING VECTORS, THE LENGNTH OF THE ARROW REPRESENTS THE MAGNITUDE.
TO ADD VECTORS, PLACE THE VECTORS YOU WANT TO ADD ON A GRID. IF YOU'RE LUCKY, SOME OF THE VECTORS MAY POINT STRAIGHT ALONG ONE OF THE AXES.
Y
A
X
NICE!
Y
B
30°
X
Y
X
C
20°
BUT THE OTHERS CUT ACROSS THE GRID. BREAK THOSE UP INTO A COMPONENT RUNNING ALONG EACH GRID DIRECTION. THIS WILL NATURALLY FORM RIGHT TRIANGLES, AND YOU CAN USE TRIGONOMETRY TO FIND THE LENGTHS OF THE SIDES.
B
30°
C
20°
THEN, SUM ALL THE COMPONENTS WHICH RUN ALONG THE X-DIRECTION TO GET THE X-COMPONENT. DO THE SAME FOR THE Y-COMPONENTS. FINALLY, REASSEMBLE THOSE COMPONENTS INTO A VECTOR WITH MAGNITUDE AND DIRECTION.
SOLUTION 2.2
A
Vector A already lies along the y-axis.
Y
60
X
B
The triangle for vector B shows us that its x-component is 100 cos 30° = 87, and its y-component is 100 sin 30° = 50.
100
30°
Y
X
C
We have to be careful with vector C. The x-component is opposite the 20°, so it is 130 sin 20° = 44. The y-component is adjacent, but points in the negative direction, so it is -130 cos 20° = -122.
Y
20°
130
X



Adding them gives us 87 + 44 = 131 in the x-direction, and 60 + 50 + (-122) = -12 in the y-direction.
y
131
x
-12
WHAT ABOUT THE MINUS SIGN?
WE HAVE ALREADY SHOWN THE DIRECTION OF THE VECTOR IN OUR SKETCH. THAT SHOULD BE GOOD ENOUGH.
The hypotenuse is given by $131^2 + 12^2 = c^2$, so the magnitude is 132. The angle it makes with the x-axis is given by $\tan\theta = 12/131 = 0.093$, so $\theta = \tan^{-1} 0.093 = 5.3°$.
12
C
θ
131
TASK 2.3
Terrance throws a rock off the edge of a 20.0 m tall vertical mesa with an initial speed of 8.0 m/s at an angle 30° above the horizontal. How far from the base of the mesa does it land? How high above the surrounding plain does it get? How long does it take (from when it was thrown) to hit the ground?
THIS IS SIMILAR TO ONE OF THE KINEMATICS TASKS, EXCEPT IT IS TWO-DIMENSIONAL.
LET'S START BY TAKING THE INITIAL VELOCITY AND BREAKING IT INTO COMPONENTS.
y
8.0 m/s
30°
x
20.0 m
ΔX
The x-component is 8.0 cos 30° = 6.9
The y-component is 8.0 sin 30° = 4.0
Careful! That's correct, but don't get in the habit of thinking x-components are always cosine and y-components are always sine. This x-component is only cosine because it's adjacent to the angle.


Now let's use our two kinematics equations with the x-component. The acceleration is downward, so it's zero in the x-direction.
$v_x = 6.9 + (0)t = 6.9$
$\Delta x = 6.9(t) + ½\,(0)t^2 = 6.9t$
TECHNICALLY, WE HAVE FOUR EQUATIONS AND FOUR UNKNOWNS: v_x, Δx, v_y, AND t.
BUT WE KNOW v_x. THE FIRST EQUATION TELLS US IT'S 6.9.
THEN WE ONLY HAVE THREE EQUATIONS. EITHER WAY, WE'RE READY TO SOLVE.
The question asks several different things regarding y. For now, let's choose the final point to be just before it hits the plain, so that Δy = -20.0m.
$v_y = 4.0 + (-9.8)t$
$\Delta y = -20.0 = 4.0(t) + ½\,(-9.8)t^2$
Solving the quadratic for t gives 2.5 or -1.7 s. We want the positive one, 2.5 s, to answer the last part of the task.
We can also answer the first part:
$\Delta x = 6.9t = 6.9(2.5) =$ 17 m
To figure out how high it goes, we need to choose a different final point. At its highest, it's not going up or down, so $v_y = 0$. Our four equations look like this:
$v_x = 6.9 + (0)t = 6.9$
$\Delta x = 6.9(t) + ½\,(0)t^2 = 6.9t$
$v_y = 0 = 4.0 + (-9.8)t$
$\Delta y = 4.0(t) + ½\,(-9.8)t^2$
The third gives t = 0.41 s. The last gives $\Delta y = 4.0(0.41) + ½\,(-9.8)(0.41)^2 = 0.8$ m.
So it reaches 20.8 m above the surrounding plain.
$V_y = 0$
h_{max}
y
ΔY
h_i
20.0m
x
ΔX

EQUATIONS IN THIS CHAPTER

$$a^2 + b^2 = c^2$$

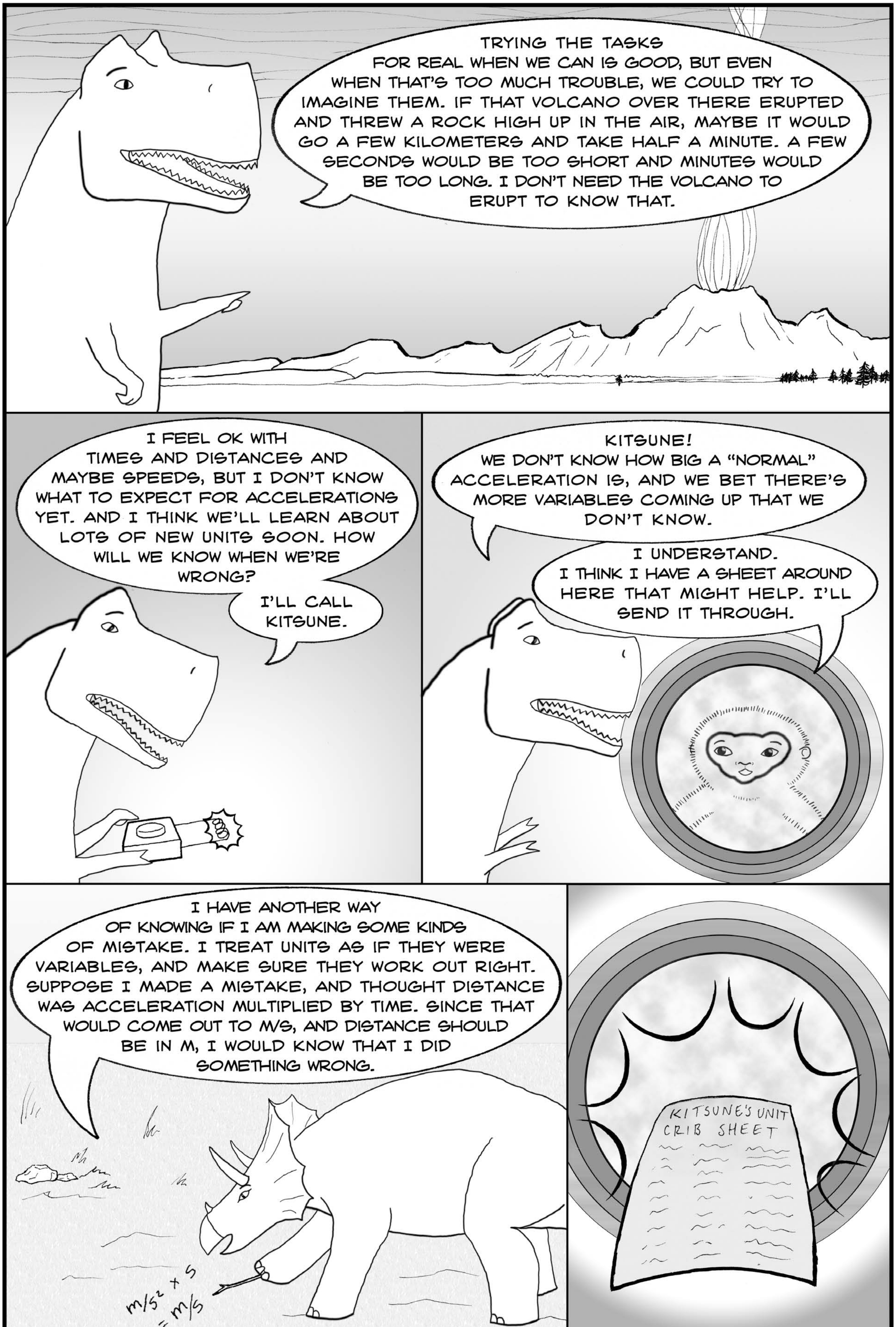
SOH CAH TOA

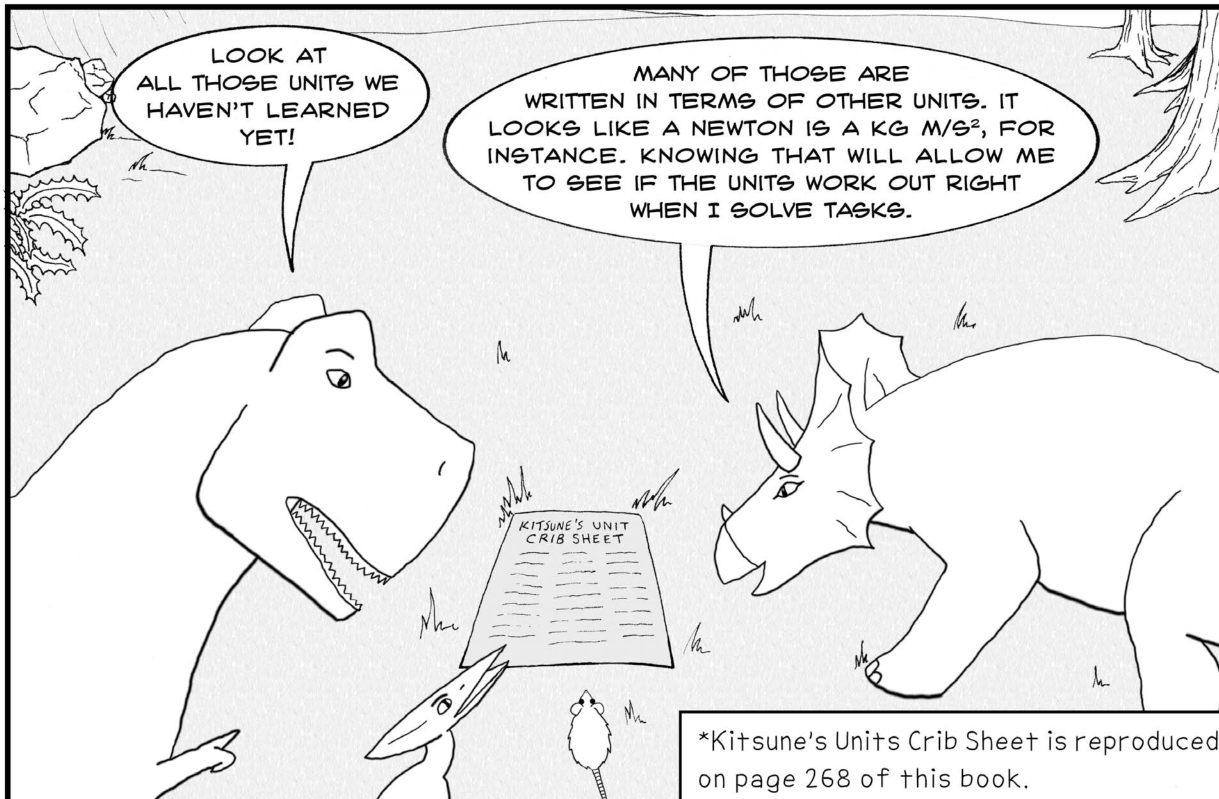
The sum of the angles in a triangle is 180°

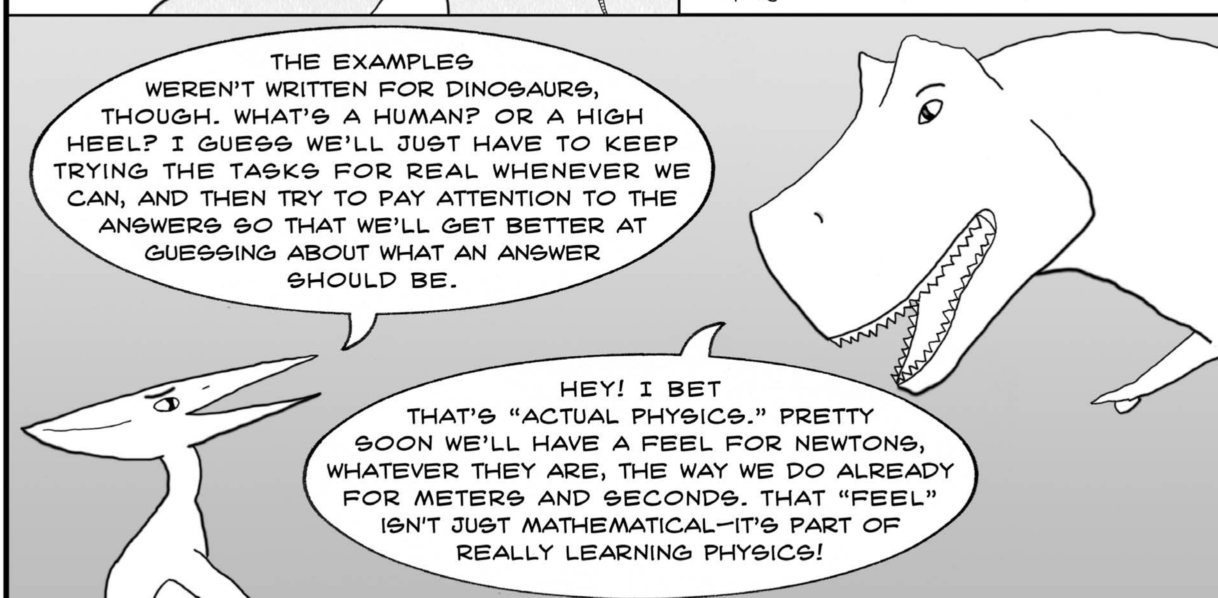
WORDS OF WISDOM

Use cosine to find the component adjacent to the angle and sine to find the component opposite to it


IS IT RIGHT?
WHAT DO YOU SUPPOSE "ACTUAL PHYSICS" IS?
I THINK WE'VE ALREADY BEEN DOING IT. PROF. ALFA SAID THOSE WERE MATHEMATICAL PRELIMINARIES ONLY BECAUSE HE DIDN'T WATCH HOW WE FIGURED OUT THE TASKS.
WHAT DO YOU MEAN?
FOR MOST OF THE TASKS, WE DIDN'T JUST WORK THEM OUT, WE TRIED THEM TOO.
eeee
WHEN WE GOT AN ANSWER, WE COULD CHECK IF IT MADE SENSE BY COMPARING IT TO WHAT ACTUALLY HAPPENS.
FOR EXAMPLE, IF WE HAD A TASK WHERE I DROPPED THE RAT-THING FROM 30 M UP, THE ANSWER SHOULD BE A FEW SECONDS. IF WE GOT AN ANSWER OF 20 SECONDS, THAT'S TOO LONG. 0.5 SECONDS WOULD BE TOO SHORT. AN ANSWER LIKE ONE OF THOSE WOULD MEAN WE HAD MADE AN ERROR CALCULATING, OR COPIED A FORMULA WRONG, OR SOMETHING LIKE THAT.


TRYING THE TASKS FOR REAL WHEN WE CAN IS GOOD, BUT EVEN WHEN THAT'S TOO MUCH TROUBLE, WE COULD TRY TO IMAGINE THEM. IF THAT VOLCANO OVER THERE ERUPTED AND THREW A ROCK HIGH UP IN THE AIR, MAYBE IT WOULD GO A FEW KILOMETERS AND TAKE HALF A MINUTE. A FEW SECONDS WOULD BE TOO SHORT AND MINUTES WOULD BE TOO LONG. I DON'T NEED THE VOLCANO TO ERUPT TO KNOW THAT.
I FEEL OK WITH TIMES AND DISTANCES AND MAYBE SPEEDS, BUT I DON'T KNOW WHAT TO EXPECT FOR ACCELERATIONS YET. AND I THINK WE'LL LEARN ABOUT LOTS OF NEW UNITS SOON. HOW WILL WE KNOW WHEN WE'RE WRONG?
I'LL CALL KITSUNE.
KITSUNE! WE DON'T KNOW HOW BIG A "NORMAL" ACCELERATION IS, AND WE BET THERE'S MORE VARIABLES COMING UP THAT WE DON'T KNOW.
I UNDERSTAND. I THINK I HAVE A SHEET AROUND HERE THAT MIGHT HELP. I'LL SEND IT THROUGH.
I HAVE ANOTHER WAY OF KNOWING IF I AM MAKING SOME KINDS OF MISTAKE. I TREAT UNITS AS IF THEY WERE VARIABLES, AND MAKE SURE THEY WORK OUT RIGHT. SUPPOSE I MADE A MISTAKE, AND THOUGHT DISTANCE WAS ACCELERATION MULTIPLIED BY TIME. SINCE THAT WOULD COME OUT TO M/S, AND DISTANCE SHOULD BE IN M, I WOULD KNOW THAT I DID SOMETHING WRONG.
$m/s^2 \times s = m/s$
KITSUNE'S UNIT CRIB SHEET

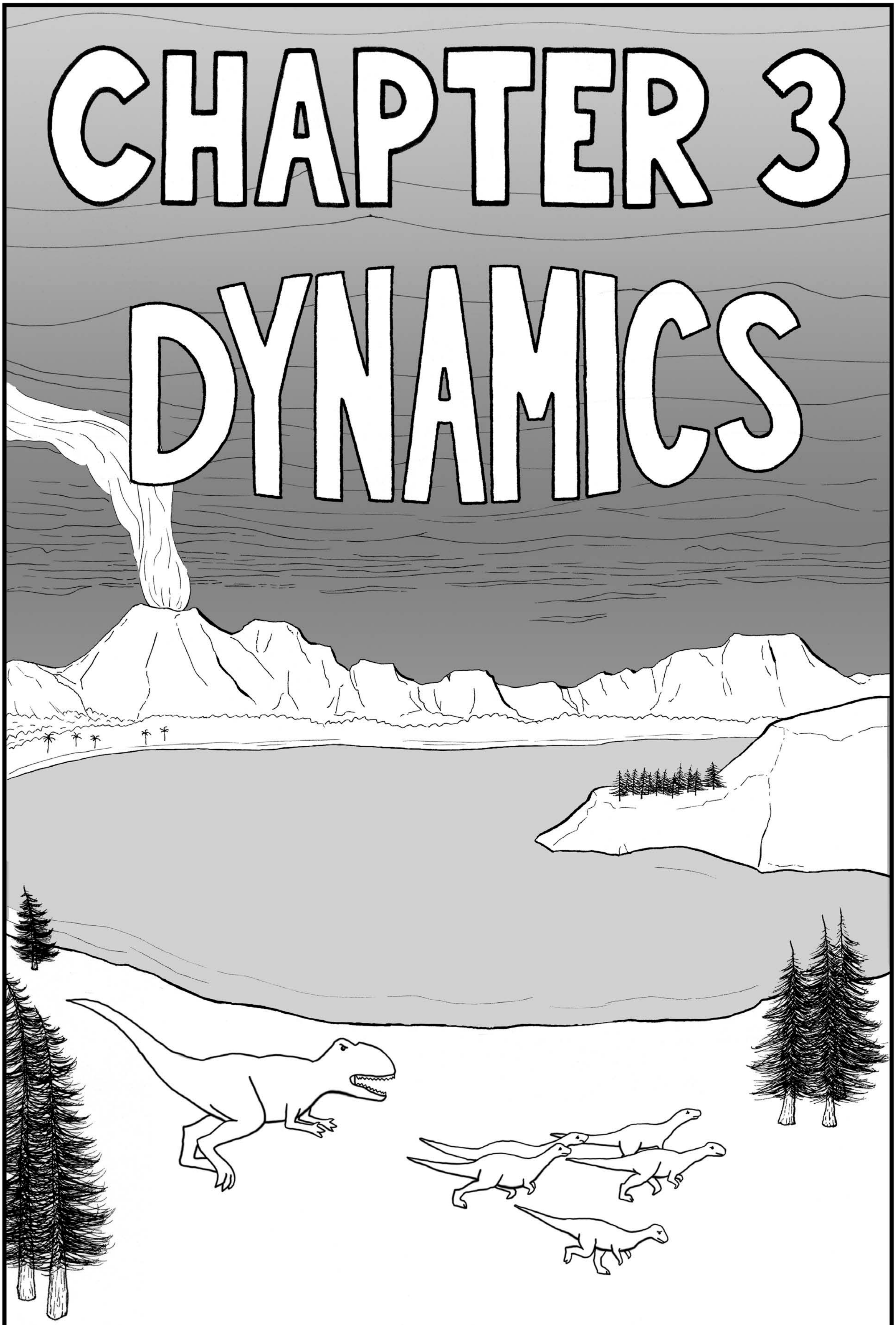


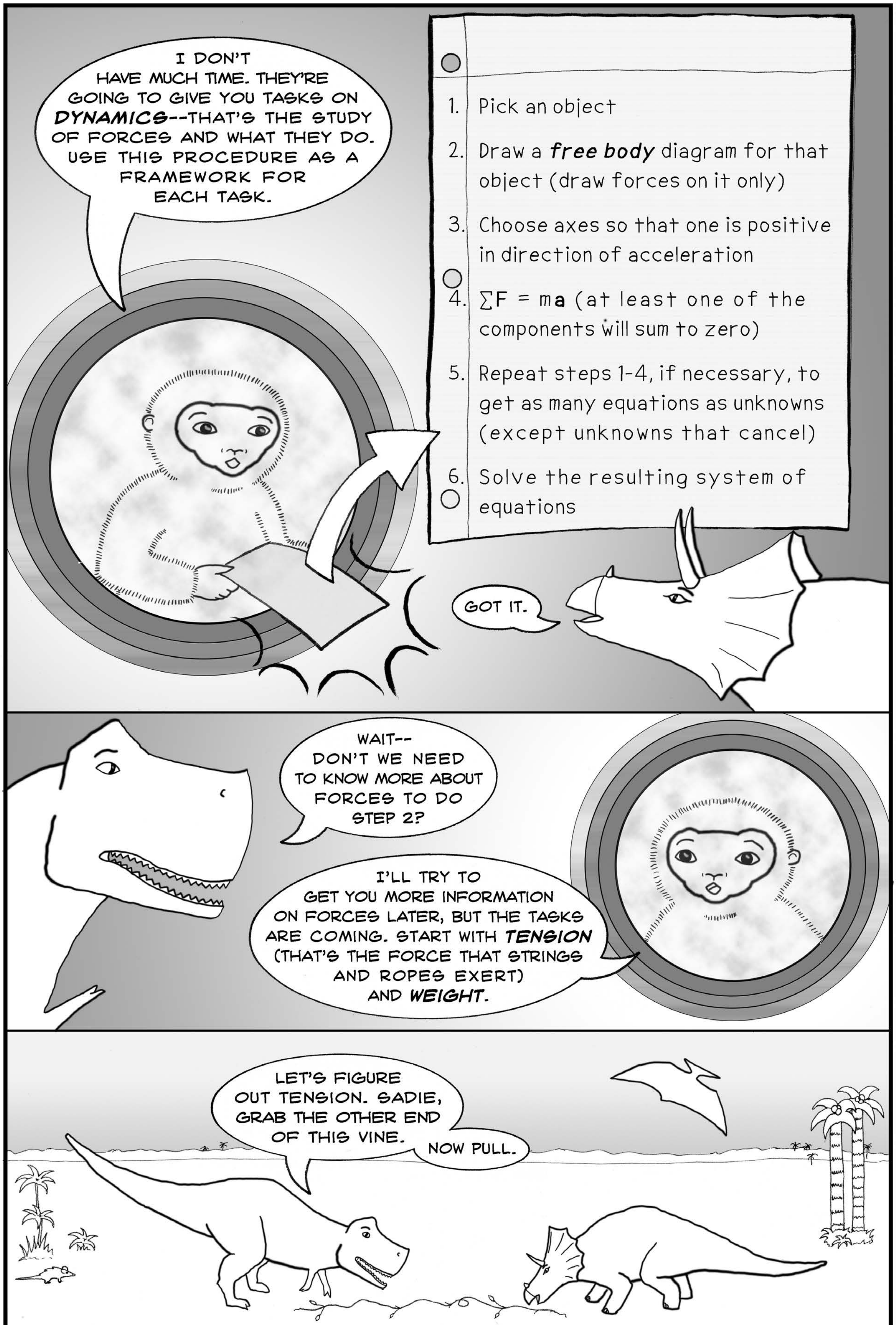


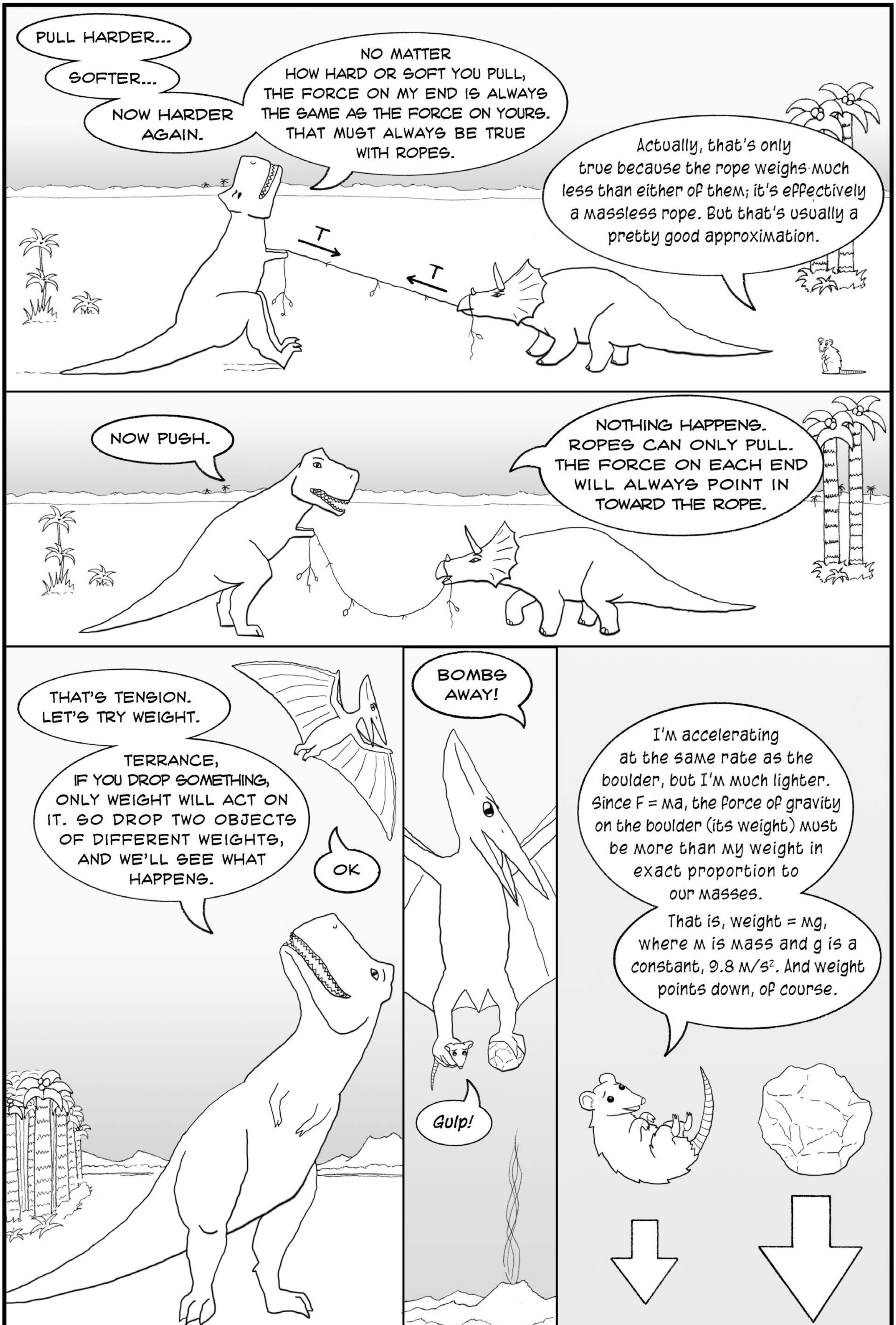
WORDS OF WISDOM

Estimation, either by experiment or imagination, helps catch mistakes

Units can be treated like variables


CHAPTER 3
DYNAMICS


I DON'T HAVE MUCH TIME. THEY'RE GOING TO GIVE YOU TASKS ON DYNAMICS--THAT'S THE STUDY OF FORCES AND WHAT THEY DO. USE THIS PROCEDURE AS A FRAMEWORK FOR EACH TASK.
1. Pick an object
2. Draw a free body diagram for that object (draw forces on it only)
3. Choose axes so that one is positive in direction of acceleration
4. ∑F = ma (at least one of the components will sum to zero)
5. Repeat steps 1-4, if necessary, to get as many equations as unknowns (except unknowns that cancel)
6. Solve the resulting system of equations
GOT IT.
WAIT-- DON'T WE NEED TO KNOW MORE ABOUT FORCES TO DO STEP 2?
I'LL TRY TO GET YOU MORE INFORMATION ON FORCES LATER, BUT THE TASKS ARE COMING. START WITH TENSION (THAT'S THE FORCE THAT STRINGS AND ROPES EXERT) AND WEIGHT.
LET'S FIGURE OUT TENSION. SADIE, GRAB THE OTHER END OF THIS VINE.
NOW PULL.


PULL HARDER...
SOFTER...
NOW HARDER AGAIN.
NO MATTER HOW HARD OR SOFT YOU PULL, THE FORCE ON MY END IS ALWAYS THE SAME AS THE FORCE ON YOURS. THAT MUST ALWAYS BE TRUE WITH ROPES.
Actually, that's only true because the rope weighs much less than either of them; it's effectively a massless rope. But that's usually a pretty good approximation.
T
T
NOW PUSH.
NOTHING HAPPENS. ROPES CAN ONLY PULL. THE FORCE ON EACH END WILL ALWAYS POINT IN TOWARD THE ROPE.
THAT'S TENSION. LET'S TRY WEIGHT.
TERRANCE, IF YOU DROP SOMETHING, ONLY WEIGHT WILL ACT ON IT. SO DROP TWO OBJECTS OF DIFFERENT WEIGHTS, AND WE'LL SEE WHAT HAPPENS.
OK
BOMBS AWAY!
Gulp!
I'm accelerating at the same rate as the boulder, but I'm much lighter. Since F = ma, the force of gravity on the boulder (its weight) must be more than my weight in exact proportion to our masses.
That is, weight = mg, where m is mass and g is a constant, 9.8 m/s². And weight points down, of course.