
THE COMIC BOOK SERIES BY physicscentral.com
APS physics www.aps.org
6
APRIL • 2014
SPECTRA
QUANTUM LEAP
Written by Rebecca Thompson, Ph.D.
Illustrated by Kerry G. Johnson

WELCOME TO PHYSICSQUEST

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History of the PhysicsQuest Program

As part of the World Year of Physics in 2005, the American Physical Society (APS) produced *PhysicsQuest: The Search for Albert Einstein's Hidden Treasure*. Designed as a resource for middle school science classrooms and clubs, the quest was received enthusiastically by nearly 10,000 classes during the course of 2005. Feedback indicated that this activity met a need within the middle school science community for fun and accessible physics material, so the American Physical Society has decided to continue this program. APS is pleased to present this ninth kit, *PhysicsQuest: Spectra's Quantum Leap (Issue #6)*.

In the past, each PhysicsQuest kit has followed a mystery-based storyline and requires students to correctly complete four activities in order to solve the mystery and be eligible for a prize drawing. For the fifth year in a row students will be following laser superhero Spectra. Past years have seen the downfall of the evil Miss Alignment, the unfortunate demise of General Relativity, the evil antics of Maxwell's Demon and descent into competitive madness of Henri Toueaux. In this edition of PhysicsQuest, Spectra and her gang will work with the mysterious Quantum Mechanic in hopes of saving a rogue minivan. Through the activities, they will learn about some modern physics and interesting uses for donuts.

About the American Physical Society (APS Physics)

APS is the professional society for physicists in the United States. APS works to advance and disseminate the knowledge of physics through its journals, meetings, public affairs efforts, and educational programs. Information about APS and its services can be found at www.aps.org.

APS also runs PhysicsCentral.com a website aimed at communicating the excitement and importance of physics to the general public. At this site, www.physicscentral.com, you can find out about APS educational programs, current physics research, people in physics and more.

PhysicsQuest: Spectra's *Quantum Leap (Issue #6)*

Written by Rebecca Thompson, Ph.D.

Illustrations by Kerry G. Johnson

Activity illustrations and graphics by Nancy Bennett-Karasik

Published by the American Physical Society

Printed in the U.S.A.

WELCOME TO PHYSICSQUEST

About PhysicsQuest

PhysicsQuest is designed with flexibility in mind – it can be done in one continuous session or split up over a number of weeks. The activities can be conducted in the classroom or as an extra credit or science club activity. The challenges can be completed in any order, but to get the correct final result all of the challenges must be completed correctly.

On Facebook

There's now a PhysicsQuest Facebook Group, that you may join to connect with other teachers and participants so that you can share and learn tips and trick.

About the PhysicsQuest Competition

APS sponsors an optional PhysicsQuest competition designed to encourage students to invest in the project. If you chose to participate in the competition, your class must complete the four activities.

SPECIAL NOTE: Due to the extreme weather on the East Coast, the school year will be ending at very different dates across the country. In order to give maximum time to all those wishing to participate in the PhysicsQuest competition, we will be extending the answer submission date. You must submit answers online by **September 12th, 2014.**

All classes that submit answers online will receive a certificate of completion and be entered into a prize drawing. Details on the prizes will be posted on the PhysicsQuest website as they become available.

The online results submission form does not require the answers to all of the questions on the Final Report. If your class only has time to complete some of the activities, they can still submit their answers, be eligible for prizes and receive a certificate of participation. Each class can only submit one entry form, so class discussions of results are encouraged.

Answers can be submitted online through the PhysicsQuest website beginning **April 15, 2014.**

The PhysicsQuest Materials

The PhysicsQuest kit includes this manual and most of the hardware your students need to complete the activities. There is also a corresponding website, www.physicscentral.com/physicsquest, and PhysicsQuest Facebook group. Information regarding PhysicsQuest will be posted in both of these locations.

The comic book

Each activity will be preceded by several pages of a comic book that will follow the adventures of Spectra. The comic is also available online.

The Materials list

For more information on these items and where they can be purchased, please visit the PhysicsQuest website. If your kit is missing any of these materials, please contact Educational Innovations, www.teachersource.com or (203) 229-0730

Included in this kit:

- Electromagnetic Spectrum Inhibitor tablets
- Diffraction grating viewer
- Red, green, and blue LEDs
- UV LED (the small one)
- CD
- Plastic Zip Tie
- Small cloth bag
- Warpable Space Time Simulator (Playdough)
- Manual/Comic book
- 2 Batteries
- Glow in the dark vinyl
- Chopsticks
- 4 binder clips
- Flashlight
- Playdough
- 6 toothpicks
- 3 Strands of ribbon

Not included in this kit:

- Water
- Scissors
- Plastic cups
- Tape
- Lots of tape
- Permanent marker

WELCOME TO PHYSICSQUEST

The Teacher Guide includes:

· **Key Question**: This question highlights the goal of the activity.

· **Key Terms**
This section lists terms related to the activity that the students will encounter in the Student Guide.

· **Before the Activity:**
Students should be familiar with these concepts and skills before tackling the activity.

· **After the Activity:**
By participating in the activity, students are practicing the skills and studying the concepts listed in this section.

· **The Science Behind…**
This section includes the science behind the activity, The Student Guide does not include most of this information; it is left to you to decide what to discuss with your students.

· **Safety**
This section highlights potential hazards and safety precautions.

· **Materials**
This section lists the materials needed for the activity. Materials that are provided in the kit are in bold type; you will need to provide the rest.

· **Bibliography and Suggested Resources**
This section lists resources used to create this activity and recommended resources for more information on the topics covered.

The Student Guide
Each activity has a Student Guide that you will need to copy and hand out to all of the students.

The Student Guide includes:

· **Key Question**
This question highlights the goal of the activity.

· **Materials**
This section lists the materials students will need for the activity.

· **Getting Started**
This section includes discussion questions designed to get students thinking about the key question, why it's important, and how they might find an answer.

· **The Experiment**
This section leads students step-by-step through the set-up and data collection process.

· **Analyzing your Results**
This section leads students through data analysis and has questions for them to answer based on their results.

PhysicsQuest Website

The PhysicsQuest website:
www.physicscentral.com/physicsquest,
has periodic updates on the program.

PhysicsQuest Logistics

Materials
The PhysicsQuest kit comes with only one set of materials. This means that if your students are working in four small groups (recommended), all groups should work simultaneously on different activities and then rotate activities, unless you provide additional materials. The Materials List on the PhysicsQuest website includes specific descriptions of the materials and where they can be purchased. All materials can be reused.

Safety
While following the precautions in this guide can help teachers foster inquiry in a safe way, no manual could ever predict all of the problems that might occur. Good supervision and common sense are always needed. Activity-specific safety notices are included in the Teacher Guide when appropriate.

Time Required
The time required to complete the PhysicsQuest activities will depend on your students and their lab experience. Most groups will be able to complete one activity in about 45-minutes.

Small Groups
Working effectively in a group is one of the most important parts of scientific inquiry. If working in small groups is challenging for your students, you might consider adopting a group work model such as the one presented here.

Group Work Model
Give each student one of the following roles. You may want to have them rotate roles for each activity so they can try many different jobs.

· Lab Director
Coordinates the group and keeps students on task.

· Chief Experimenter
Sets up the equipment and makes sure the procedures are carried out correctly.

· Measurement Officer
Monitors data collection and determines the values for each measurement.

· Report Writer
Records the results and makes sure all of the questions in the Student Guide are answered.

· Equipment Manager
Collects all equipment needed for the experiment. Makes sure equipment is returned at the end of the class period and that the lab space is clean before group members leave.

PhysicsQuest in the Classroom

This section suggests ways to use PhysicsQuest in the classroom. Since logistics and goals vary across schools, please read through the suggestions and then decide how best to use PhysicsQuest. Feel free to be creative!

· PhysicsQuest as a stand-alone activity
PhysicsQuest is designed to be self-contained – it can be easily done as a special project during the day(s) following a test, immediately preceding/following a break, or other such times. PhysicsQuest also works well as a science club activity and extra credit opportunity.

· PhysicsQuest as a fully integrated part of regular curriculum
The topics covered in PhysicsQuest are covered in many physical science classes, so you might have students do the PhysicsQuest activities during the corresponding units.

· PhysicsQuest as an all-school activity
Some schools set up PhysicsQuest activity stations around the school gym for one afternoon. Then small groups of students work through the stations at assigned times.

· PhysicsQuest as a mentoring activity
Some teachers have used PhysicsQuest as an opportunity for older students to mentor younger students. In this case, 8th or 9th grade classes first complete the activities themselves, and then go into 6th or 7th grade classrooms and help students with the activities.

ACTIVITY 1 - A

TEACHER GUIDE

ACTIVITY 1: COLOR BLOCKERS

INTRO
As the ziplock bag commercial says: "Yellow plus blue makes green." But why, exactly? Why do we see the colors we do through transparent things such as ziplock bags and water? This experiment will use rainbows to explore why.

KEY QUESTION
Wh colors of light are absorbed and transmitted by different colors of water?

KEY TERMS
Absorb: To take something in. In the case of light, it means a atom takes in the photon's energy and doesn't let the photon pass through.

Transmit: Allow to pass through. The opposite of absorb. Light is either absorbed or it is transmitted.

Spectrum: The different colors of light. The "spectrum" of a blue LED is different than the "spectrum" of a red LED.

MATERIALS
- Electromagnetic Spectrum Inhibitor tablets
- Diffraction grating viewer
- Red, green, and blue LEDs
- Batteries
- Flashlight
- Water
- 3 clear plastic cups*
- Tape*

**Not included in the PhysicsQuest Kit*

BEFORE THE ACTIVITY STUDENT SHOULD KNOW
- White light is made up of many colors
- When looked at through a special grating the light is split into those colors
- Light is made up of photons

AFTER THE ACTIVITY STUDENTS SHOULD BE ABLE TO
- Discuss what it means for light to be transmitted and what it means to be absorbed
- Say which colors of light are absorbed and transmitted by different colors of water.

THE SCIENCE BEHIND ABSORPTION AND TRANSMISSION
What does "Quantum Mechanics" mean?

First off, Quantum Mechanics isn't some magic theory that is a mystical way of looking at the world. It won't make you rich or thin, despite what some popular books might say. I've seen plenty of overweight physicist. Welcome to the modern physics PhysicsQuest kit. The first question you may have is how are rainbows related to the Quantum Mechanic. And what is "quantum mechanics" exactly. Which are very reasonable questions. Quantum Mechanics is a way of looking at the very small things that make up atoms, like neutrons and electrons, and other small bits like photons. Things that small don't behave the way you would think they should. They pretty much behave exactly the opposite of how you think they should but physicists can describe how they work using Quantum Mechanics.

What does the term "Quantum Mechanics" actually mean? "Quantum" means something that comes in specific amounts. Electrons have a charge of 1.6×10^{-19} coulombs. You can only get charge in that amount, not 2.3×10^{-19} coulombs or 1.0×10^{-19} coulombs. Charge has to come in multiples of 1.6×10^{-19}. It is "quantized". "Quantum Mechanics" is a way of looking at the "mechanics," or interactions, of these small, quantized things. Charge isn't the only thing quantized, energy is too. In the comic book, when Dr. Hene's mini van can only go two specific speeds but nothing in between, her energy is "quantized" meaning it can be one way or another but nothing in between.

ACTIVITY 1 - B

TEACHER GUIDE

ACTIVITY 1: COLOR BLOCKERS

Quantum Mechanics and Light

Light is made up of small particles called photons. When you look at a rainbow, the different colors are made up of photons with different energies. Violet has more energy than red. In fact, the energy in each photon increases as you move from red to violet, so green has more energy than yellow. The reason the rainbow splits the way it does is because of the amount of energy in each color's photons.

Atoms are made of electrons in clouds around a nucleus. The energy of these electrons is also "quantized." Electrons around an atom can have one energy or another but nothing in between. The way an atom is usually drawn, with electrons at specific points around a nucleus, is a good way to think of energy levels. The different orbits of the electrons represent different energy levels. There are many different energy levels and electrons can move between one and the other. To get an electron to move from one energy to another, it has to have something add exactly the right amount of energy to kick it up to another energy level. (Fig. 1) Just like Dr. Hene's foot on the gas pedal caused her mini van to move from one speed right to another. For atoms this "foot on the gas" is a photon. If a photon with just the right amount of energy hits an atom, the electrons jump around. When this happens, the photon is "absorbed." And different atoms have electrons that can have different energy levels. So the electrons in hydrogen can have different energy levels than the electrons in oxygen. Which means oxygen "absorbs" different color photons than hydrogen. Photons that don't have the right energy to knock around the electrons will just pass right on by. They are "transmitted."

In this activity the students will look at what happens to light as it passes through different colors of water. They will see that for colored water, only a few colors of light will pass through. The rest of the colors are absorbed by the colored water. In the case of the blue water, the molecules that make up the blue dye have the right energy levels to absorb almost all colors. Every color photon except blue and green will be absorbed. This is why the water appears blue.

SAFETY

Electromagnetic Spectrum Inhibitor tablets (fizzy food coloring) should not be eaten due to the fizzing. Follow safety instructions on packet.

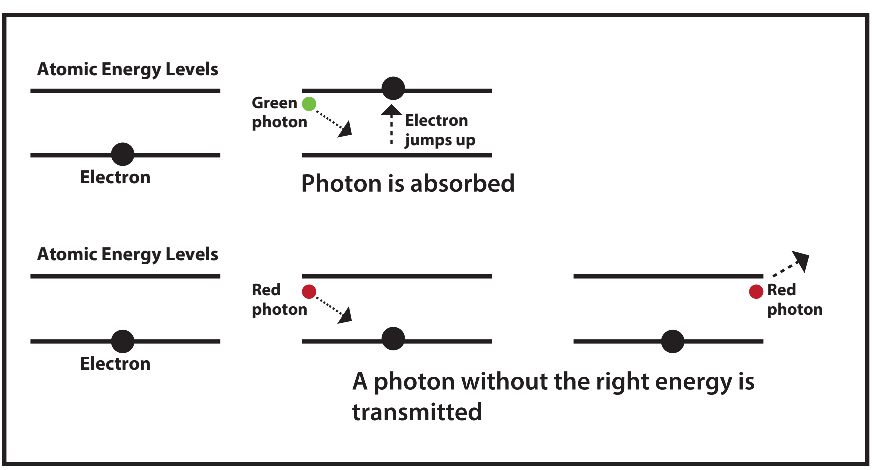
SUGGESTED RESOURCES

■ Great explanation of absorption spectra:
http://www.colorado.edu/physics/2000/quantumzone/fraunhofer.html

■ Good intro to energy levels of the atom:
http://www.colorado.edu/physics/2000/quantumzone/bohr2.html

■ Intro to the atom and energy levels:
http://csep10.phys.utk.edu/astr162/lect/light/bohr.html

Figure 1



ACTIVITY 1 - C

STUDENT GUIDE

ACTIVITY 1: COLOR BLOCKERS

INTRO

As the ziplock bag commercial says: "Yellow plus blue makes green." But why, exactly? Why do we see the colors we do through transparent things such as ziplock bags and water? This experiment will use rainbows to explore why.

KEY QUESTION

What colors of light are absorbed and transmitted by different colors of water?

KEY TERMS

Absorb: To take something in. In the case of light, it means a atom takes in the photon's energy and doesn't let the photon pass through.

Transmit: Allow to pass through. The opposite absorb. Light is either absorbed or it is transmitted.

Spectrum: The different colors of light. The "spectrum" of a blue LED is different than the "spectrum" of a red LED.

MATERIALS

- Electromagnetic Spectrum Inhibitor tablets
- Diffraction grating viewer
- Red, green, and blue LEDs
- Batteries
- Flashlight
- Water
- 3 clear plastic cups*
- Tape*

**Not included in the PhysicsQuest Kit*

GETTING STARTED

What are the colors of a rainbow? ______________________________

What color do you think is the most "energetic"? Why? ______________________________

What does it mean when light is "transmitted?" What about "absorbed?" ______________________________

____

Why do oceans look blue? ______________________________

SETTING UP THE EXPERIMENT

1. Fill the three plastic cups half way full of water

2. Color the water red, yellow, and blue using the "Electromagnetic Spectrum Inhibitor Tablets" (Fig. 1)

3. Tape the flashlight to the edge of a table or chair so that it is pointing straight up. (Fig. 21)

4. Straddle the battery with the red LED making sure to put the longer leg on the positive side of the battery (the one with the "+" sign).

5. Tape the lit LED to the edge of the table or chair about a foot away from the flashlight. (Fig. 2)

ACTIVITY 1 - D

STUDENT GUIDE

ACTIVITY 1: COLOR BLOCKERS

ANALYZING YOUR RESULTS

Looking at white light:

1. Look through take the diffraction grating viewer at the flashlight. What do you see? Draw it here:

2. Tape the diffraction grating viewer over the cup with red water and hold it over the flashlight (Fig. 3). What do you see? Draw it here:

3. Do the same thing with the yellow and blue water, drawing what you see.

When white light passes through water, some colors of light are **absorbed**, which means they are blocked, and some are **transmitted**, meaning they pass through. The colors that you see are the ones that are transmitted. The other colors are **absorbed**.

Write down which colors are transmitted and which are absorbed by each color of water:

Water	Colors transmitted	Colors absorbed
Yellow		
Red		
Blue		

Looking at different colors of light

1. This time we're going to do the same thing, but instead of looking at white light, we're going to look at specific colors of light, red, blue, and green.

2. What colors do you think you would see if you looked through the diffraction grating viewer at the red LED. Try it and see if you are right.

3. Look at the chart you made above. Now instead of white light, you only have red. What do you think will happen when you look through the red, yellow, and blue water? What will you see? Record your predictions in the "Prediction" table.

4. Try it and record your results in the "results" table.

5. Do the same for the blue and green LEDs

Prediction (LED)	Red water	Yellow water	Blue water
Red			
Blue			
Green			

Results (LED)	Red water	Yellow water	Blue water
Red			
Blue			
Green			

Were your predictions correct? ______________________________

What did you find surprising? ______________________________

■ What do you think would happen if you looked at the LEDs through two colors of water at once?

■ Try the combinations in the table and see what you find!

Prediction (LED)	Red water / yellow water	Red water / blue water	Yellow water / blue water
Red			
Blue			
Green			

Results (LED)	Red water / yellow water	Red water / blue water	Yellow water / blue water
Red			
Blue			
Green			

■ **What other combinations do you think would be interesting?**

■ **What would happen if you looked through all three colors of water at the white light?**

■ **Which colors are absorbed by blue and yellow water?**

1. Yellow and blue **.** Everything but blue and yellow **.** Everything but green **4.** Everything but blue

Figure 1

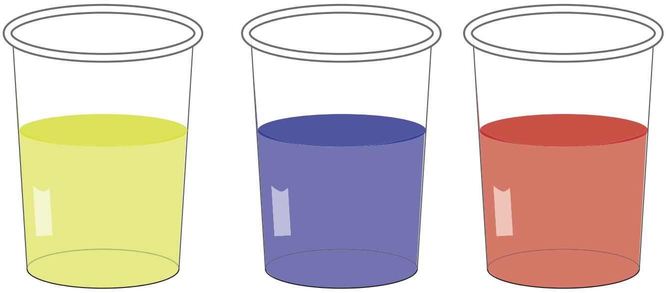


Figure 2

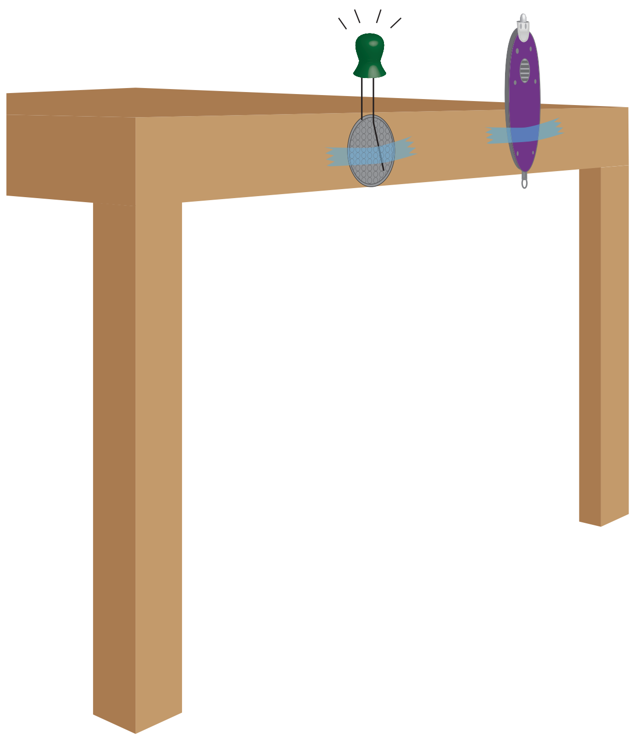
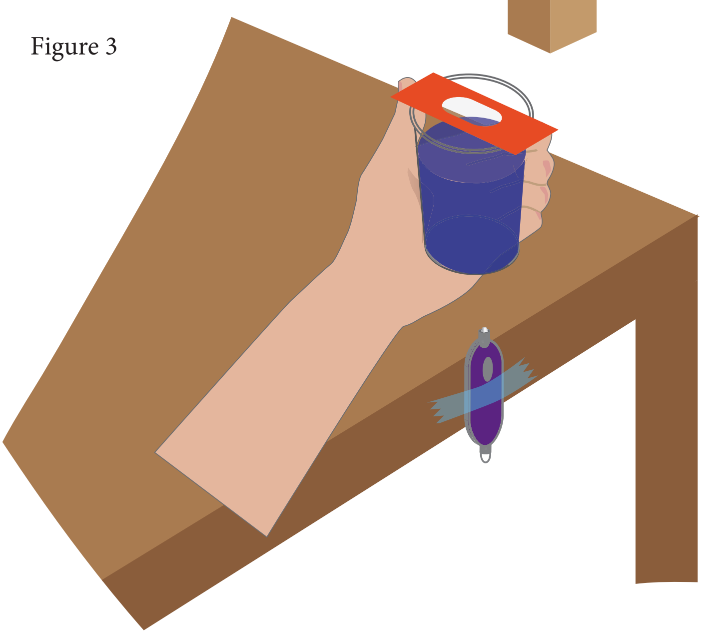


Figure 3

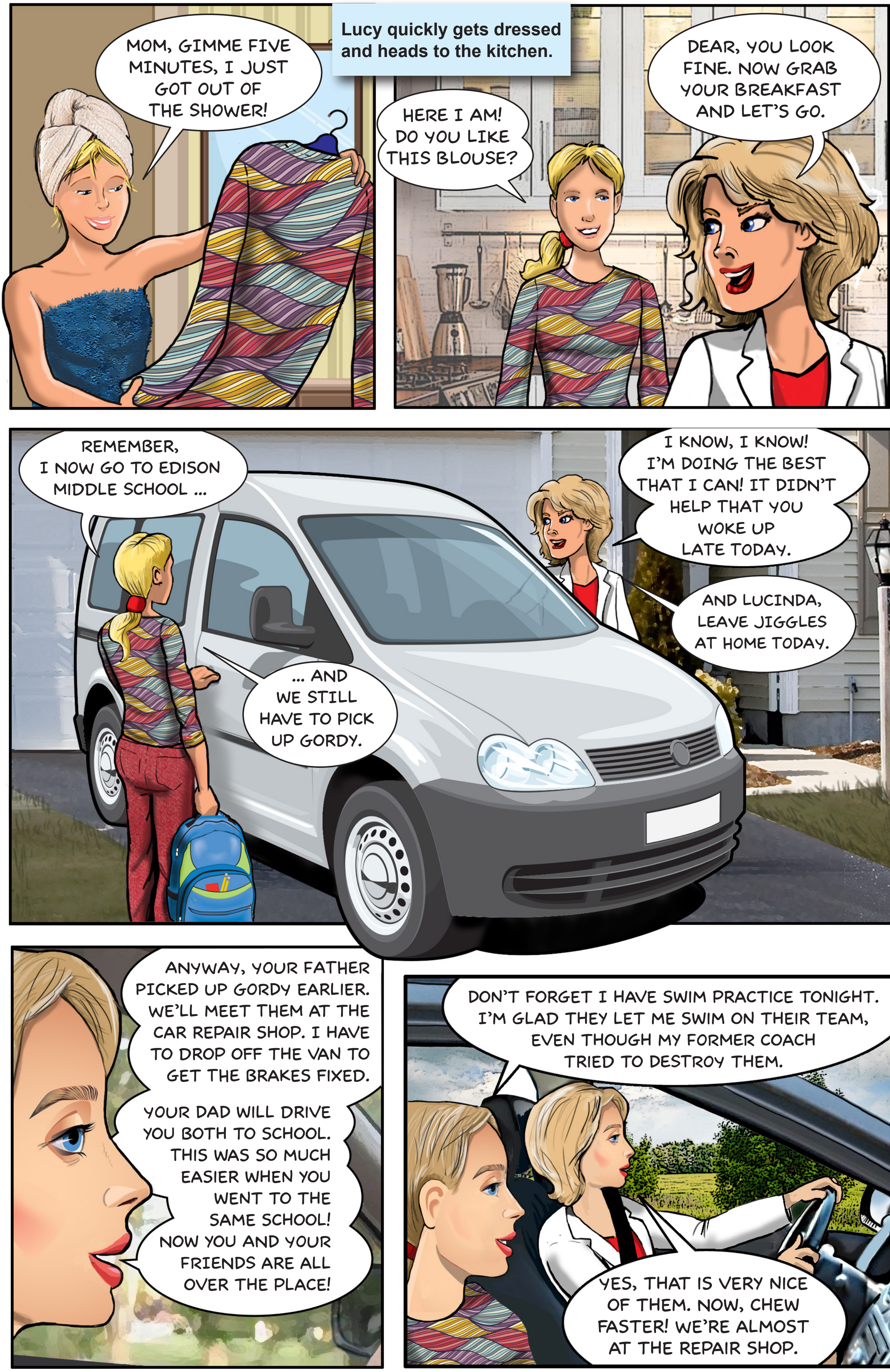


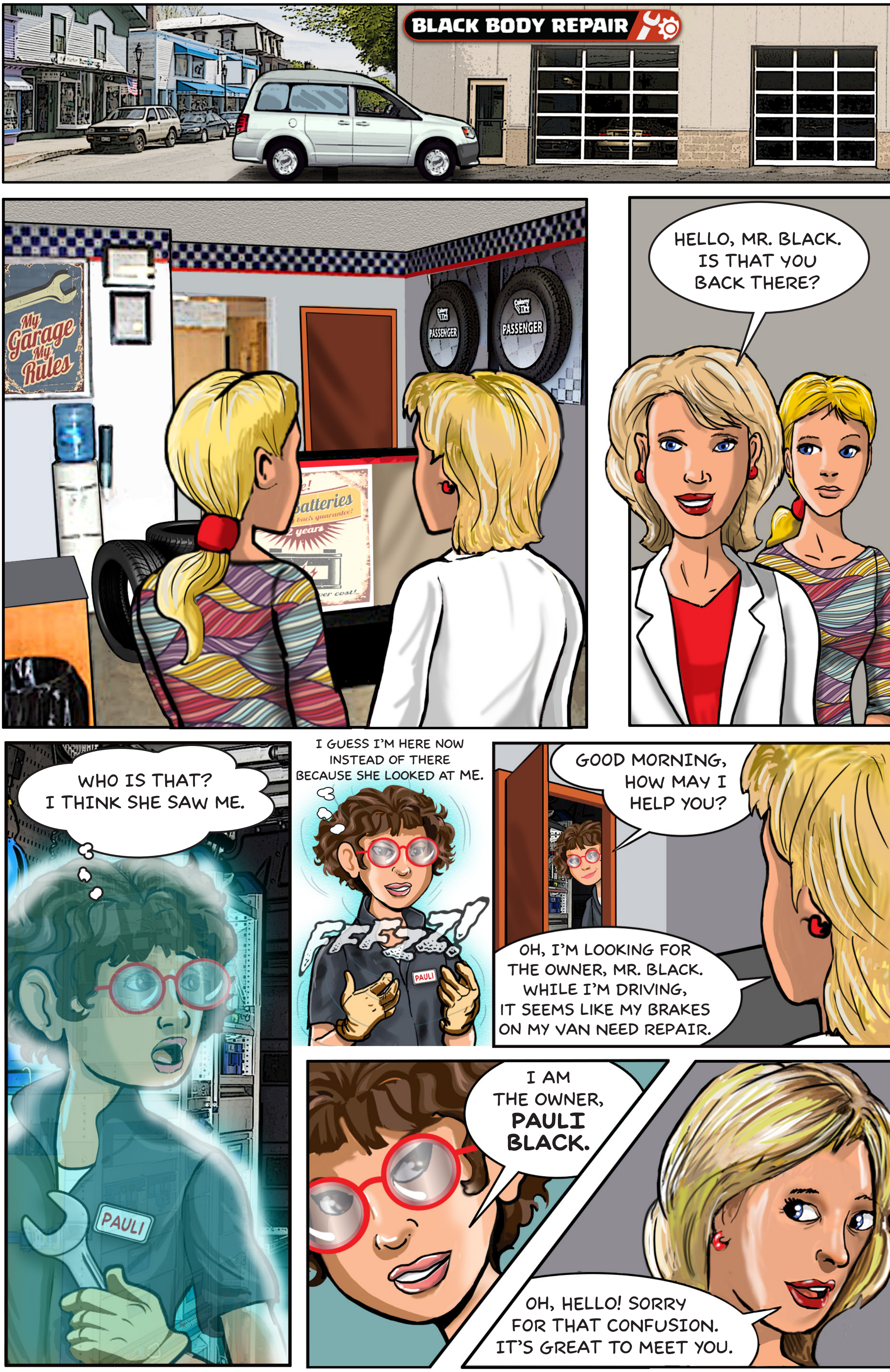
It's another school year for Lucinda Hene (Spectra). Her middle school, Nikola Tesla Junior High is in ruins after the villainous swim coach H. Toueaux (H20) destroyed the gym and aquatic center during the swim meet championship in Issue #5. While the school is being renovated, Lucy, Kas, Ruby and Gordy have been scattered between three different schools as they wait for their school to be rebuilt. This is where the story begins...

SPECTRA'S QUANTUM LEAP

WRITTEN BY REBECCA THOMPSON, PH.D.
ILLUSTRATED BY KERRY G. JOHNSON

It's 5:50 a.m. at the Hene household and you can hear the blaring sound of Lucy's alarm clock app!


Lucy quickly gets dressed and heads to the kitchen.
MOM, GIMME FIVE MINUTES, I JUST GOT OUT OF THE SHOWER!
HERE I AM! DO YOU LIKE THIS BLOUSE?
DEAR, YOU LOOK FINE. NOW GRAB YOUR BREAKFAST AND LET'S GO.
REMEMBER, I NOW GO TO EDISON MIDDLE SCHOOL ...
... AND WE STILL HAVE TO PICK UP GORDY.
I KNOW, I KNOW! I'M DOING THE BEST THAT I CAN! IT DIDN'T HELP THAT YOU WOKE UP LATE TODAY.
AND LUCINDA, LEAVE JIGGLES AT HOME TODAY.
ANYWAY, YOUR FATHER PICKED UP GORDY EARLIER. WE'LL MEET THEM AT THE CAR REPAIR SHOP. I HAVE TO DROP OFF THE VAN TO GET THE BRAKES FIXED.
YOUR DAD WILL DRIVE YOU BOTH TO SCHOOL. THIS WAS SO MUCH EASIER WHEN YOU WENT TO THE SAME SCHOOL! NOW YOU AND YOUR FRIENDS ARE ALL OVER THE PLACE!
DON'T FORGET I HAVE SWIM PRACTICE TONIGHT. I'M GLAD THEY LET ME SWIM ON THEIR TEAM, EVEN THOUGH MY FORMER COACH TRIED TO DESTROY THEM.
YES, THAT IS VERY NICE OF THEM. NOW, CHEW FASTER! WE'RE ALMOST AT THE REPAIR SHOP.


BLACK BODY REPAIR
My Garage My Rules
PASSENGER
PASSENGER
HELLO, MR. BLACK. IS THAT YOU BACK THERE?
WHO IS THAT? I THINK SHE SAW ME.
PAULI
I GUESS I'M HERE NOW INSTEAD OF THERE BECAUSE SHE LOOKED AT ME.
FFFZZ!
PAULI
GOOD MORNING, HOW MAY I HELP YOU?
OH, I'M LOOKING FOR THE OWNER, MR. BLACK. WHILE I'M DRIVING, IT SEEMS LIKE MY BRAKES ON MY VAN NEED REPAIR.
I AM THE OWNER, **PAULI BLACK.**
OH, HELLO! SORRY FOR THAT CONFUSION. IT'S GREAT TO MEET YOU.

ACTIVITY 2 - A

TEACHER GUIDE

ACTIVITY 2: Hidden Rainbow

INTRO

We know that UV light gives us a sunburn, but why? Are there colors of light beyond what our eye can see? Is there a way of "seeing" them? In this activity students will use glow-in-the-dark material to "see" some of the hidden part of the rainbow.

KEY QUESTION

Is there anything beyond the violet end of the rainbow and if so, how can we see it?

KEY TERMS

Ultraviolet light: This type of light has a higher energy than violet light. It often can't be seen. It is the type of light responsible for sunburns.

Photon: A particle of light. Photons of different colors of light have different energies

MATERIALS

- Glow in the dark vinyl
- Binder clips
- UV LED (the small one)
- 2 batteries
- CD
- Flashlight
- Adhesive tape*

* *Not included in the PhysicsQuest Kit*

BEFORE THE ACTIVITY STUDENTS SHOULD KNOW

- Light is made of photons
- Violet light has a higher energy than red light

AFTER THE ACTIVITY, STUDENTS SHOULD BE ABLE TO ...

- Explain that there are "colors" of light beyond what the eye can see
- Understand that it is possible to detect things even if we can't see them
- Talk about ways to effectively measure things we can't directly see

The science behind UV light.

In the "about the science" section of Activity 1: Color Blockers, we talked about what happens when ***photons****, particles of light, run into atoms and molecules. It would probably be a good idea to read that section if you haven't yet, this activity builds on the ideas discussed there.*

In this activity the students will use glow-in-the-dark material to see light past the violet of the normal visible rainbow. Like we talked about in Activity 1, photons of different colors have different energies and blue has higher energy than red. Anything past the violet we can see is going to have even higher energy. These are called "Ultraviolet" or "UV" photons. In many cases our eyes can't see that far into the UV. But glow in the dark material can detect it.

The glow in the dark material is made up of special molecules called phosphors. Normally to make this stuff glow, it needs to be charged up with white light. When photons from a light source hit the molecules they excite the electrons and make them jump up to a higher energy level. Once they are up there they don't stay there forever. They slowly fall back down to a lower energy level and something has to happen to the energy they are losing because we know that energy can't be created or destroyed. The energy the electrons lose pops out as photons and the material seems to glow. But this isn't all the material can do.

As we talked about in the explanation for Activity 1, to get an electron to jump from one energy level to a higher level it must be hit by a photon with the right energy is Fig. 1. The energy levels. If the difference in energy from one level to the next is the energy a blue photon carries, if the electron is hit by a red photon, it won't jump up. It will just sit right where it is and the red photon will simply continue on its way.

However, if that same electron is hit by a blue, or even violet photon it will jump up and then eventually fall down and emit a photon again. One really cool thing to realize is that this electron which needs a blue photon to jump up could be hit by hundreds, millions, quadrillions of red photons and it still won't budge. It must have the energy of a blue photon.

This is true even for the wavelengths of light our eyes can't see. When UV light hits the glow in the dark material, it "charges up" the material and causes it to glow. Because there is so much energy in UV photons, they very quickly charge up the molecules in the material and it glows very brightly. So when a rainbow made up of both a regular white LED and a UV LED is shone on a glow in the dark square, the section with UV begins to glow brightly. So even though our eyes can't see that part of the UV spectrum, the glow in the dark material can tell us where it is.

TEACHER GUIDE

ACTIVITY 2: Hidden Rainbow

SAFETY

Looking directly at the UV diode for an extended amount of time can cause eye damage.

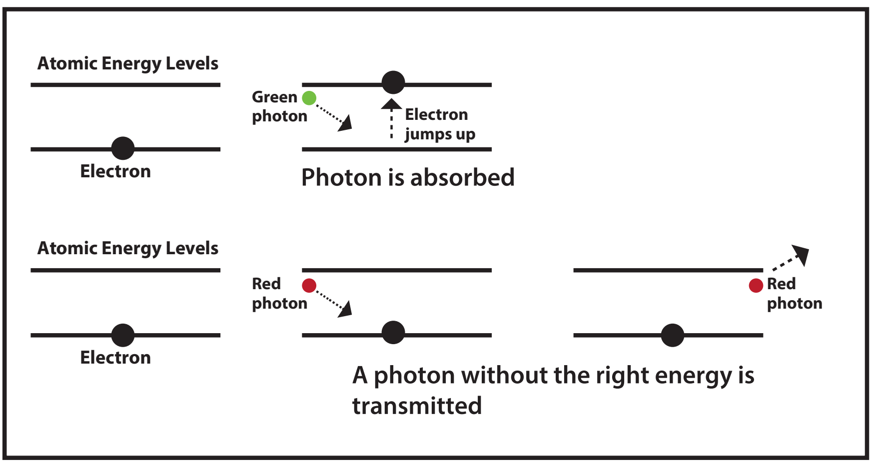
SUGGESTED RESOURCES

■ **More ways to detect UV:**
http://www.teachersource.com/product/ultraviolet-detecting-beads/light-color

■ **Great article on Glow in the Dark material and great overall site:**
http://www.physics.org/article-questions.asp?id=63

■ **Great video on photons and their importance in Quantum Mechanics.**
I highly recommend minutephysics
https://www.youtube.com/watch?v=hSgIDgGpRpk

Figure 1



ACTIVITY 2 - C

STUDENT GUIDE

ACTIVITY 2: Hidden Rainbow

KEY QUESTION

Is there anything beyond the violet end of the rainbow and if so, how can we see it?

INTRO

Everyone can name the colors of the rainbow, but is that all there is to it? Is there anything just beyond what our eye can see? And if so, is there any way we can detect it? In this activity you'll see a little piece of what's hidden beyond the rainbow we know.

MATERIALS

- Glow in the dark vinyl
- 4 binder clips
- UV LED (the small one)
- 2 batteries
- CD
- Flashlight
- Tape*

** Not included in the PhysicsQuest Kit*

GETTING STARTED

What are the colors of the rainbow? Draw them:

Do you think there is light beyond what we see? Where would it fit on the rainbow?

How do you think it might be possible to detect colors of light you can't see?

SETTING UP THE EXPERIMENT

You are going to be creating a rainbow by reflecting light from a flashlight off of a CD.

1. Attach binder clips to the CD so that it can stand up. (Fig. 1)
2. Attach a binder clip to the flashlight so that you can put it on a table and aim it at the CD. It may help to take the key ring off. (Fig. 2)

Making the UV LED light up (Fig. 3):

1. Put the two batteries together so that the smooth side of one is against the bumpy side of the other. Don't tape them together yet.
2. Take the UV LED and straddle the batteries with the legs of the LED making sure the longer leg is on the smooth side of the battery. The LED should glow purple.
3. Tape the whole thing together so that it stays lit.
4. Put it in a binder clip just like the flashlight.

ANALYZING YOUR RESULTS

To be able to "see" the hidden part of the rainbow, the first step is to make a rainbow.

1. In a dark room, set the CD at angle about 1-2 feet away from a wall.

2. Put the flashlight at an angle about 6 inches from the CD so the light from the flashlight bounces off the CD onto the wall.

3. Move it around until you can see a rainbow on the wall. This might be a little tricky and require some work, but keep trying, you can do it. (Fig. 4)

4. What colors do you see? Draw the rainbow here:

5. Now put the glow in the dark square on the wall so the rainbow is projected on it. What do you see now?

6. Take the glow in the dark square away so the rainbow is just on the wall again.

7. Bring the UV LED up right next to the flashlight so that they are both being projected on the wall. (Fig. 5)

ACTIVITY 2 - D

STUDENT GUIDE

ACTIVITY 2: Hidden Rainbow

8. What colors do you see now? Is anything different?

9. Again put the glow in the dark square on the wall so that the rainbow is projected on it.

10. What do you see right away and what do you see if you wait a few seconds?

11. Take the glow in the dark square out of the way of the rainbow. What does it look like?

The glow in the dark square glowed ...

1. More with the UV diode, which has more energy than other colors of light

2. The same with or without the UV diode

3. More with the UV diode, which has less energy than the other colors of light.

4. Less with the UV diode

Figure 1

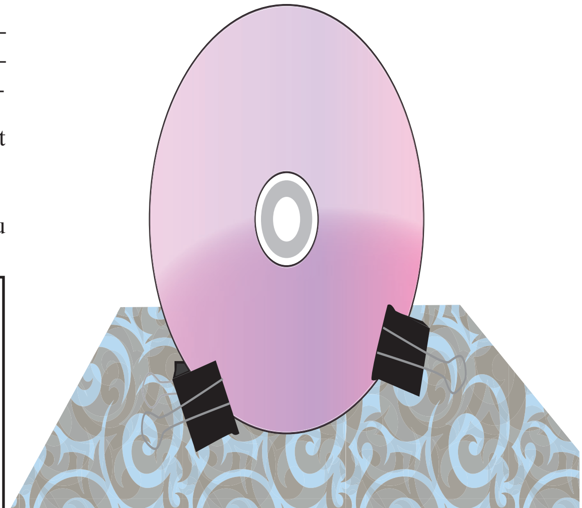
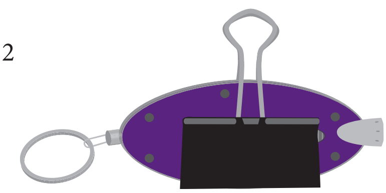


Figure 2



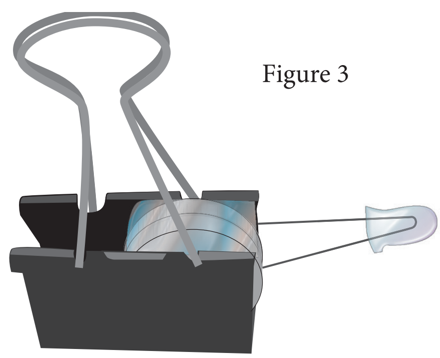
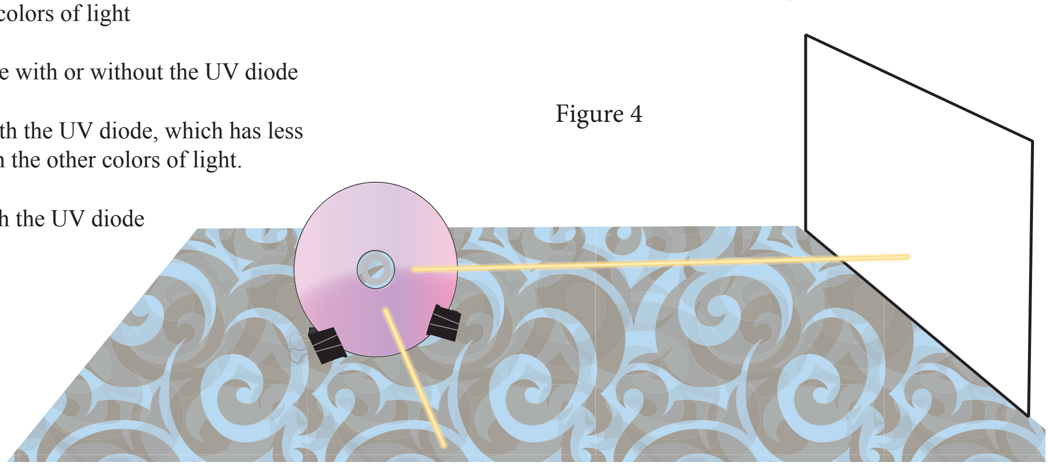
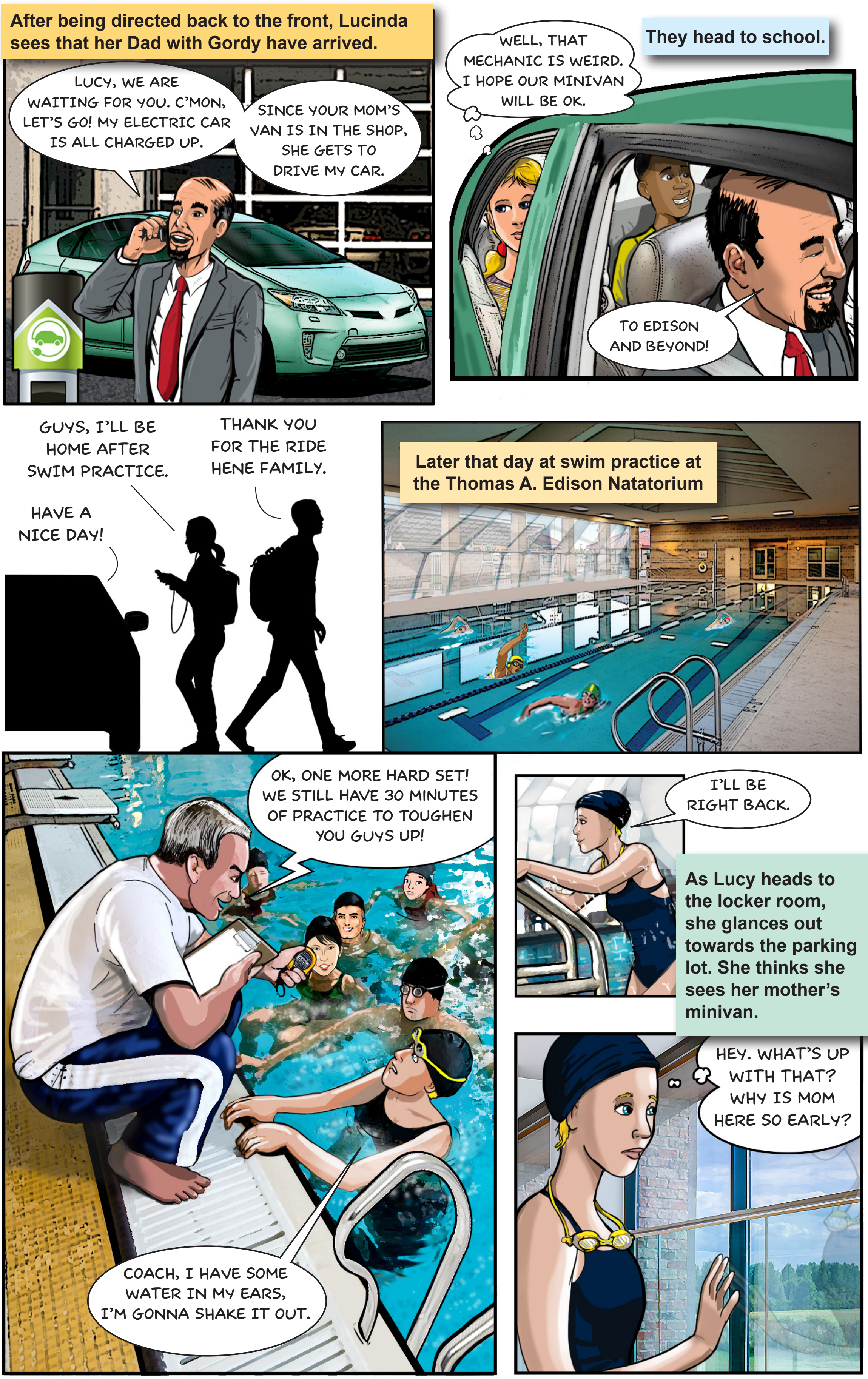


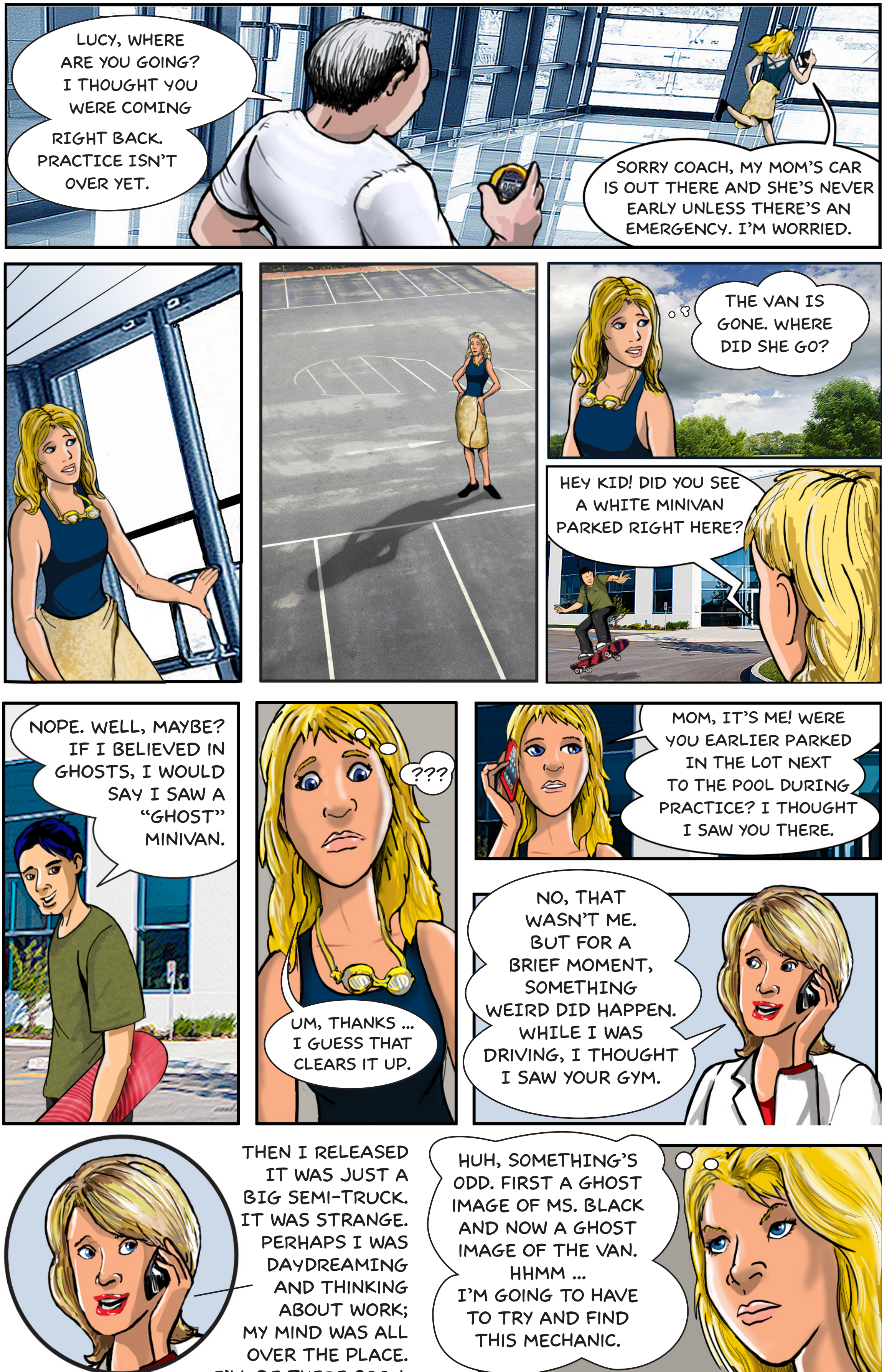
Figure 3

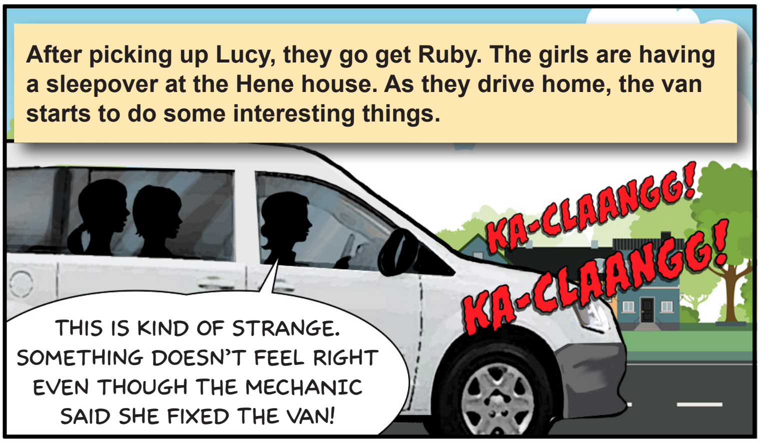
Figure 4



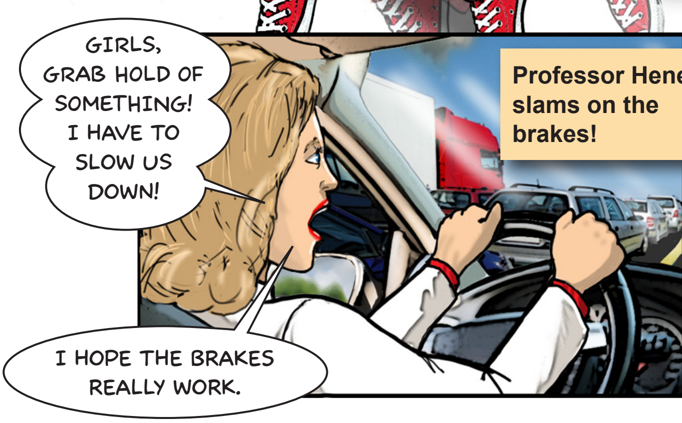

DO YOU HAVE TIME TO CHECK MY BRAKES TODAY?
CERTAINLY, I WILL CALL YOU WHEN THE WORK HAS BEEN COMPLETED.
GREAT, HERE ARE MY KEYS.
physics central
The Quantum Mechanic takes the van keys from Dr. Hene then slowly fades when Dr. Hene isn't looking.
HHMM, WOW, NOT SURE WHERE SHE WENT. SHE SEEMS TO COME AND GO RATHER QUICKLY. NOW WHERE DID LUCY GO? AND SHE BETTER ANSWER MY TEXT MESSAGE.
Elsewhere in the shop, Lucinda doesn't reply to her mother's text message. While looking for the restroom, she takes the wrong door and ends up in the garage.
She's not alone.
BLACK BODY REPAIR
HMM... NICE WRENCH.
Lucy notices a shadowy figure in the corner .
THERE YOU ARE. HI, I'M LUCY, I WAS JUST ADMIRING YOUR WRENCH. I LIKE TOOLS.
THAT'S NICE. MAY I PLEASE HAVE MY WRENCH? I MUST GET STARTED ON YOUR MOTHER'S MINI VAN. THANK YOU.

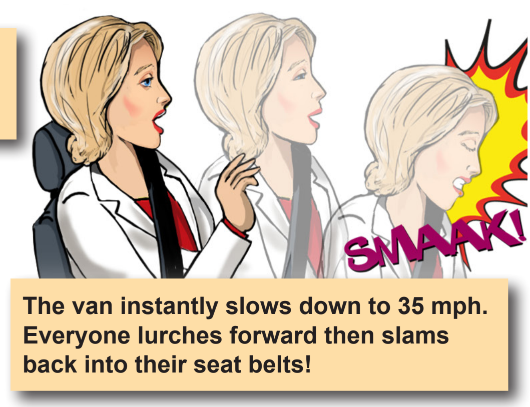

After being directed back to the front, Lucinda sees that her Dad with Gordy have arrived.
LUCY, WE ARE WAITING FOR YOU. C'MON, LET'S GO! MY ELECTRIC CAR IS ALL CHARGED UP.
SINCE YOUR MOM'S VAN IS IN THE SHOP, SHE GETS TO DRIVE MY CAR.
They head to school.
WELL, THAT MECHANIC IS WEIRD. I HOPE OUR MINIVAN WILL BE OK.
TO EDISON AND BEYOND!
GUYS, I'LL BE HOME AFTER SWIM PRACTICE.
THANK YOU FOR THE RIDE HENE FAMILY.
HAVE A NICE DAY!
Later that day at swim practice at the Thomas A. Edison Natatorium
OK, ONE MORE HARD SET! WE STILL HAVE 30 MINUTES OF PRACTICE TO TOUGHEN YOU GUYS UP!
COACH, I HAVE SOME WATER IN MY EARS, I'M GONNA SHAKE IT OUT.
I'LL BE RIGHT BACK.
As Lucy heads to the locker room, she glances out towards the parking lot. She thinks she sees her mother's minivan.
HEY. WHAT'S UP WITH THAT? WHY IS MOM HERE SO EARLY?


LUCY, WHERE ARE YOU GOING? I THOUGHT YOU WERE COMING
RIGHT BACK. PRACTICE ISN'T OVER YET.
SORRY COACH, MY MOM'S CAR IS OUT THERE AND SHE'S NEVER EARLY UNLESS THERE'S AN EMERGENCY. I'M WORRIED.
THE VAN IS GONE. WHERE DID SHE GO?
HEY KID! DID YOU SEE A WHITE MINIVAN PARKED RIGHT HERE?
NOPE. WELL, MAYBE? IF I BELIEVED IN GHOSTS, I WOULD SAY I SAW A "GHOST" MINIVAN.
???
UM, THANKS ... I GUESS THAT CLEARS IT UP.
MOM, IT'S ME! WERE YOU EARLIER PARKED IN THE LOT NEXT TO THE POOL DURING PRACTICE? I THOUGHT I SAW YOU THERE.
NO, THAT WASN'T ME. BUT FOR A BRIEF MOMENT, SOMETHING WEIRD DID HAPPEN. WHILE I WAS DRIVING, I THOUGHT I SAW YOUR GYM.
THEN I RELEASED IT WAS JUST A BIG SEMI-TRUCK. IT WAS STRANGE. PERHAPS I WAS DAYDREAMING AND THINKING ABOUT WORK; MY MIND WAS ALL OVER THE PLACE. I'LL BE THERE SOON.
HUH, SOMETHING'S ODD. FIRST A GHOST IMAGE OF MS. BLACK AND NOW A GHOST IMAGE OF THE VAN. HHMM ... I'M GOING TO HAVE TO TRY AND FIND THIS MECHANIC.



Professer Hene steps on the gas pedal. The vehicle instantly jumps from 35 mph to 65 mph; there's no immediate speed. Everyone is thrown backwards ...





ACTIVITY 3 - A

TEACHER GUIDE

ACTIVITY 3: Losing Your Shirt

INTRO

There is a lot of math and physics in such everyday things as folding laundry and tying your shoes. To get a better understanding of how our universe might be put together, physicists study how sheets, strings and other more complicated shapes can move, twist and tie in knots. In this experiment students will learn some tricks with a special type of shape, a t-shirt.

KEY QUESTION

Is it possible to turn the t-shirt you're wearing inside out while your hands are tied together?

KEY TERMS

Topology: A type of math and physics that studies shapes and knots

Constraint: A restriction of some sort that usually makes a problem harder (and more fun!) to solve.

Perpendicular: Two things are perpendicular when they are at right angles to each other.

MATERIALS

- Chopsticks
- Plastic Zip Tie
- Playdough
- Small bag
- Adhesive Tape*
- Scissors*
- Pen or Marker*

** Not included in the PhysicsQuest Kit*

BEFORE THE ACTIVITY STUDENTS SHOULD KNOW

- How to turn a t-shirt inside out.

AFTER THE ACTIVITY STUDENTS SHOULD SHOULD BE ABLE TO ...

- Give several different ways to turn a t-shirt inside out

- Define the key terms listed above

- Discuss how knowing some properties of shapes, such as number of holes and sides, lets you understand how something can move.

- Understand the concept of a "constraint"

THE SCIENCE OF SURFACES

You may be asking yourself, "why is this physics kit talking to me about folding laundry and what does an inside out t shirt teach anyone about the physical world?"

Shapes such as knots, donuts and even t shirts is used in many branches of science. From protein folding to the very fabric of our universe, it is important to understand how shapes can move and twist. What's really neat is that learning about how something like a t-shirt, with its arm and neck holes, can move and turn inside out, can then give clues about how other things with the same number of holes and sides can flip around. There is an entire branch of mathematics, called **topology,** that studies how knots tie and untie.

The same ideas they use to describe knots and surfaces can be used to describe electric fields and vortices in water. The goal of this activity is to get the students thinking about how the shapes around them may move, what properties they have and how they are similar and how they are different. Its an intro to spatial reasoning using chopsticks and fashion.

Normally to take off a shirt you would just pull it over your head. This brings the bottom of the shirt up and over the neck and arms and turns the shirt inside out. If you want to turn it right side in, you would probably reverse the process and bring the neck and arms through the bottom of the shirt. But that's not the only way to turn a shirt inside out. Its just the way that stretches out the neck and sleeves the least. If you want to turn a shirt inside out, all you have to do is pull it through one of the shirt's 4 holes; two arm holes, a neck hole or the bottom.

Most of the time you are dealing with a t-shirt in a situation where you can turn it inside out any way you want. But in this experiment the goal is to turn a t-shirt inside out while wearing it and having your hands tied together. The fact that your hands are tied together is a **constraint,** meaning it is some sort of restriction on the problem. Now when you take off your shirt it is stuck on your arms. And it is impossible to turn it inside out the normal way because your arms get in the way. You can't pull the top through the bottom or the bottom through the top. But that's not the only way to turn a shirt inside out. It's also possible to turn the shirt inside out by pulling it through one of the sleeves. If you pull the whole shirt through one sleeve, the constraint or your arms doesn't get in the way. You are moving along the direction of your arms instead of against it so its possible to turn the shirt inside out. Now put it back on and you are all set!

TEACHER GUIDE

ACTIVITY 3: Losing Your Shirt

The second half of the activity introduces a second constraint; trying to turn your shirt inside out while you have your hands tied together and you are hugging a pole. The pole is a second **constraint**. The pole is **perpendicular** to your arms. Now there is a constraint in each direction. Try as you might, there is no way to pull the shirt through one of its 4 holes. Not at all. Pulling it through the top and bottom is blocked by your arms and through the sleeves is blocked by the pole. There are too many constraints to solve this problem.

The neat thing about experiments like this is that what we've learned can be used any time there is a t-shirt like shape. Any time there is a shape with an inside and an outside and four holes, we now know that with a constraint in one direction it can be turned inside out. But with constraints in two directions it can't. This is true for anything at any size, which is a pretty powerful thing to be able to say! Also, you will never look at laundry the same way again.

SAFETY

■ Chopsticks pose an eye hazard. You may wish to require students wear eye protection. Chopsticks may also cause splinters.

BIBLIOGRAPHY/SUGGESTED RESOURCES

An excellent introduction to topology with some fun activities:
http://www.education.com/science-fair/article/mathematics_unchanged/

A very cute video illustrating this activity:
http://www.youtube.com/watch?v=3VqGkqSVWsA

Here are some interesting things you can do by understanding how knots tie and sheets fold.
http://www.youtube.com/watch?v=dNr1oLhZ0zs&feature=endscreen
(quick way to fold a shirt)
http://kottke.org/13/07/how-to-tie-your-shoes (new way to tie your shoes)

ACTIVITY 3 - C

STUDENT GUIDE

ACTIVITY 3: Losing Your Shirt

INTRO

Let's say your friend has got you trapped in a Chinese Finger Trap and you suddenly realize that your shirt is inside out. Is it possible to turn it right side out without having to figure out how to get your fingers untrapped? And if you can, what does this tell us about our world?

KEY QUESTION

Is it possible to turn a t-shirt inside out while your hands are tied together?

MATERIALS

- Chopsticks
- Playdough
- Adhesive tape*
- Pen or Marker*
- Plastic zip tie
- Small bag
- Scissors*

** Not included in the PhysicsQuest Kit*

GETTING STARTED

Think about a t shirt, or better yet, if someone has an extra gym shirt, take a look at it. How many sides does it have?

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Can you turn the shirt inside out? How?

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Can you think of other ways to turn it inside out? List them all here.

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What might make it hard to turn the shirt inside out?

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SETTING UP THE EXPERIMENT

Making a *"stick person"*

1. Separate the chopsticks and pick one to be your "stick person." If you want, use the marker to draw a face on the stick person.

2.. Take the plastic tie and attach it to the upper part of the chopstick using tape to make "arms."

3. To keep him upright, use the "Warpable spacetime simulator" (playdough) as a base.

Getting him dressed (Fig.1)

1. Take the small cloth bag and hold it so that the opening in down.

2. The opening will be the bottom of the shirt.

3. Cut two small "arm holes" in the front of the shirt. Be careful to cut through the fabric of the front and not along the seams. Cutting through the seams will cause them to rip out.

4. Cut a "neck hole" in the top of the bag, again being careful not to cut through the seams.

5. If you'd like, draw a design on the outside of your t-shirt.

6. Turn the "shirt" inside out and put it on your stick person! (Fig. 2)

ANALYZING YOUR RESULTS

Handcuffed shirt reverse

Handcuff your stickman and play with his t-shirt.

1. Insert one end of the zip tie into the other to tie the hands of your stickman together.

2. Try to turn his shirt right side out. You don't want an improperly dressed stickman.

3. Having trouble? Look back at all the ways you listed to turn a shirt inside out. Have you tried them all?

4. Still having trouble? Ask another group or your teacher. They might be able to look at what you are doing and suggest other way to try.

How were you able to turn the shirt inside out? Draw it here:

STUDENT GUIDE

ACTIVITY 3: Losing Your Shirt

Can you think of another way to turn it inside out?

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■ Handcuffed shirt reverse while hugging a pole

1. Start with you stickman wearing his shirt inside out again.

2. This time, put the second chopstick in the Playdough with your stickman and arrange it so he is "hugging" the pole (Fig.3)

3. Again, try to turn his shirt inside out. Can you do it the same way? Why or why not?

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4. A "constraint" is something that restricts what you are allowed to do or what moves you are allowed to make. What are the constraints in this problem?

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____
____

5. What if you needed to turn your pant right side out with your legs tied together? Could you do that? What makes the t shirt special?

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Figure 1

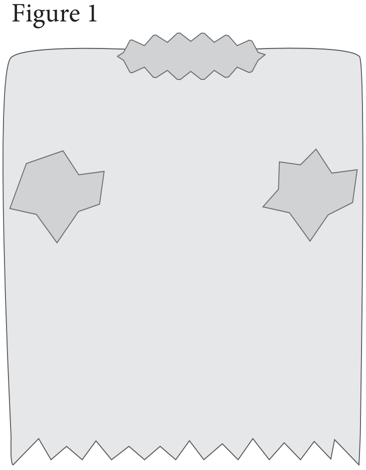


Figure 2

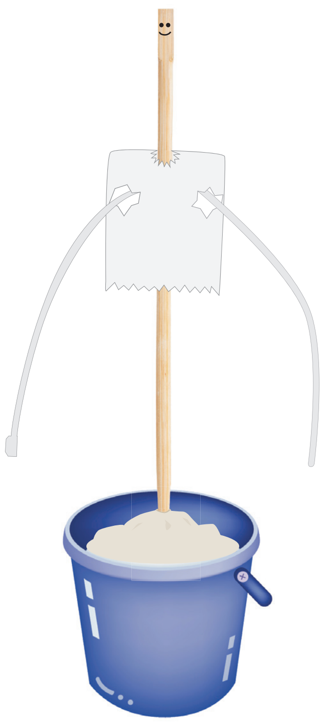
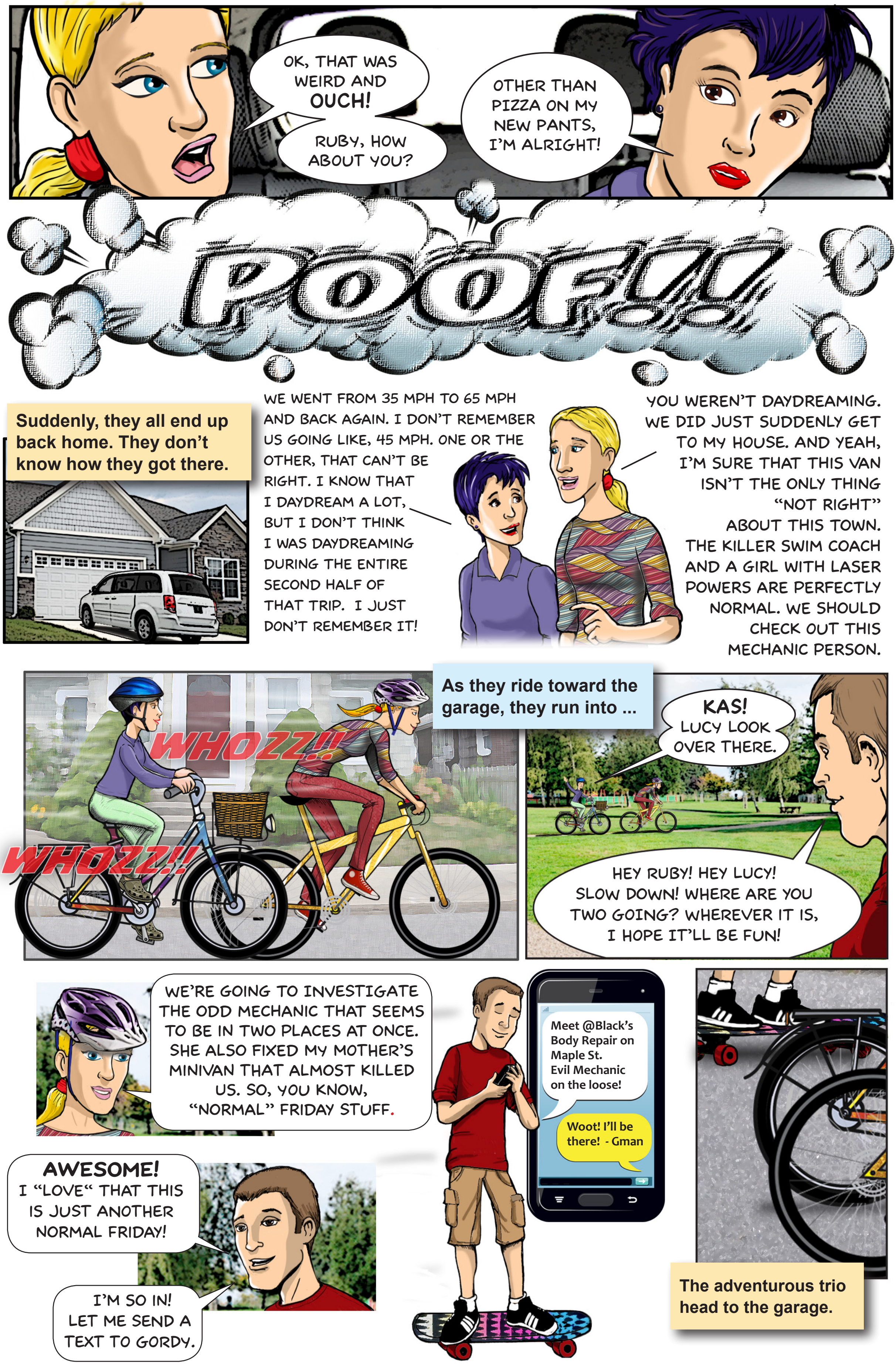
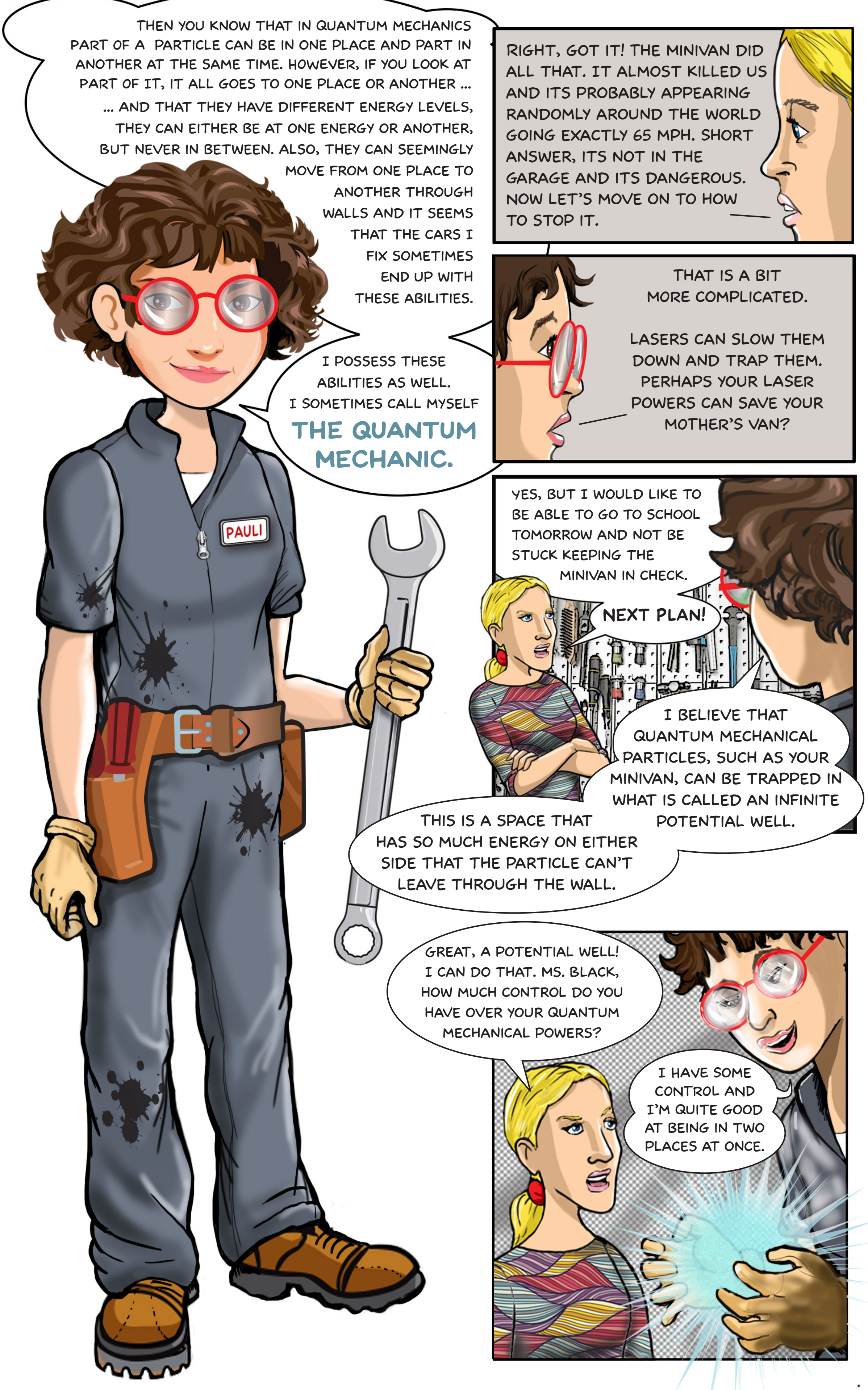
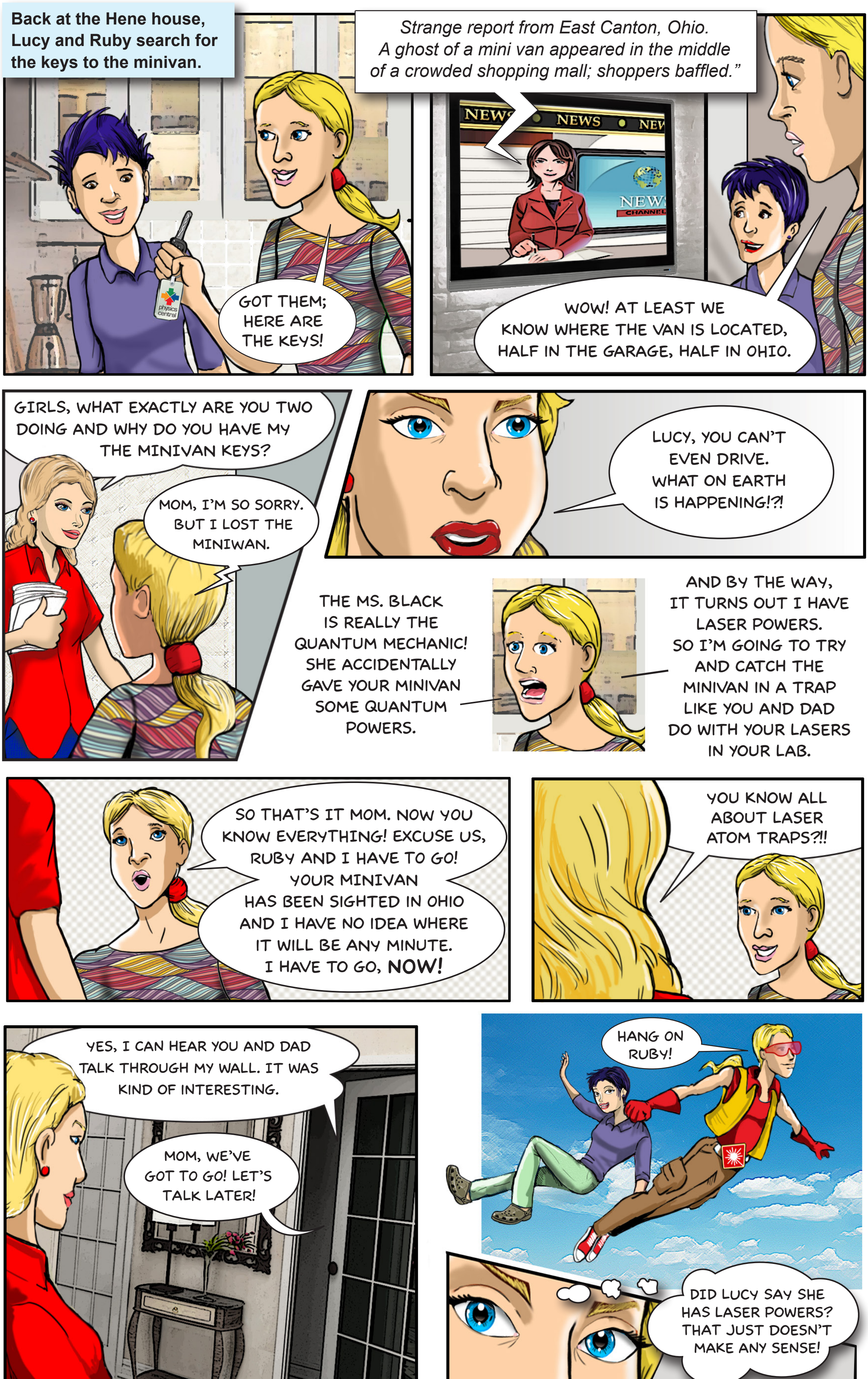


Figure 3


OK, THAT WAS WEIRD AND OUCH!
RUBY, HOW ABOUT YOU?
OTHER THAN PIZZA ON MY NEW PANTS, I'M ALRIGHT!
POOF!!
Suddenly, they all end up back home. They don't know how they got there.
WE WENT FROM 35 MPH TO 65 MPH AND BACK AGAIN. I DON'T REMEMBER US GOING LIKE, 45 MPH. ONE OR THE OTHER, THAT CAN'T BE RIGHT. I KNOW THAT I DAYDREAM A LOT, BUT I DON'T THINK I WAS DAYDREAMING DURING THE ENTIRE SECOND HALF OF THAT TRIP. I JUST DON'T REMEMBER IT!
YOU WEREN'T DAYDREAMING. WE DID JUST SUDDENLY GET TO MY HOUSE. AND YEAH, I'M SURE THAT THIS VAN ISN'T THE ONLY THING "NOT RIGHT" ABOUT THIS TOWN. THE KILLER SWIM COACH AND A GIRL WITH LASER POWERS ARE PERFECTLY NORMAL. WE SHOULD CHECK OUT THIS MECHANIC PERSON.
WHOZZ!!
WHOZZ!!
As they ride toward the garage, they run into ...
KAS! LUCY LOOK OVER THERE.
HEY RUBY! HEY LUCY! SLOW DOWN! WHERE ARE YOU TWO GOING? WHEREVER IT IS, I HOPE IT'LL BE FUN!
WE'RE GOING TO INVESTIGATE THE ODD MECHANIC THAT SEEMS TO BE IN TWO PLACES AT ONCE. SHE ALSO FIXED MY MOTHER'S MINIVAN THAT ALMOST KILLED US. SO, YOU KNOW, "NORMAL" FRIDAY STUFF.
AWESOME! I "LOVE" THAT THIS IS JUST ANOTHER NORMAL FRIDAY!
I'M SO IN! LET ME SEND A TEXT TO GORDY.
Meet @Black's Body Repair on Maple St. Evil Mechanic on the loose!
Woot! I'll be there! - Gman
The adventurous trio head to the garage.


As they reach the garage, Gordy is there waiting for them.
SO WHAT EXACTLY IS GOING ON HERE?
Ruby and Lucy give Gordy a brief summary about the odd behavior of the minivan.
OK, WHAT'S OUR NEXT MOVE?
ALRIGHT, YOU GUYS STAY HERE. I'M GOING TO TRY AND FIND HER. MAYBE SHE CAN CLEAR THIS UP.
MS. BLACK, ARE YOU HERE?
PLEASE COME TALK TO ME.
MY MOM'S MINIVAN HAS BEEN DOING SOME UNUSUAL THINGS SINCE YOU "FIXED" IT.
Pauli Black appears!
FFFZZZ!
I AM VERY SORRY FOR YOUR MOTHER'S PROBLEMS. I DON'T THINK I CAN HELP. HER BRAKES WERE PROPERLY REPAIRED.
LOOK, I KNOW YOU MUST'VE DONE SOMETHING! THE VAN IS DOING THINGS NO VAN SHOULD DO. IT ONLY HAS A FEW SPEEDS, IT CAN BE IN TWO PLACES AT ONCE AND IT'S MOVING FROM ONE PLACE TO ANOTHER ALMOST INSTANTANEOUSLY!.
AND I'M NO STRANGER TO WEIRD POWERS!
AGAIN, I AM SORRY FOR YOUR TROUBLES, BUT IT'S NOT MY FAULT.
ARE YOU WORRIED WE WON'T BELIEVE YOU IF YOU TELL THE TRUTH, BECAUSE ITS WEIRD?
YES.
WELL DON'T BE WORRIED. I CAN TURN INTO A LASER!
AND THAT'S JUST AS WEIRD AS ACCIDENTALLY MAKING DISAPPEARING MINIVANS. SO SPILL IT! WHAT HAPPENED? WHAT CAN THIS AMAZING MINIVAN DO?
IT SEEMS THAT THE VEHICLES I FIX DEVELOP SPECIAL CHARACTERISTICS. WHAT DO YOU KNOW OF "QUANTUM MECHANICS?"
NOT MUCH, JUST WHAT I'VE OVERHEARD MY PARENTS TALKING ABOUT. THEY'RE LASER SCIENTISTS. I OCCASIONALLY DO PAY ATTENTION DURING DINNER CONVERSATION.


THEN YOU KNOW THAT IN QUANTUM MECHANICS PART OF A PARTICLE CAN BE IN ONE PLACE AND PART IN ANOTHER AT THE SAME TIME. HOWEVER, IF YOU LOOK AT PART OF IT, IT ALL GOES TO ONE PLACE OR ANOTHER ...
... AND THAT THEY HAVE DIFFERENT ENERGY LEVELS, THEY CAN EITHER BE AT ONE ENERGY OR ANOTHER, BUT NEVER IN BETWEEN. ALSO, THEY CAN SEEMINGLY MOVE FROM ONE PLACE TO ANOTHER THROUGH WALLS AND IT SEEMS THAT THE CARS I FIX SOMETIMES END UP WITH THESE ABILITIES.
I POSSESS THESE ABILITIES AS WELL. I SOMETIMES CALL MYSELF THE QUANTUM MECHANIC.
PAULI
RIGHT, GOT IT! THE MINIVAN DID ALL THAT. IT ALMOST KILLED US AND ITS PROBABLY APPEARING RANDOMLY AROUND THE WORLD GOING EXACTLY 65 MPH. SHORT ANSWER, ITS NOT IN THE GARAGE AND ITS DANGEROUS. NOW LET'S MOVE ON TO HOW TO STOP IT.
THAT IS A BIT MORE COMPLICATED.
LASERS CAN SLOW THEM DOWN AND TRAP THEM. PERHAPS YOUR LASER POWERS CAN SAVE YOUR MOTHER'S VAN?
YES, BUT I WOULD LIKE TO BE ABLE TO GO TO SCHOOL TOMORROW AND NOT BE STUCK KEEPING THE MINIVAN IN CHECK.
NEXT PLAN!
I BELIEVE THAT QUANTUM MECHANICAL PARTICLES, SUCH AS YOUR MINIVAN, CAN BE TRAPPED IN WHAT IS CALLED AN INFINITE POTENTIAL WELL.
THIS IS A SPACE THAT HAS SO MUCH ENERGY ON EITHER SIDE THAT THE PARTICLE CAN'T LEAVE THROUGH THE WALL.
GREAT, A POTENTIAL WELL! I CAN DO THAT. MS. BLACK, HOW MUCH CONTROL DO YOU HAVE OVER YOUR QUANTUM MECHANICAL POWERS?
I HAVE SOME CONTROL AND I'M QUITE GOOD AT BEING IN TWO PLACES AT ONCE.



Back at the Hene house, Lucy and Ruby search for the keys to the minivan.
GOT THEM; HERE ARE THE KEYS!
physics central
Strange report from East Canton, Ohio. A ghost of a mini van appeared in the middle of a crowded shopping mall; shoppers baffled.”
NEWS • NEWS • NEWS
NEWS
WOW! AT LEAST WE KNOW WHERE THE VAN IS LOCATED, HALF IN THE GARAGE, HALF IN OHIO.
GIRLS, WHAT EXACTLY ARE YOU TWO DOING AND WHY DO YOU HAVE MY THE MINIVAN KEYS?
MOM, I'M SO SORRY. BUT I LOST THE MINIWAN.
LUCY, YOU CAN'T EVEN DRIVE. WHAT ON EARTH IS HAPPENING!?!
THE MS. BLACK IS REALLY THE QUANTUM MECHANIC! SHE ACCIDENTALLY GAVE YOUR MINIVAN SOME QUANTUM POWERS.
AND BY THE WAY, IT TURNS OUT I HAVE LASER POWERS. SO I'M GOING TO TRY AND CATCH THE MINIVAN IN A TRAP LIKE YOU AND DAD DO WITH YOUR LASERS IN YOUR LAB.
SO THAT'S IT MOM. NOW YOU KNOW EVERYTHING! EXCUSE US, RUBY AND I HAVE TO GO! YOUR MINIVAN HAS BEEN SIGHTED IN OHIO AND I HAVE NO IDEA WHERE IT WILL BE ANY MINUTE. I HAVE TO GO, NOW!
YOU KNOW ALL ABOUT LASER ATOM TRAPS?!!
YES, I CAN HEAR YOU AND DAD TALK THROUGH MY WALL. IT WAS KIND OF INTERESTING.
MOM, WE'VE GOT TO GO! LET'S TALK LATER!
HANG ON RUBY!
DID LUCY SAY SHE HAS LASER POWERS? THAT JUST DOESN'T MAKE ANY SENSE!

ACTIVITY 4 - A

TEACHER GUIDE

ACTIVITY 4: Ball vs. Donut

INTRO

You've probably heard that physicists think there may be more than 3 dimensions. Some physicists think there may be as many as 26! But why do they think that? What is the point of these "extra dimensions?" This activity will show how sometimes problems that can't be solved in one type of space can be solved if the space is changed around a bit. This is the same reason physicists think there may be extra dimensions. The problems can't be solved in just three dimensions.

KEY QUESTION

Is it possible to connect three "houses" to three "utilities" without crossing the lines?

KEY TERMS

Torus: The generic term for something shaped like a donut or bagel.

Dimension: Direction in which something came move. A piece of paper has two dimensions, length and width. A cube has three dimensions, length, width and height.

Topology: A type of mathematics that studies shapes and knots.

Constraint: A restriction of some sort that usually makes a problem harder (and more fun!) to solve.

MATERIALS

- Warpable Space Time Simulator (Playdough)
- 6 toothpicks
- Ribbon
- Degree of freedom

BEFORE THE ACTIVITY STUDENTS SHOULD KNOW

- The definitions of the key terms listed above.

AFTER THE ACTIVITY STUDENTS SHOULD BE ABLE TO ...

- Describe and explain a solution for the famous "utility problem"

- Discuss how there are problems can be solved in one space but not another

- Understand what a dimension is and why it is important.

THE SCIENCE BEHIND MOVING IN TWO AND THREE DIMENSIONS.

This is the second **topology** experiment in this kit. This time, instead of looking at how a shape can move and flip while it is **constrained** in different ways, we'll deal with what can happen with the space around the problem changes. This activity shows how a famous math problem, the "utilities problem" can't be solved on a flat piece of paper or on a ball, but can be solved on a donut shape, or torus.

If you haven't done Activity 3, *Losing Your Shirt,* you should be fine but it might help to read the "science behind…" section to get a bit of an intro. The info from that section won't be repeated here so flip back to that section if you needed.

In this problem, the goal is the connect three houses to three utility stations (gas, water and electric) without crossing lines.

Clearly no real contractor would be worried about crossing utility lines. Its seems kind of silly. But it is one of the oldest math problems in existence. What your students will find is that it is impossible to connect the utilities to the houses without crossing lines no matter how much they try. When they are **constrained** to move on a surface like a sphere with no holes, there is no way they can solve the problem. It isn't possible. They are forced to move in two **dimensions.** They are only allowed to move on the surface, not leave the surface into the **third dimension.**

By trying and proving to themselves they can't, they have done some high level math in a branch of mathematics called "graph theory." In graph theory, mathematicians (and your students!) prove mathematical ideas by trying to connect points with lines (usually on paper, but I've always had more fun with ribbon) and seeing how they can and can't be connected. It doesn't matter how the "houses" and "utility stations" are places on the sphere or pancake. The fact that they can't be connected is independent of where you put them. The fact that what you can prove with some PlayDough and ribbon something that can be applied to other surfaces like the earth or the universe is pretty darn cool.

This activity then takes things one step further and creates a space where the problem can be solved, a torus. When the same problem is done on a torus, it is easy to solve. The key thing is that a ribbon needs to be wrapped through the hole in the middle of the torus. Making it a torus instead of a sphere added an extra dimension, the third dimension. Now that the ribbons can move around into another dimension by going through the hole in the middle, the problem can be solved. What's really neat is that this can be done on any surface that has one hole, such as a roll of tape or a coffee cup with a handle.

ACTIVITY 4 - B

TEACHER GUIDE

ACTIVITY 4: Ball vs. Donut

Because problems that can be solved on a torus can also be solved on a coffee cup with a handle, the surface are called **topologically equivalent.** To mathematicians their morning donut is no different than the coffee cup sitting next to it or the skirt they are wearing!

What does all this have to do with the 26 dimensions that some physicists think are needed to describe the world? Just like this problem couldn't be solved in the two dimensions of a sphere, one theory of the universe ends with problems that can't be solved in the three dimensions we live in. Because they can't solve these problems in the world we see, they think there may be dimensions, up to 26, that we can't actually detect. So, 26 dimensions makes the math possible!

SETTING UP THE EXPERIMENT

Always be careful with toothpicks. They're sharp! Use caution when using scissors.

SUGGESTED RESOURCES

A more in-depth look at the utilities problem. It is a bit higher level:
http://www.cut-the-knot.org/do_you_know/3Utilities.shtml

This is a great visual of a coffee cup and a torus. It shows how they are similar:
http://upload.wikimedia.org/wikipedia/commons/2/26/Mug_and_Torus_morph.gif

This requires downloading a plug-in, but is safe and worth it. Your students (and you!) can play around with surfaces on the computer and then it in real life with Playdough.
http://demonstrations.wolfram.com/BetweenSphereAndTorus/

This is another demo from that series that looks at lines on a torus:
http://demonstrations.wolfram.com/MazesOnATorus/

STUDENT GUIDE

ACTIVITY 4: Ball vs. Donut

INTRO

Did you ever wonder what life would be like if we were living on a giant donut instead of a giant sphere? Would we be able to do neat, new things? If Columbus set off from Spain in search of the New World on this new donut-shaped planet, where would he have ended up? In this activity you will find out at least one neat trick that can't be done on our spherical earth, but could be done if we lived on a giant bagel.

KEY QUESTION

Is it possible to connect three "houses" to three "utilities" without crossing the lines?

MATERIALS

- Warpable Space Time Simulator (Playdough)
- 6 toothpicks
- Ribbon

GETTING STARTED

Pick three objects in the room. Anything you want, anything at all. Look at their shapes, how they are put together, what is the same and what is different?

What would it be like for an ant that was walking on those shapes?

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How many holes and loops does each of your shapes have?

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Think of a donut and a coffee cup with a handle. What is the same and what is different about them?

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SETTING UP THE EXPERIMENT

In this activity you are going to see if it is possible to connect three utility stations to three different houses without crossing the utility lines. Toothpicks will play the part of the houses and utility stations and ribbons will act like the lines.

CREATING THE "UTILITY STATIONS"

1. Take the each of the pieces of colored ribbons and cut them into three pieces. You should now have nine pieces of ribbon, three of each color.

2. Tie one end of each of the three red ribbons around a toothpick. This will be your "gas" utility station and lines. Do the same for green (electric) and blue (water). (Fig. 1)

ANALYZING YOUR RESULTS

- **Experiment 1, Our Earth:**

1. The "Warpable Spacetime Simulator" and roll it into a ball. This is going to represent our current Earth.

2. Take the three toothpicks representing houses and place them anywhere on the ball.

3. Take the three "utility stations" with their "utility lines" attached and put them anywhere on the ball.

4. Connect each "house" to each "utility." Each house should have a red ribbon, green ribbon, and blue ribbon attached to it.

5. Chances are good that some of the "utility lines" are crossed. Like, a water line is running over an electricity line or a gas line is running over a water line.

6. Try to do it without crossing the "utility lines."

7. If you couldn't, try moving the "houses" and "utility stations" and try again.

STUDENT GUIDE

ACTIVITY 4: Ball vs. Donut

8. Do this for at least three different locations. Draw all of your attempts:

9. What happened? Were you able to connect all the “houses” without crossing the lines?

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Can you think of what you might have to change to be able to connect the “houses” without crossing lines?

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■ **Experiment 2, Donut World:**
If you weren’t able to connect all the “utility wires” on your round earth, try it on a “donut planet.”

1. This time, make the Warpable Spacetime Simulator into a bagel shape.

2. Repeat steps 2-7 from activity one. Were you able to connect all the “utility lines” without crossing?

3. What was it about the donut that allowed you to do that?

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4. What if you had 4 houses instead of 3? What about 4 utilities?

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5. What other “world shapes” can you think of that would let you connect everything without crossing lines? Try them! The best part about your Warpable Spacetime Simulator is that you can make a world in any shape you want.

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6. What do all these worlds have in common?

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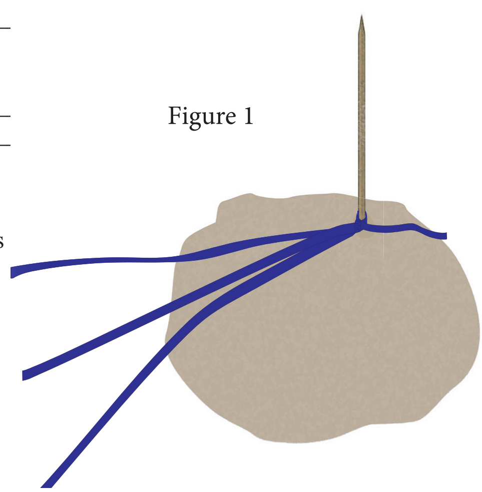
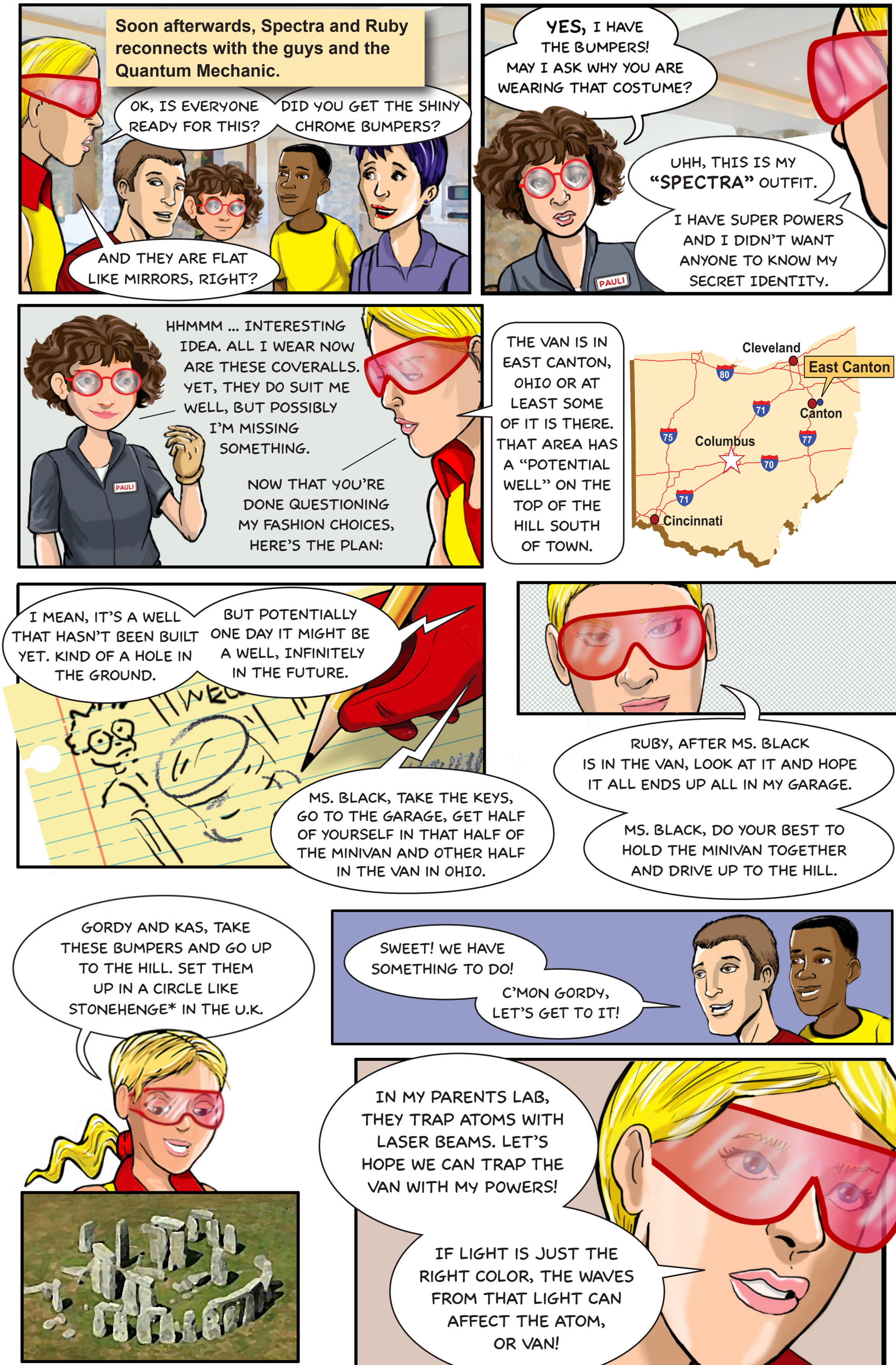
Which statement is true?

- Houses and utilities could be connected without crossing lines
- A sphere but not a donut
- A donut but not a sphere
- A donut and a sphere
- Neither a donut nor a sphere

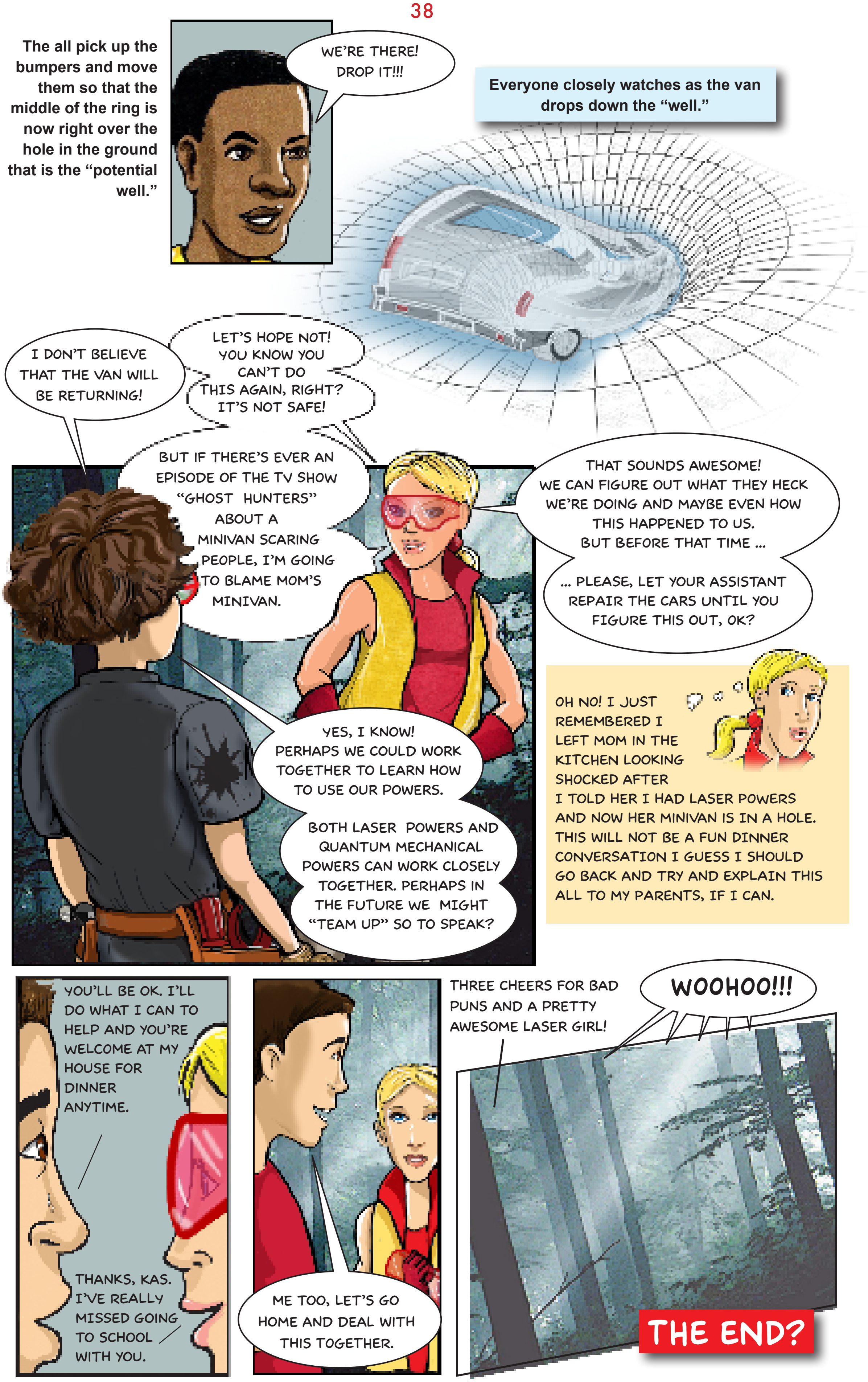
Figure 1





* https://www.english-heritage.org.uk/daysout/properties/stonehenge/

IF THE ATOM TRIES TO GET AWAY, THE LIGHT WAVES PUSH IT BACK TO THE CENTER. IT GETS TRAPPED. WHEN MS. BLACK DRIVES THE VAN UP THE HILL, I'LL USE THE BUMPERS AS MIRRORS, REFLECT AROUND AND HOPEFULLY TRAP THE MINIVAN THE SAME WAY MY PARENTS TRAP ATOMS.
ONCE I TRAP IT, MS. BLACK, YOU NEED TO GET OUT OF THE VAN, AND THEN ALL FOUR OF YOU NEED TO MOVE THE MIRRORS IN SYNC,
WHILE THE VAN I'VE TRAPPED US OVER THE "POTENTIAL WELL.
LUCY, I MEAN "SPECTRA", THIS PLAN SEEMS VERY COMPLICATED
AND I DON'T BELIEVE THAT THIS IS THE RIGHT TYPE OF "POTENTIAL WELL."
I HAVE NO IDEA IF THIS TYPE OF INFINITELY PO-TENTIAL WELL WILL WORK, I ONLY HOPE THAT QUANTUM MINIVANS CAN BE TRAPPED BY BAD PUNS! LET'S GO
Everyone works hard to follow Spectra's instructions. After completing the tasks, the friends meet on the hill. They are waiting for the Quantum Mechanic to drive up the hill.
The bumpers are all set up. Spectra is waiting to be a laser and trap her mother's minivan.
GUYS, GET READY, HERE SHE COMES!
LET'S HOPE THIS WORKS! RUBY, WHEN I'M A GREEN LASER, YOU'RE IN CHARGE!
WHEN THE VAN IS TRAPPED, YOU KNOW HOW TO MOVE, RIGHT?
ZA-OOM!!
I HAVE TO CONCENTRATE TO MAINTAIN THE RIGHT HUE OF GREEN TO TRAP THE MINIVAN!
The van drives up into the middle of the ring of bumpers.
In her green laser form, Spectra bounces around, off and on the bumpers, always going through the middle and hitting the van.
She traps the van!


The all pick up the bumpers and move them so that the middle of the ring is now right over the hole in the ground that is the "potential well."
WE'RE THERE! DROP IT!!!
Everyone closely watches as the van drops down the "well."
I DON'T BELIEVE THAT THE VAN WILL BE RETURNING!
LET'S HOPE NOT! YOU KNOW YOU CAN'T DO THIS AGAIN, RIGHT? IT'S NOT SAFE!
BUT IF THERE'S EVER AN EPISODE OF THE TV SHOW "GHOST HUNTERS" ABOUT A MINIVAN SCARING PEOPLE, I'M GOING TO BLAME MOM'S MINIVAN.
YES, I KNOW! PERHAPS WE COULD WORK TOGETHER TO LEARN HOW TO USE OUR POWERS.
BOTH LASER POWERS AND QUANTUM MECHANICAL POWERS CAN WORK CLOSELY TOGETHER. PERHAPS IN THE FUTURE WE MIGHT "TEAM UP" SO TO SPEAK?
THAT SOUNDS AWESOME! WE CAN FIGURE OUT WHAT THEY HECK WE'RE DOING AND MAYBE EVEN HOW THIS HAPPENED TO US. BUT BEFORE THAT TIME ...
... PLEASE, LET YOUR ASSISTANT REPAIR THE CARS UNTIL YOU FIGURE THIS OUT, OK?
OH NO! I JUST REMEMBERED I LEFT MOM IN THE KITCHEN LOOKING SHOCKED AFTER I TOLD HER I HAD LASER POWERS AND NOW HER MINIVAN IS IN A HOLE. THIS WILL NOT BE A FUN DINNER CONVERSATION I GUESS I SHOULD GO BACK AND TRY AND EXPLAIN THIS ALL TO MY PARENTS, IF I CAN.
YOU'LL BE OK. I'LL DO WHAT I CAN TO HELP AND YOU'RE WELCOME AT MY HOUSE FOR DINNER ANYTIME.
THANKS, KAS. I'VE REALLY MISSED GOING TO SCHOOL WITH YOU.
ME TOO, LET'S GO HOME AND DEAL WITH THIS TOGETHER.
THREE CHEERS FOR BAD PUNS AND A PRETTY AWESOME LASER GIRL!
WOOHOO!!!
THE END?