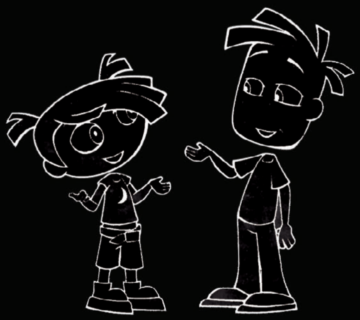
PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

02 Perimeter Inspirations

Process of Science

TEACHER'S GUIDE

Based on *Alice & Bob in Wonderland* Animations



PROCESS OF SCIENCE

An Additional Activity, Case Studies, and a News Flash can be found on the CD-ROM.

ABOUT PERIMETER INSTITUTE

Perimeter Institute for Theoretical Physics

Perimeter Institute for Theoretical Physics is an independent, non-profit, research institute whose mission is to make breakthroughs in our understanding of our universe and the forces that govern it. Such breakthroughs drive advances across the sciences and the development of transformative new technologies. Located in Waterloo, Ontario, Canada, Perimeter also provides a wide array of research, training, and educational outreach activities to nurture scientific talent and share the importance of discovery and innovation with students, teachers, and the general public. In partnership with the Governments of Canada and Ontario, Perimeter is a successful example of public-private collaboration in scientific research, training, and outreach.

Perimeter Inspirations

This series of in-class educational resources is designed to help teachers inspire their students by sharing the mystery and power of science. Perimeter Inspirations is the product of extensive collaboration between experienced teachers, Perimeter Institute's outreach staff and international researchers. Each module has been designed with both junior and senior high school students in mind and has been throughly tested in classrooms.

INTRODUCTION

This Perimeter Institute classroom resource contains student activities that highlight certain aspects of the process of science—the creative, inquisitive, collaborative process by which scientific exploration and discovery occurs. The activities were designed and tested by classroom teachers from a variety of backgrounds and are intended for a wide range of grade levels.

The accompanying CD-ROM has digital versions of this Teacher's Guide and the student activities in editable format.

The multimedia supports on the video DVD include *Alice & Bob in Wonderland* animations, *MinutePhysics* episodes, and the *Scientifically Speaking* rap. These supports are featured in some of the activities but are also provided as examples of how science is being communicated in creative ways.

ALICE & BOB IN WONDERLAND

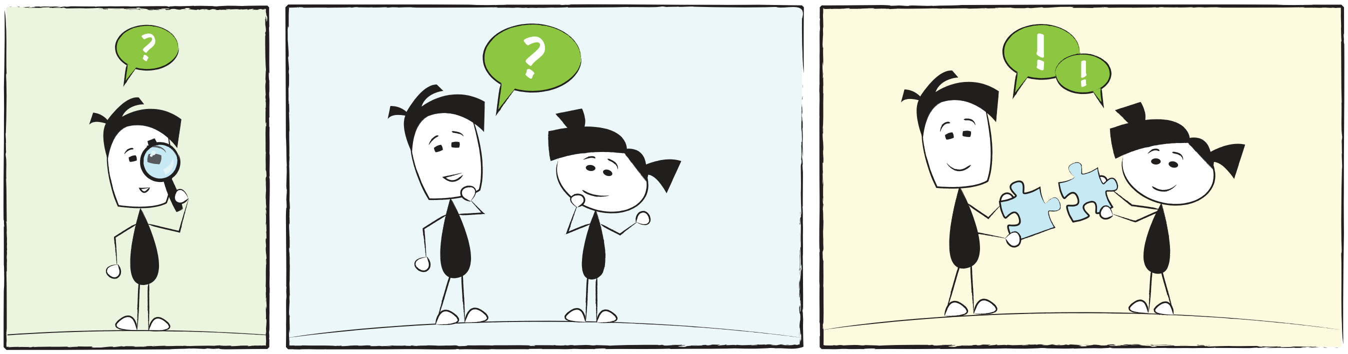
These engaging and inspiring 60-second animations feature a brother and sister modeling the process of science. Each episode begins with Alice asking a simple curiosity-driven question about the world. Bob responds with the obvious commonsense answer which they then proceed to question together. As a team they use their imaginations and simple reasoning to discover amazing insights into the universe—realizing that there must be more to the answer than Bob had originally thought.

MINUTEPHYSICS

These powerful explanations of simple physics concepts are featured on YouTube and have been viewed by more than 20 million viewers. These narrated illustrations are the brainchild of Henry Reich, a young physicist with an artistic flair. In each episode Henry uses clear, accessible language to show how complex ideas can be understood in just minutes.

SCIENTIFICALLY SPEAKING

This rap was written by award-winning science teacher Ed Piva. Ed uses rap in his classroom as an engaging tool that enables his students to connect concepts in a creative, memorable way.



PROCESS OF SCIENCE

Science has changed our world. Scientific discoveries have led to the eradication of diseases, understanding of matter, development of technology and exploration of space. These discoveries have given us a deeper, more profound appreciation for who we are and where we are in the universe. The ability of science to explore, explain, and modify our world will be even more important as we move ahead to the challenges facing us in the future.

"Science is an imaginative adventure of the mind seeking the truth in a world of mystery."
– Sir Cyril Hinshelwood

An essential part of preparing students for the future is ensuring that they are scientifically literate. Since the scientific revolution began over 500 years ago, we have accumulated a vast amount of knowledge about our world. Science has branched out into various disciplines and sub-disciplines, each focusing on increasingly specific topics. This accumulation of knowledge and specialization of disciplines can create a mistaken impression that science is just a large body of accumulated knowledge. Science education often reinforces this impression by emphasizing content—the facts and figures of scientific discovery rather than the process of discovery itself. This, however, is changing as science educators around the world place a greater emphasis on the process of science.

The process of science has to do with the habits of mind practiced by scientists that lead to discoveries. The stereotype of a scientist alone in a lab following a set routine does not even come close to describing what real scientists do. As scientists themselves describe the process, science is a creative and collaborative endeavour in which scientists balance objective analysis with imaginative thinking.
Many scientists see themselves as artists, using established tools and techniques to discover new ideas and to create new models. Just as you cannot really distill art into a set of techniques, so the methods used by these scientists cannot properly be reduced into a flowchart or a method. However, just as there are themes in art, we can discover general principles followed by most scientists.

Scientists are *curious*. A sense of wonder and awe is essential to scientists. They are always asking questions about the world around them; looking for ways to improve our understanding. Scientists are never satisfied with an explanation, or model; they are always probing for flaws in accepted models that can be exposed through careful thinking that leads to deeper understanding. Models are always being challenged through new observations that lead to new questions. The essential power of science comes from the insatiable curiosity of the scientists. Science can never be complete because there will always be more questions to be asked.

Science requires *collaboration*. Collaboration involves the sharing of ideas and expertise to achieve a common goal. Modern research problems are usually too big and too complicated for one person to grapple with alone. It is not uncommon for experiments to involve dozens of scientists from around the world working together. Collaboration allows researchers to access specialized skills or knowledge needed to solve the problem. It also involves the sharing of opinions and insights to refine models and ideas. The scrutiny and involvement of other scientists in the review process make models stronger. Collaboration can be difficult. Scientists are deeply passionate about what they study and interactions with other passionate researchers can lead to conflicts.

Science necessitates *communication*. Scientists must be able to communicate effectively with each other in order to collaborate. They must be able to communicate with the general public in order to generate support for their research. Communication comes in many forms, and traditional avenues such as technical papers, seminars, and articles are being complemented by more contemporary avenues like blogs, videos, and animations. The rise of internet communication allows scientists to interact with colleagues from around the world on a daily basis. New media also allows scientists to create powerful animations and simulations that communicate abstract ideas in a more concrete form.

Scientists are *creative*. The task of creating models for complex phenomena is difficult and progress often comes after intuitive leaps and creative thinking. Since most scientific models fail, scientific creativity requires an atmosphere that encourages risk-taking. Science and science education can only progress if the participants are encouraged to take risks and allowed to make mistakes—not mistakes that arise from poor technique, but honest mistakes that arise from reaching beyond current understanding.

This *Process of Science* resource contains several classroom activities designed to highlight some of these general principles. As students participate in activities and engage with multimedia supports, they will begin to grasp the creative enterprise in which scientists engage. Activities provided can be used across many age levels and in any science class. Multimedia supports both introduce the concepts and model the ways in which science is a creative enterprise. Students are encouraged to ask questions throughout the activities and to think deeply about the world around them, participating in this basis of all science. The content of the classroom activities is merely an example, serving to illustrate and offer students opportunities to participate in the process of science. Teachers are encouraged to adapt the content to suit their needs.

Check out the Symphony of Science website at http://symphonyofscience.com/

CURRICULUM CONNECTIONS

Topic	Connection to Resource	Activity
Nature of Science	Science is a collaborative enterprise that involves both creative and critical thinking. Theories are rigorously tested and refined by other scientists as they are developed.	Asking Questions Science in the News Thinking Deeper Making Models
Process of Scientific Modeling	We build scientific models to explain complex phenomena. Good models must be logically self-consistent, explain the observations accurately, make testable predictions of new observations, and give new insights into the phenomena.	Asking Questions Why Is It Like That? Science in the News Making Models
Observation and Inference	Scientists observe the world with their senses and instruments to gather information then use prior knowledge and logic to make sense of those observations.	Asking Questions Why Is It Like That? What Do You See?
Scientific Inquiry	Science is the art of asking questions and thinking deeply about possible answers. Good questions lead to new insights and often to more questions.	Asking Questions Why Is It Like That? Thinking Deeper
Diversity of Life	There is great beauty and wonder in the world around us. Scientists examine the many fascinating forms of life that exist, and look for reasons behind the many different forms.	Asking Questions Why Is It Like That
Atoms and Elements	All matter is made of atoms. Scientists synthesize heavy elements in accelerators. The discovery of new elements is an important part of understanding matter.	Case Study: Element 118
Space Exploration	Scientists have discovered amazing things about our universe. Careful analysis of observations points to new planets, the Big Bang, and maybe even Dark Matter.	Science in the News Case Study: CMB Case Study: Dark Matter Case Study: Neptune
Ecosystems	Living organisms are closely connected with their environment. Small changes to the environment can have a large impact on populations.	Case Study: Bisphenol-A Science in the News
Cells and Systems	Cells are the fundamental unit of living organisms. Scientists study how cells respond to subtle changes in their environment.	Case Study: Bisphenol-A Science in the News

TEACHER TIPS

The goal of this resource is to provide a framework that helps students understand and develop the habits of mind practiced by actual researchers. Each activity in this resource has been designed by experienced classroom teachers to highlight one or two aspects of the process of science. The science content in the lessons is secondary to the process. The content can be changed to match curriculum needs without changing the outcome of the activity.

ASKING QUESTIONS

Scientists are curious and ask good questions. Using an adapted Frayer Model as a graphic organizer, students examine objects or images (see Appendix). Students rotate through stations, each of which contains an object/image and a graphic organizer. Since the graphic organizer stays with the object, the students begin to look deeper and to ask more penetrating questions as the activity progresses through each successive object/image. This activity can be used in any grade level for a variety of purposes: introduction, instruction, consolidation.

WHY IS IT LIKE THAT?

Scientists are filled with awe and wonder of the natural world. In this activity, students examine a variety of fascinating images and use an adapted Frayer Model to ask questions about the images (see Appendix). This activity can be adapted for any grade level or unit by substituting the images to suit your needs or subject. The set of images provided as inserts in this resource are also available on the Teacher Support CD-ROM.

WHAT DO YOU SEE?

Scientists make careful observations and use logic to draw reasonable conclusions. In this activity, students explore the difference between observation and inference. Alice and Bob expand on this in episodes *“What keeps us stuck to the Earth?”* and *“Why is it dark at night?”* Students analyze these episodes to discover that some of the things that they think are real, like the force of gravity, are actually inferences. The difference between observation and inference comes alive with the potato candle demonstration (see Teacher Demonstrations).

SCIENCE IN THE NEWS

Scientists have to work together to solve problems. In this activity, students work together to solve a mystery, much as they would if playing a murder mystery game. The source of the mystery is a short newsflash describing a scientific discovery. Every student receives one of ten possible clues; since there are only ten different clues there will be multiple copies of each clue. Each group will get a summary sheet outlining the mystery and leaving space to record the clues. The groups begin by recording the clues that they have. The teacher then instructs them to mix with the other groups and for each student to exchange their clue with one other student in the class. The groups then reconvene and combine their clues. The process is repeated until groups have all ten clues. Once a group has all ten clues, they use them to solve the mystery. This activity can be made competitive or kept co-operative, depending on the teacher’s preference.

THINKING DEEPER

Scientists ask probing questions that go beyond the surface: the *Alice & Bob in Wonderland* animations offer great examples of this. This activity illustrates how a simple question leads to a deeper insight when good questions are asked. Choose three *Alice & Bob in Wonderland* episodes that are appropriate for your students. After the students have watched and analyzed the *Alice & Bob in Wonderland* episodes, have them watch the *MinutePhysics* episode *“What is Fire?”* This episode provides enough information about a common phenomenon that the students will be able to create their own *Alice & Bob in Wonderland* episode about *“What is Fire?”*

MAKING MODELS

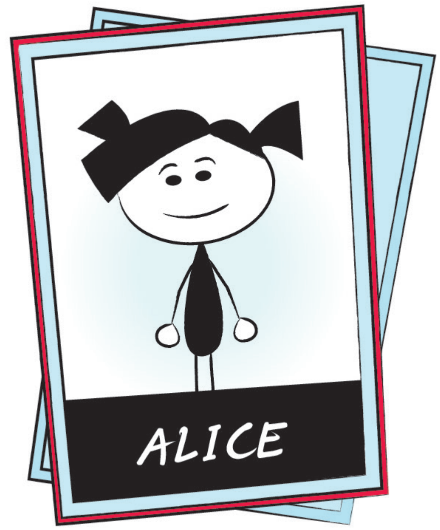
Scientists use peer review to refine their work. In this activity, students make models and then critique each other's work (instructions for the Black Box and Jumping Shampoo are in the Teacher Demonstrations). The goal of this activity is for students to experience the peer review process–not to explain the phenomena.

Check out the MinutePhysics episodes on Dark Matter and Neutrinos!

CASE STUDIES

Each of these case studies provides insight into the process of science using real examples. The articles can be used as a literacy activity, content instruction, or discussion material. Additional case studies are included on the Teacher Support CD-ROM.

SCIENTIST TRADING CARDS (ON TEACHER SUPPORT CD-ROM)



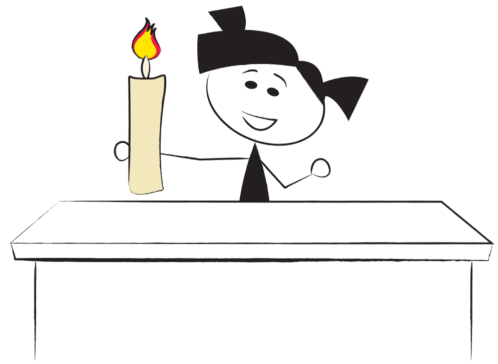
Science is a human endeavour. Scientists are people who face the same adversity as everyone else, and sometimes more. In this activity, students research a scientist who faced some kind of adversity, preferably one that the student can identify with. The goal of this activity is twofold: to see that scientists are normal people and to see that adversity can be overcome. This activity can be used as an introduction to the course or as a research project during the course.

We are confident that these activities will help your students understand the habits of mind involved in the process of science. For more inquiry and skill-based activities, we recommend the materials developed by Youth Science Canada (www.smarterscience.ca).

TEACHER DEMONSTRATIONS

POTATO CANDLE

WARNING: Allergy alert – this demo uses almond slivers

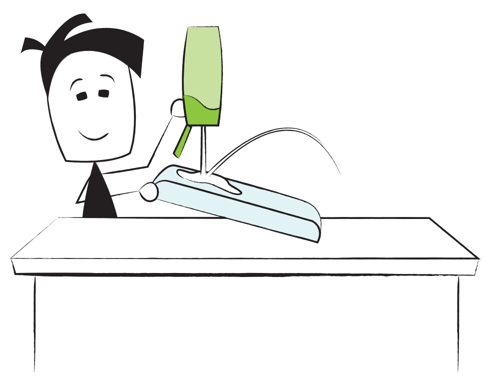


This demonstration illustrates the power of inference. When students observe a candle, they infer it is made out of wax. The candle is actually made out of a potato so when the teacher bites into the candle, it is quite shocking to the students.

Make the potato candle by using an apple corer on a potato to create a 10 cm long white cylinder, a paring knife to shape the ends and an almond sliver for the wick. Keep the candle wrapped in a wet paper towel to preserve the colour of the potato.

Using a real wax candle (unlit) with the classroom lights on, give students the opportunity to call out observations. Turn off the classroom lights under the pretext that “we are now going to observe the flame.” With the lights off, switch to the potato candle and light the almond wick. Students call out their observations of the flame, unaware that the wax candle has been switched out for a potato candle. After about a minute of observations, blow out the candle and take a bite! The students will be convinced that you just ate a wax candle—giving you a perfect opportunity to talk about the power of inference.

JUMPING SHAMPOO

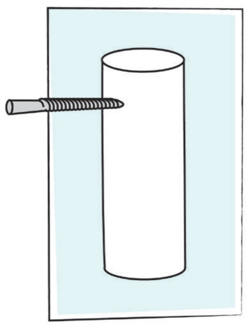


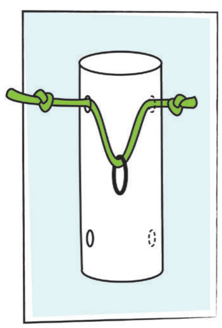
This demonstration invites students to work collaboratively. Jumping Shampoo demonstrates a surprising and fascinating phenomenon called the Kaye Effect. A thin stream of shampoo drizzled from a height of about 15-20 cm onto a tilted surface will produce a puddle that builds up and then erupts periodically in a streamer. Use thin shampoo and explore different heights and angles to get the most dramatic effect. Several variations of the demo can be seen on the internet (search “Kaye Effect”). The actual explanation for the effect involves advanced concepts which took researchers more than 40 years to figure out. The point of the exercise is to have the students work together to create an explanation.

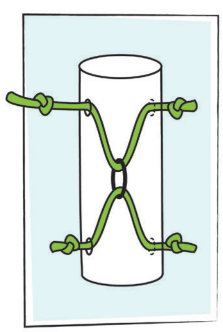
BLACK BOX

This demonstration invites students to make observations. Pull the top cords back and forth. Invite students to think about how they might be connected inside. Now pull one of the bottom cords. Continue pulling different combinations of cords while drawing students into the mystery. Ask students to draw a picture of what they imagine is inside the box. Encourage creative thinking!

NOTE: Never divulge what is inside the Black Box. In science we only ever have access to indirect observations—we can never know what is inside.







Building Your Black Box

Materials: (all dimensions are approximate)

- 2 pieces of 8 mm (5/16”) nylon rope, each 70 cm (27 1/2”) long
- 1 harness ring with a 4 cm (1 1/2”) diameter
- 35 cm (13 3/4”) cm long piece of drainage pipe (7.5 cm (3”) diameter)
- 2 drainage pipe end caps (7.5 cm (3”) diameter)

Tools:

- power drill with 10 mm (3/8”) drill bit

Procedure:

1. Drill the top holes directly across from one another, each 5 cm (2”) from the top. Repeat for the bottom holes, each 5 cm (2”) from the bottom (see top Figure).
2. Thread one rope through the top holes and the harness ring (see middle Figure).
3. Tie a knot 15 cm (6”) from each end of the rope.
4. Thread the other rope through the bottom holes. Again, ensure that the rope passes through the harness ring as indicated (see bottom Figure). Tie a knot 15 cm (6”) from each end of the rope.
5. Secure the end caps.

NOTE: Variations on the design (without a ring for example) will enrich the discussion and work equally well. You may also wish to encourage students to build their own versions of the device with bathroom tissue tubes and string.

ACTIVITY 1

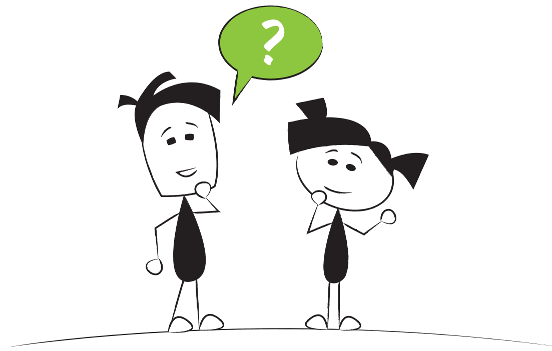
Asking Questions

Scientists ask questions.

Some of the most profound discoveries about our universe have come from seemingly simple questions. Today you will examine a number of objects and generate questions about the objects.

Your questions and insights will be collected on a graphic organizer with the following headings:

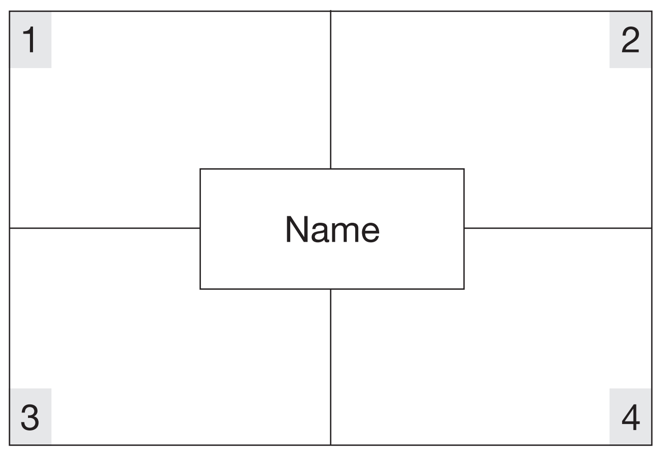
Quadrant 1: Describing words
Quadrant 2: Where might it come from?
Quadrant 3: Possible uses?
Quadrant 4: Questions you have about it



"Half of science is putting forth the right questions."
– Sir Francis Bacon

Instructions

1. Examine the object at your station. Discuss your observations with your group. Record your observations and questions in the space on the graphic organizer.
2. Leave the graphic organizer with the object when you are instructed to move to the next station.
3. At the next station, begin by reviewing the information and questions already recorded. Examine the object and add your own observations and questions. Do NOT repeat what others have already recorded.
4. Continue the rotation as instructed until you arrive back at your starting point.
5. Review the accumulated notes generated by your classmates. Take a blank graphic organizer and summarize the observations and questions. Present your findings to the class.



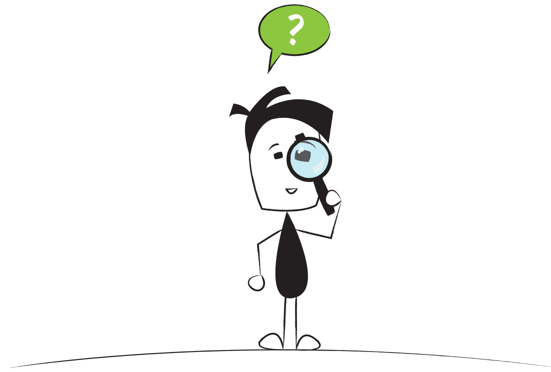
Consider This

1. Did it become harder or easier to come up with questions as you moved through the stations?
2. How did the questions change as you moved through the stations?
3. Which question will you take home to research tonight?

ACTIVITY 2

Why Is It Like That?

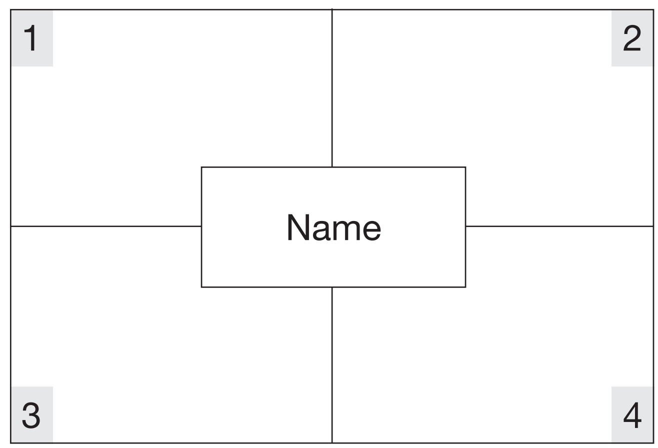
Our world is full of beauty and mystery. Scientists explore mysteries by making careful observations, asking insightful questions and making valid inferences. Inferences answer questions by connecting observations with each other or with existing knowledge. For example, you observe that penguins have wings but don't fly which leads to a question, "Why do penguins have wings?" You know that penguins eat fish. You make an inference that maybe penguins use their wings to help them swim.



"The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science." – Albert Einstein

Today you are going to explore images of mysterious things. You will organize your exploration with a graphic organizer that has the following headings:

Quadrant 1: Describing words
Quadrant 2: Specific characteristics
Quadrant 3: Questions about the object
Quadrant 4: Inferences that you can make



Instructions

1. Examine the image and talk about it with your group. Record your observations, questions and inferences on the graphic organizer.
2. Leave the graphic organizer with the image when you are instructed to move to the next station.
3. At the next station, review the information and examine the image. Add your own observations, questions and inferences. Do NOT repeat what is already recorded.
4. Continue the rotation as instructed until you arrive back at your starting point.
5. Review the accumulated notes generated by your classmates. Take a blank graphic organizer and summarize the exploration. Share your findings with the class.

ACTIVITY 3

What Do You See?

Observation and Inference

OBSERVATION Learning about your surroundings through your senses	**INFERENCE** Drawing conclusions based on observations and information
"The ground is wet."	"It must have rained last night."
"That person is running fast."	"Someone must be chasing them."
"The liquid is clear and colourless."	"The liquid is water."

Try These! (Put your answers in the spaces above.)

1. A thin rod with heavy ends is held horizontally by the middle. What do you observe? What do you infer?
2. A student is sitting outside the Principal's office. What do you observe? What do you infer?
3. A set of tracks has been photographed. What do you observe? What do you infer?
4. Create a story that would produce this set of tracks. Share your story with a classmate. How were your stories different?

5. Are inferences always right? How do you choose one inference over another?

Demonstration

1. Look at an unlit candle. Write down three observations and one inference.

2. Look at a lit candle. Write down three observations and one inference.

3. What impact does the amount of light in the room have on your observations?

4. What factors affect the quality of your inference?

5. How do magicians use inference to trick you?

***Alice & Bob in Wonderland* animations**

Watch and list the observations and inferences in each episode.

***Alice & Bob in Wonderland* Episode**	**OBSERVATIONS**	**INFERENCES**

Applying Your Knowledge

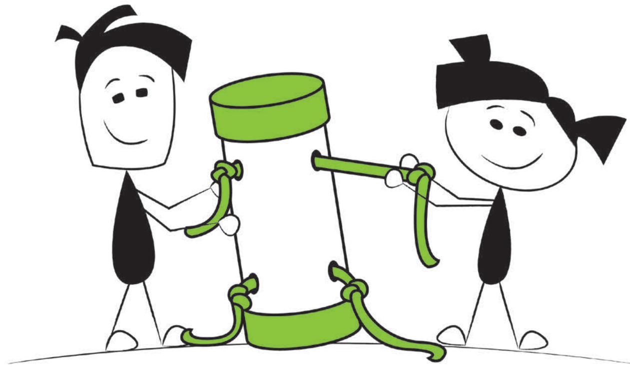
Design, practice and perform a simple trick that uses inference to fool your classmates.

ACTIVITY 4

Making Models

Scientific models are created to explain observations. Good models provide clear explanations for all known data and make predictions for new observations. New observations either support and strengthen the model or refute it. Models that fail to explain an observation are wrong and must be modified or replaced with better models—the old model might still be useful in a limited way but ultimately it has failed and must be replaced.

One way that scientists improve a model is by letting other scientists look at it and give their opinion about the model. Many breakthroughs have come as the result of one scientist providing key insights to another.



Models can never be proven right, but they can be proven wrong.

The Black Box

1. Observe the Black Box.
2. Sketch a model that explains what is happening inside the tube.
3. Exchange your model with a classmate who has a different model.
4. Discuss your models and suggest improvements to each other's work.
5. Is there an experiment that you could do to distinguish between your models?

Alice & Bob in Wonderland: Why Doesn't the Moon Fall Down?

1. Watch the *Alice & Bob in Wonderland* episode.
2. Describe the model created by Alice and Bob.
3. Do you agree with their model?
4. Can you find any flaws in their thinking?
5. This model works well for the Moon, but it fails when describing the motion of Mercury around the Sun. What happens to a model that fails to make correct predictions?

Jumping Shampoo

1. Observe the Jumping Shampoo demo.
2. Create a model that explains this strange phenomenon.
3. Gather into groups and discuss your models.
4. Create one model for your group.
5. Share your group's model with the class.
6. Are there experiments that you could do that would distinguish between your models?

Discussion

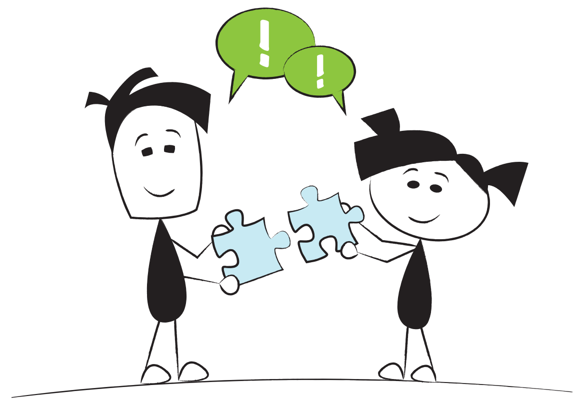
1. How does it feel when someone criticizes your model?
2. Did your model improve because of the criticism?
3. What role does experiment play in developing good models?

ACTIVITY 5
Science in the News

TEACHER NOTES

Science is a collaborative endeavour. Researchers build on the work of others and rely on feedback from colleagues to correct and refine their work. Understanding the world is too big a task to be done individually. It is only as a collective entity that scientists are able to make substantial progress.

This activity exposes students to the collaborative nature of science by having them work together to solve a mystery. Do not tell students that the theme of this activity is collaboration.



"If I have seen further than others, it is by standing upon the shoulders of giants."
– Isaac Newton

Initial Activity: *Describe a scientist*

Grades 7 – 8: White board/scrap paper sketch what a scientist looks like and add adjectives that describe a scientist.

Grades 9 – 12: White board the personality traits and skills a scientist has.

Main Activity

- The class is divided into small groups.
- Photocopy and distribute a News Flash summary sheet for each group.
- Photocopy and cut the relevant Fact Card sheet to provide one Fact Card per student.
- The students move around the room and trade Fact Cards without looking at them. Once they have made a trade they return to their group to record the Fact on the summary sheet.
- All the Facts are true, but not all are relevant. There are multiple copies of the same Facts in circulation during the activity.
- Once the group accumulates all ten facts they can solve the mystery.
- Solutions are presented to the class. Other groups can add to or refute the solution being offered.

Additional News Flash is available on the CD-ROM.

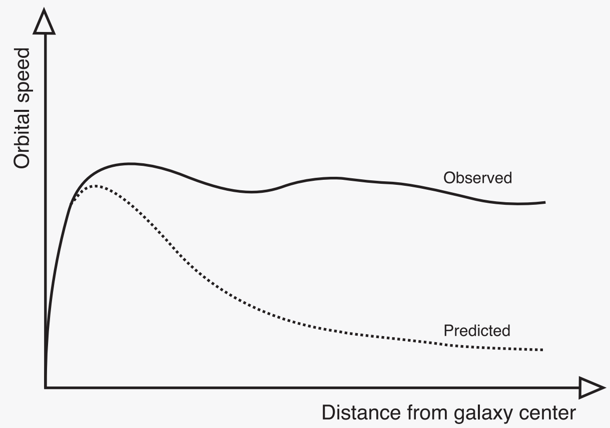
Wrap-Up Discussion

1. Did students indicate that scientists need to be collaborative?
2. Were students able to solve the mystery without collaborating?
3. What would prevent someone from collaborating with others?
4. If you were a scientist, what could you do to encourage others to collaborate with you?

NEWS FLASH:

STARS ARE GOING TOO FAST!

EARTH, *Milky Way Galaxy*— Astronomers looking at stars in the outer regions of distant galaxies have found that the stars are moving much faster than they should be! According to Newton's Law of Gravitation, stars orbit around galaxies because the mass of the galaxy pulls on the stars. Stars that are farther from the centre of the galaxy should feel less force and travel more slowly. But when astronomers look at the light coming off the stars and analyze that light, their observations indicate that these more distant stars are moving just as fast as the more central ones. What could possibly make stars travel so much faster than expected?



Summary of Facts

Conclusion

What could possibly make stars travel so much faster than expected?

FactCards: Stars Are Going Too Fast!

The objects in outer space include: planets and moons, stars, and black holes.	Black holes are heavy objects that do not emit light so they cannot be observed directly.
Most of the mass in our solar system is in the Sun. Planets are very light in comparison.	Black holes are heavy objects that can be observed by astronomers indirectly.
The speed of an orbiting star depends on the force acting on the star.	Our theory for gravity is well established and supported by many observations.
Distant planets and moons are hard to see.	There is no reason to expect that all matter that has mass would also be visible to astronomers.
The mass of all the gas and stars in a galaxy can be determined.	Astronomers can tell how much mass is in a region of space by how much it bends light.

NEWS FLASH:

SEASIDE SPARROW DECLARED EXTINCT!!

MERRITT ISLAND, *Florida*— The Dusky Seaside Sparrow that once thrived in the salt-marshes on the east coast of Florida's Merritt Island has been declared extinct. The last Dusky Seaside Sparrow is thought to have died on June 16, 1987. No further sightings have been recorded. The sudden disappearance of this once common bird has researchers puzzled. What caused the extinction of the Dusky Seaside Sparrows of Merritt Island?

The last Dusky Seaside Sparrow

Summary of Facts

Conclusion

What caused the extinction of the Dusky Seaside Sparrow?

FactCards: Seaside Sparrow Declared Extinct!

Merritt Island is home to the John F. Kennedy Space Center.	DDT was used extensively in the 1940s to reduce the number of mosquitoes on Merritt Island.
Salt marshes on Merritt Island were protected in 1973 by the Endangered Species Act.	One salt marsh was drained to build a highway to connect the Space Center with Disney World.
The Dusky Seaside Sparrow was not hunted for sport or food.	In 1963 one marsh on the island was flooded in an attempt to reduce the mosquito population.
The introduction of a new predator can have a negative effect on populations.	In the early 1970s Merritt Island experienced an increase in real estate development.
The sparrows could only nest in the cordgrass that grew in the salt marshes.	The sparrows were ground foragers that ate insects and invertebrates on dry ground.

NEWS FLASH:

THOUSANDS OF FISH DIE!

CHAROLETTE, *North Carolina*— Thousands of Atlantic menhaden are washing ashore in a massive fish kill in the Neuse River system of North Carolina. Based on previous years, scientists estimate that the final death count this summer will exceed several million fish. The exact cause of death has not yet been established but the fish are covered with sores. Researchers are taking measurements and performing careful analysis of the water.

Dead fish in the Neuse River

Summary of Facts

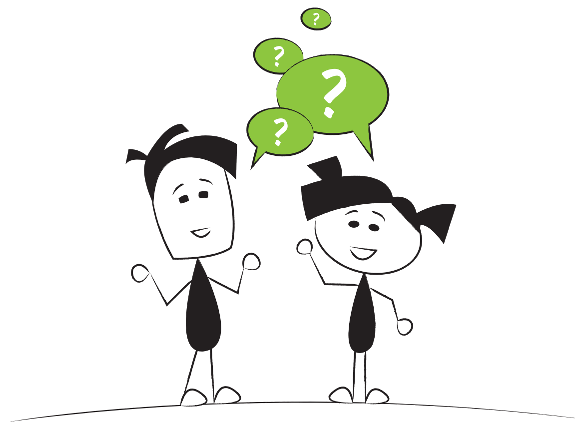
Conclusion

What caused the massive fish kill?

FactCards: Thousands of Fish Die!

Sunlight increases water temperature and stimulates photosynthetic organisms.	Some forms of Pfiesteria produce toxins that can destroy the skin of a fish.
Atlantic menhaden feed on microscopic phytoplankton.	Measurements reveal adequate levels of dissolved oxygen in the water.
Increased nitrate levels cause explosive growth in algae and phytoplankton.	Thick mats of algae on the surface of the river reduce the oxygen levels in the water.
Microorganisms called Pfiesteria are common in freshwater rivers.	There were several days of heavy rains in the weeks prior to the fish kill.
Some Pfiesteria release toxins when stimulated by chemicals given off by fish.	The 10 million hogs in North Carolina produce a lot of nitrogen-rich waste every day.

ACTIVITY 6
Thinking Deeper



Many advances in science happen when someone asks questions that push past an apparently commonsense answer. Thinking like a scientist means using your imagination to question the world around you. Good questions require creativity.

"To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science."
– Albert Einstein

Observe

Watch three *Alice & Bob in Wonderland* episodes.

Reflect

Identify the questions that are asked, the answers that are offered and the imaginative thinking that provides new insight.

- How did one question lead to another?
- Why did the simple, obvious answer not work?
- What was the insight that led to the deeper question?

Research

Watch one of the *MinutePhysics* episodes.

Apply

Take the information from the *MinutePhysics* episode and turn it into an *Alice & Bob in Wonderland* episode. Create a storyboard for your episode outlining the initial question, simple answer and creative thinking that gives deeper insight into the topic.

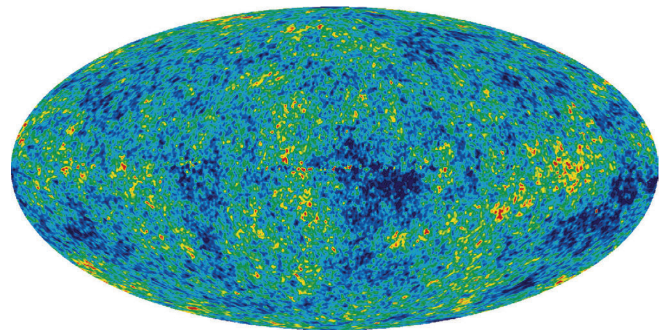
Extend

What other phenomena do you have questions about? Generate a list of questions and then choose one to investigate. Research the phenomenon, create a storyboard and share it with your classmates.

CASE STUDY 1

Cosmic Microwave Background

The Cosmic Microwave Background (CMB) is one of the most important astronomical observations of the last century. In 1963, Arno Penzias and Robert Wilson built a radio telescope for Bell Labs. A radio telescope collects the same kinds of information as a light telescope only it uses a different frequency. Penzias and Wilson planned to use their radio telescope to make accurate measurements of objects in the Milky Way galaxy. When they began taking measurements, they realized that all of the signals were 3K warmer than they had expected. This kind of result usually indicates a systematic error caused by a problem with the equipment so they spent over a year trying to find the problem with their equipment, even sweeping bird droppings out of the receiver. After testing and re-testing their equipment, they reluctantly accepted the data but did not understand what to make of it.



WMAP 5 year data

The Kelvin (K) scale measures temperature. It starts at absolute zero (-273.15°C). 3K is very cold.

Unknown to Penzias and Wilson, fifteen years earlier, a group of physicists had predicted this phenomenon: George Gamow and two of his students had calculated how the heat from the Big Bang would have dissipated over time. They predicted a background radiation of 5K, but their paper had very little impact and the prediction was beyond the reach of 1948 technology so no experiments could be done to test their theory.

Also unknown to Penzias and Wilson, a physicist at Princeton had been working on a theory about the early universe that predicted a background radiation. Robert Dicke gave his student James Peebles the task of calculating the temperature of the background according to his theory. Peebles completed the task and submitted the paper for publication only to have it rejected since it had already been done 15 years before by Gamow and his two students Alpher and Herman.

A colleague at Princeton heard Peebles give a talk about his calculation and his need for observational data. This colleague was aware of Penzias and Wilson's dilemma of a background noise that had no apparent explanation so he suggested they get together. As soon as Peebles saw the data, he knew exactly what was causing the background noise—Penzias and Wilson were measuring the remnants of the Big Bang.

The two groups then published companion papers: one paper reporting the data, the other interpreting the data which came to be known as Cosmic Microwave Background. CMB has become one the most carefully studied phenomena in astronomy. Several generations of satellite telescopes have been used to map the distribution of CMB to incredible levels of precision. Cosmologists rely on these precise measurements to create models for the universe that tell us how old it is (13.8 billion years), what it is made of (4.6% matter, 24% dark matter, 71% dark energy) and even what geometry best describes the universe on large scales (flat). The tiny fluctuations in temperature, displayed as colours in the image, are evidence that the universe was not perfectly uniform which leads to the formation of stars and galaxies. What started out as noise in an antenna has become one of the most important clues to understanding our universe.

Understanding Content

1. 3K is:
   (a) very hot.
   (b) very humid.
   (c) very windy.
   (d) very cold.

2. CMB stands for:
   (a) Cosmic Microband Background.
   (b) Cosmic Microwave Background.
   (c) Comical Microwave Background.
   (d) Cosmic Microwave Backup

3. Which of the following was NOT done by Penzias and Wilson?
   (a) They built a radio telescope.
   (b) They spent over a year trying to find a problem with their equipment.
   (c) They wrote a paper about the early universe that required background radiation.
   (d) They measured the remnants of the Big Bang.

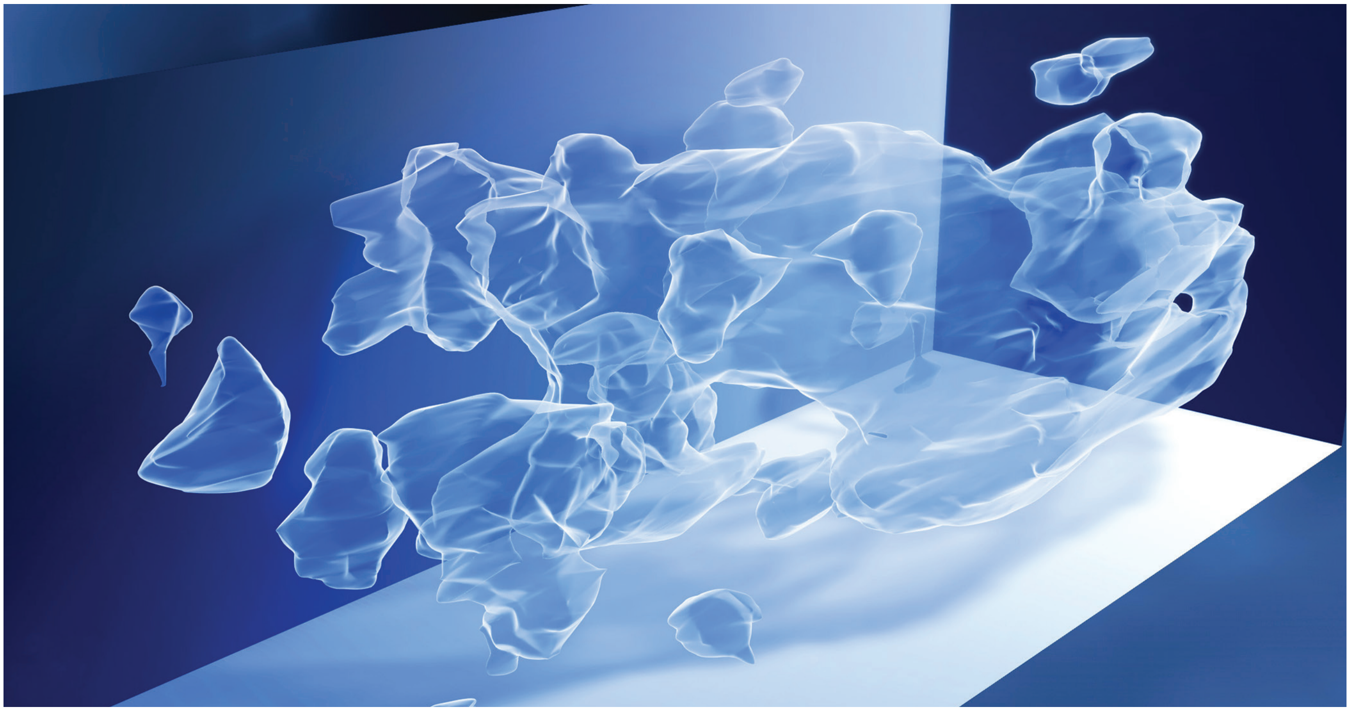
4. When did George Gamow first predict the temperature of the background radiation as 5K?
   (a) 1943
   (b) 1948
   (c) 1963
   (d) 1968

5. Write a summary statement describing the universe revealed by the measurements of the CMB.

Exploring Context

1. Penzias and Wilson made their discovery in a time where communication of ideas was restricted to live meetings or printed journals. How does the internet change things?
2. Astronomers have a lot to learn in their own discipline and cannot be expected to keep up with the latest ideas in cosmology. How does collaboration address this shortfall?
3. The original prediction for CMB was made by Alpher, Gamow and Herman in 1948 but they are often overlooked in the story. Does it really matter who gets the credit?
4. Were Penzias and Wilson looking for the background radiation? Is it right to say that they "accidentally" discovered the CMB?
5. Imagine that you are James Peebles. How would you feel after solving a difficult problem and writing a paper about it only to have it rejected?

CASE STUDY 2
Dark Matter



When Isaac Newton published his Principia in 1687, he demonstrated that the same laws of motion that worked on earth could explain how the planets moved. His theory of gravity says that planets orbit around the Sun because the Sun's mass exerts a force on them that controls their motion. As our understanding of the universe grew, this theory was extended to stars orbiting the centre of galaxies, and galaxies moving around in clusters.

The fundamental tool used by astronomers to obtain information about distant objects is the telescope. In the early 1930's, astronomers developed new tools that gave them new insight into the nature of our universe. Spectrometers added to telescopes allowed astronomers to analyze light emitted by distant objects in greater detail. Using these new tools and creative techniques, astronomers learned a lot about stars and galaxies. For example, the colour of a star tells us how hot it is, while the spectrum of colour tells us what elements are in the star and how fast it is moving.

Fritz Zwicky was a brilliant astronomer studying light from the Coma galaxy cluster in 1933 when he realized that the galaxies were moving 400 times faster than they should, based on the mass of the cluster. No existing theories could explain these results so Zwicky proposed that there must be a new kind of matter that had mass but could not be seen—Dark Matter. This proposal was pretty radical at the time and Zwicky, who was known for being somewhat eccentric and abrasive, was unable to convince his colleagues to pursue his idea. Nothing much came of his observations during this "golden age of cosmology" when astronomers were busy solving other very interesting problems. It would take almost 40 years before anyone else showed interest in the problem of Dark Matter.

> *"Consider that at this moment we can account for only about 15% of all the gravity we have ever measured in the universe. We are simply clueless about what's causing the rest."*
> *– Neil DeGrasse Tyson*

That person was Vera Rubin, a young female astronomer who had experienced some resistance from the established community as a woman in a male-dominated field. In the late 1960's, she decided to do some 'safe' research that would build her reputation as a professional astronomer. Her colleague Kent Ford had developed a new kind of spectrometer that allowed them to measure the speed of very dim stars. Rubin decided to look at the stars in Andromeda to see how fast they were moving. To her astonishment, they were moving much faster than they should. She then proceeded to study hundreds of other galaxies and found that the outer stars were orbiting with much higher speeds than the observable mass of the galaxy alone could account for.

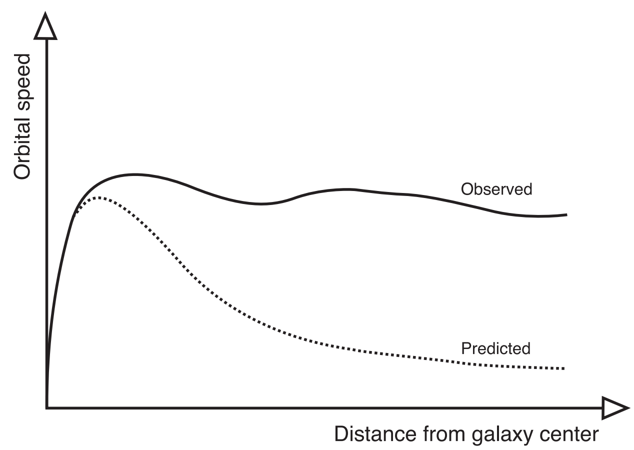
The data that Rubin and Ford accumulated compared the speed of the star with its orbital radius. They expected to see the speed drop off for more distant stars—just as Neptune moves slower than Mercury, but instead they found that the speeds remained roughly constant. Stars on the outer edge of the galaxy moved with the same speed as those closer to the centre. There were only three possibilities:

1. Something was wrong with their measurements.
2. Something was wrong with the theory of gravity.
3. Something must be there that we cannot see but has mass.

Rubin believed that her measurements were good and that gravity was well understood. This left her with only one conclusion—there must be some kind of substance in and around every galaxy that has mass but does not produce, absorb, or reflect light.

Subsequent observations and calculations have estimated that Dark Matter accounts for 84% of the matter in our universe.

Vera Rubin measuring galaxy rotation curves (1970)



Understanding Content

1. Isaac Newton demonstrated that:

   (a) the laws of motion that work on Earth explain how the planets move.
   (b) the laws of motion that work on Earth explain how the Sun moves.
   (c) the laws of motion that work on Earth do not explain how the planets move.
   (d) the laws of motion that work on Earth do not explain how the Sun moves.

2. Kent Ford developed a new type of
   (a) spectrometer.
   (b) telescope.
   (c) matter.
   (d) microscope.

3. Vera Rubin experienced some resistance from the established astronomy community because:
   (a) she was American.
   (b) she was female.
   (c) she measured stars.
   (d) she studied hundreds of galaxies.

4. According to the graph above:
   (a) the observed orbital speed is higher that the predicted orbital speed.
   (b) the predicted orbital speed is higher than the observed orbital speed.
   (c) the distance from the galaxy centre is greater for observed orbital speed.
   (d) dark matter is 84% of the matter in our universe.

5. Summarize the three possibilities that would explain Rubin and Ford's data on the speed of the stars compared with their orbital radius.

Exploring Context

1. When observations don't agree with the accepted theory, scientists can either rework their theory or wait for more observational evidence. How do you think they make that decision?
2. Sometimes scientists have to be creative and invent things to make their theories agree with observation. How reasonable is this when these things have never been directly observed?
3. Are scientists always trying to find evidence for radical ideas?
4. What previous science had to be developed before this discovery could be made?
5. What kind of personality conflicts can interfere with the progress of science?

CASE STUDY 3

Element 118

The Periodic Table lists all of the elements known to exist. There are about ninety naturally occurring elements and the rest are synthetic, created in a laboratory by smashing heavy elements together. If the conditions are just right, the two elements will fuse together into one super-heavy element, but such super-heavy elements are extremely unstable and fall apart within a fraction of a second. The only evidence for their existence is a trail of radioactive decay products. The new element is never actually observed; its presence is inferred by reconstructing the decays measured by a detector.

“Science is self-correcting. If you get the facts wrong, your experiment is not reproducible. There are many lessons here, and the lab will extract all the value it can from this event. The path forward is to learn from the mistakes and to strengthen the resolve to find the answers that nature still hides from us.”
– Charles Shank (Berkeley)

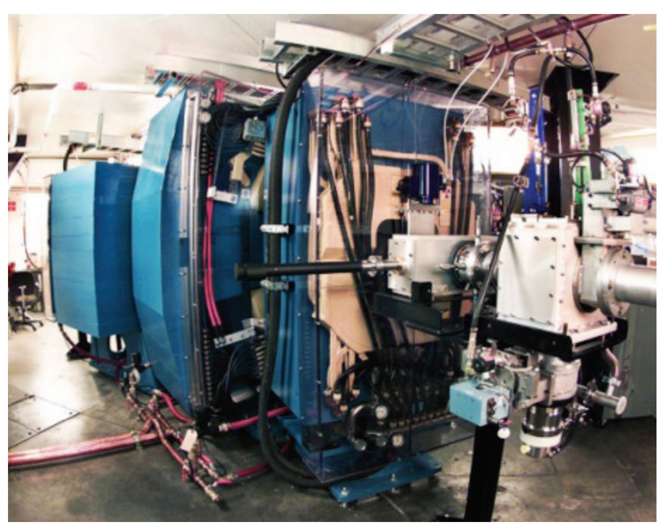
The quest for creating heavier and heavier elements is an important one: pushing the limits of our models is how we move forward in science. With each new element, we learn more about the rules that govern the structure of the nucleus. There is also prestige that comes with the production of a new element. While element names are determined by an international committee, the lab that creates an element is given the honour of naming it. Many elements are named after the locations where they were produced: a lab can have an element named after it (eg. Berkelium, Dubnium) or a nation can be honoured (eg. Americium, Polonium). Other elements are named after scientists (eg. Einsteinium, Bohrium, Meitnerium). Several researchers have been awarded the Nobel Prize for their role in the discovery of new elements and some have even had elements named after them (eg. Lawrencium, Seaborgium). One of the highest honours science can bestow on someone is to name an element after them.

In the 1980’s, the top lab in the world for creating heavy elements was the Lawrence Berkeley National Lab in USA. However, after German researchers produced elements 107 through 112 and Russians announced the discovery of element 114, it looked like American labs were being left behind. American researchers responded by building a new detector and recruiting high profile researchers.

In 1999, the team at Berkeley announced they had produced three atoms of element 118 which then decayed to element 116, 114, 112, 110, 108 and finally 106. This meant that they had produced two new elements since 116 had never been observed before. The American scientists were euphoric. Papers were published, press conferences were held and plans to push ahead to element 119 were discussed.

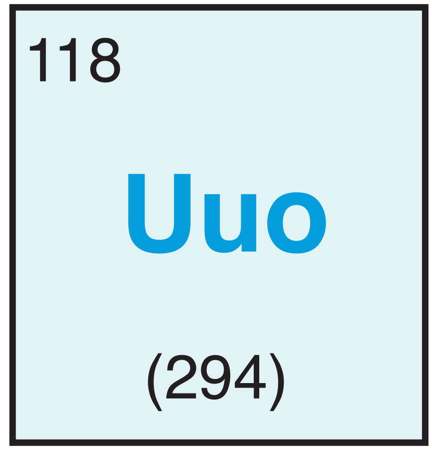
Yet, within a few months, there were rumblings and questions were being raised. Other labs were unable to reproduce the results and even the team at Berkeley was unable to produce their result again.

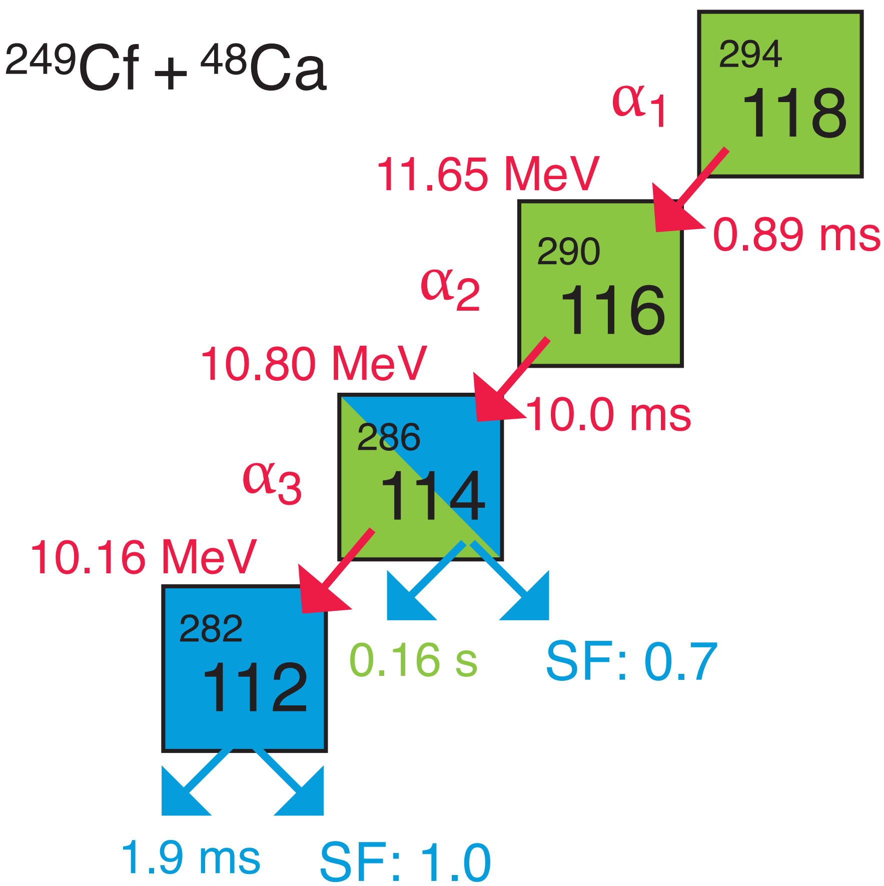
In 2001, the Berkeley lab retracted their announcement and launched an internal investigation to determine what had gone wrong. The investigation focused on the role of Victor Ninov, a researcher who had been recruited from the German facility. Ninov was an expert on the software that turned raw data from the detector into meaningful signals. In fact, he was the only person on the team who knew how to use the complicated software and it was this software that produced the signals that he interpreted as



evidence for the new elements. Upon closer inspection, it was discovered that the raw data had been edited. When the original data was used, the signals could not be reproduced. Ninov was fired and other researchers were reprimanded for not having checked his work more carefully.

Five years after the retraction, the Russian lab in Dubna announced that they had produced three atoms of element 118 using a different method which has yet to be confirmed by another experiment.





The decay chain of element 118

Understanding Content

1. The Periodic Table lists:
   (a) only the naturally occurring elements.
   (b) only the synthetic elements.
   (c) both naturally occurring and synthetic elements.
   (d) only the elements found on Earth.

2. Elements are often named after:
   (a) people.
   (b) places.
   (c) nations.
   (d) all of the above.

3. Element 110 was discovered in:
   (a) America.
   (b) Germany.
   (c) Russia.
   (d) Japan.

4. What did the Americans do to regain their leadership in the element field?
   (a) They built a bigger accelerator.
   (b) They built a new detector.
   (c) They developed new computers.
   (d) They created new theories.

5. Write a paragraph summarizing the outcome of the Berkeley investigation.

Exploring Context

1. What's the point of creating super-heavy elements if they just fall apart right away?
2. What kinds of pressures are scientists under?
3. Element 118 was announced based on evidence from three atoms. Do you think this amount of data is adequate?
4. What kind of procedures should labs follow to ensure that they do not make announcements based on false data?
5. Charles Shank was the head of Lawrence Berkeley Labs at the time of the element 118 announcement and retraction. How would if feel to be in his shoes?

CASE STUDY 4

Neptune

In 1781, while working on his star catalogue, William Herschel observed a fuzzy star that grew into a sharper disk when it was magnified. He had stumbled upon the planet Uranus. The discovery of a new planet inspired a whole new generation of astronomers. As astronomers watched Uranus over the next 50 years, they discovered an intriguing mystery: as Uranus travelled around Sun, it seemed to wobble. This strange behaviour could only be explained by the presence of yet another planet in the solar system, one that tugged on Uranus when they got too close together.

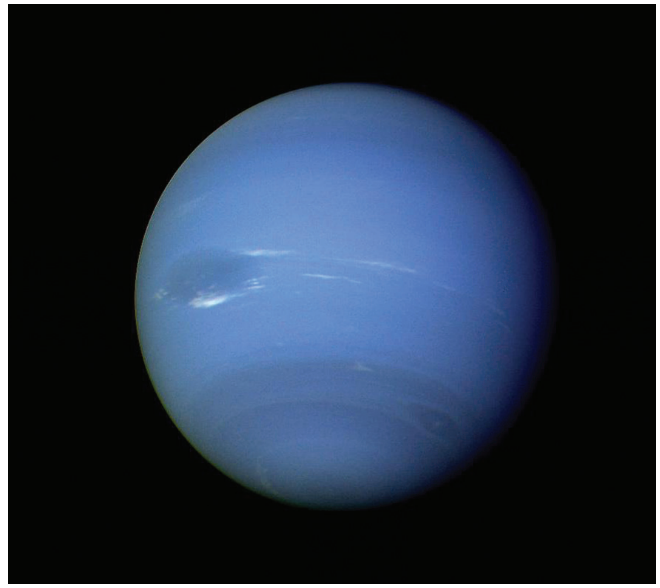
Another clue that pointed toward the possibility of a new planet had been provided by Johann Bode who, ten years before Herschel's discovery of Uranus, had used the work of Johann Titius to generate a description of the solar system using a geometric series [$0.4 + 0.3(2^n)$], as follows:

PLANET	TITIUS-BODE PREDICTION	OBSERVED RADIUS (AU)
Mercury	0.4	0.38
Venus	0.7	0.72
Earth	1.0	1.0
Mars	1.6	1.52
Asteroid Belt*	2.8	2.8
Jupiter	5.2	5.2
Saturn	10.0	9.55
Uranus	19.6	19.2
Neptune	38.8	30.1

* Discovered after Bode published his work.

Although Bode had actually published his table ten years before Herschel observed Uranus, the precision with which it predicted the orbit of Uranus led astronomers to search for a planet between Mars and Jupiter (which we now know to be the location of an asteroid belt).There is no known reason for why this pattern works—it is called an empirical relation because it is based only on data.

In the 1840s, two people took up the mathematical challenge of the wobble of Uranus: John Couch Adams, a British mathematician, and Urbain Le Verrier, a French mathematician. Working independently and using Bode's pattern, each man calculated the possible orbit for a planet that would produce the wobble. Once the calculations were complete, the mathematicians had to convince astronomers to take their prediction seriously. Both men had a difficult time persuading anyone to look at their results and attempt to find the planet.



Voyager-2 image of Neptune

After being rejected by French observatories, Le Verrier was able to convince a junior astronomer in Germany to try to find the planet. British astronomers only took Adams seriously when they saw that Le Verrier had published similar calculations. Unfortunately, Adams' predictions were not as accurate as Le Verrier's so the British astronomers looked in the wrong place.

The first person to recognize the planet Neptune was the young German astronomer Galle in 1846. When his results were published, it turned out that British astronomers had also seen the object but had not recognized it as the planet they were looking for. In fact, further research showed that many astronomers dating back to Galileo had actually observed Neptune but had not recognized what it was.

"The discovery in 1846 of the planet Neptune was a dramatic and spectacular achievement of mathematical astronomy."
– James Newman

Understanding Content

1. According to the table above:
   (a) the Titius-Bode prediction gives an exact description of the solar system.
   (b) the Titius-Bode prediction is completely wrong.
   (c) the Titius-Bode prediction gives a good approximation of where the planets are.
   (d) the Titius-Bode prediction was only good for the observed planets.

2. Three different nationalities are mentioned in this article. They are:
   (a) Canadian, French and British.
   (b) German, French and American.
   (c) Canadian, British and German.
   (d) British, French and German.

3. The orbit of Uranus around the Sun is described as having a:
   (a) geometric series.
   (b) wobble.
   (c) sharper disk.
   (d) precession.

4. Who discovered Uranus?
   (a) Herschel
   (b) Le Verrier
   (c) Adams
   (d) Galle

5. Write an engaging headline for this article if it was to be published in a newspaper.

Exploring Context

1. Many historians argue over who should get credit for discovering Neptune. Who do you think should get the credit and does it really matter?

2. Another solution to the wobble was to abandon Newtonian mechanics and replace it with something else. Why is it not always appropriate to abandon well established theories on the basis on one anomaly?

3. The planet Mercury also has a strange orbit. For years astronomers searched for a planet called Vulcan but to no avail. If another planet didn't cause the strange orbit what option is left?

4. Le Verrier and Adams were both convinced that the new planet existed and that they could predict where it was but they couldn't convince anyone to look for it. How do you think they felt? How would you respond to such adversity?

ANSWERS

ACTIVITY 2 Why Is It Like That?

Antlion
The antlion larvae build pits in sandy soil and then bury themselves at the bottom of the pit. Unsuspecting insects come along and fall into the pit and are funneled directly into the mandibles of the waiting antlion.

Axolotl
This salamander has several fascinating features, such as external gills, but the one that is drawing the most attention from researchers is its ability to regenerate tissue. This salamander can regrow entire limbs, replace injured lungs and even recover from spinal cord injuries.

Isopod
The Isopod is a parasitic insect that lives inside the mouth of the host fish. The isopod enters the fish through its gills, eats the fish's tongue and then attaches itself to the artery that had been supplying blood to the tongue. As the isopod grows it actually functions as the tongue for the fish.

Lotus Leaf
The lotus leaf has evolved a fascinating mechanism for repelling water and staying clean. These abilities are being studied by researchers hoping to develop self-cleaning paints, textiles or even windows.

Hadal Snailfish
This snailfish lives in the extreme conditions at depths of almost 8000 m. Researchers are interested to know what kind of adaptations allow this fish to live in near freezing water at pressures of 8000 t/m^2.

Tarantula and Tarantula Hawk Wasp
The tarantula is a large, hairy spider that lives in underground burrows. It hunts at night and uses powerful venom to both paralyze and digest its prey. The tarantula hawk wasp is one of the world's largest wasps, growing up to 5 cm in length. The wasp searches for tarantulas and then lures them out of their burrow for a fight. The wasp stings the spider repeatedly until it is paralyzed then it lays its eggs inside the spider. The tarantula will be food for the wasp larvae.

Snowflakes
Snowflakes are ice crystals. When water turns into ice, the molecules line up according to very simple rules, resulting in a repeated pattern called six-fold symmetry. The exact nature of the crystals depends on the temperature.

Crab Nebula
The Crab Nebula is the remnant of a supernova recorded by Arab, Chinese and Japanese astronomers in 1054. It is about 6500 light years away and expanding at a rate of 1500 km/s. At the centre of the nebula – the core of the star that exploded - there is a rapidly rotating neutron star.

ACTIVITY 3 What Do You See?

Observation vs Inference

1. You observe that the rod bends. You infer that there is a force pulling on the rod.
2. You observe a student sitting. You infer that the student is in trouble or sick.
3. You observe two different sets of footprints going to a location where the prints mix and then only one set of prints leaves. You can infer many things, such as that two animals meet and one eats the other.
4. The stories can vary greatly. Note that the tracks do not have to occur at the same time.

Demonstration

1. Common observations: white, cylindrical, waxy, hard, etc.
   Common inferences: made of wax, weight, feels waxy.
2. Common observations: yellow flame, flame is 3 cm tall, smoky, etc.
   Common inferences: flame is hot.
3. Less light reduces the quality and quantity of observations.
4. The quality of an inference depends on the quality of the observations, the prior knowledge of the person and their ability to reason.
5. Magicians rely heavily on inference to make you think you see something that you did not actually see. They control the observations and influence your reasoning by talking in a misdirecting manner.

ACTIVITY 5 Science in the News

Stars Are Going Too Fast!
Astronomers can account for all the mass in a galaxy due to planets, stars and even black holes. Stars are orbiting at higher than expected speeds so there must be something else applying a large gravitational force on them. We are confident in our understanding of gravity so that leaves only one option: there must be some new kind of matter that has mass but does not interact with light. We call this new kind of matter Dark Matter.

Seaside Sparrow Declared Extinct!
The demise of the Dusky Seaside Sparrow began with DDT spraying in the 1940s. DDT reduced the population from 2000 to 600 breeding pairs. The sparrows were ground foragers so when the marshes were flooded in 1963, they declined further. The final blow to the population came when the last remaining marsh was drained for development in the early 1970s. The Endangered Species Act of 1973 came too late to save them: the damage had already been done and the population could not recover.

Thousands of Fish Die!
Fish kills in the Neuse River start with nitrates from intensive hog farming operations entering the river and increasing the algae and plankton populations. More algae and plankton attracts fish to the area which changes the chemistry of the water. Pfiesteria respond to this change by releasing a toxin that destroys the skin of fish, causing them to die in massive numbers.

Case Study 1 Cosmic Microwave Background

Understanding Content

1. (d)
2. (b)
3. (c)
4. (b)
5. The universe described by the CMB is 13.77 ± 0.11 billion years old. It is composed of dark matter (24%), dark energy (71.4%) and normal matter (4.6%). This matter is distributed in such a way that the universe is best described as flat.

Exploring Context

1. The internet allows researchers access to a huge searchable archive of papers and to have immediate communication with other scientists around the world.
2. Astronomers collaborate with cosmologists in order to understand the implications of their observations. The astronomers concentrate on how to make observations and the cosmologists concentrate on how to interpret the observations.
3. On one level it does not really matter who gets credit for a discovery, but on another level it is extremely important. Scientists are people and people need affirmation that what they are doing is valued. Research funding, tenure and prizes are also awarded based on previous success.
4. Although Penzias and Wilson were not looking for CMB specifically, it was not really accidental. They had designed their equipment to be sensitive to the microwave range and were astute enough to recognize that they were observing something significant. This is an example of serendipity—a significant discovery that was not the original goal of the experiment.
5. Having papers rejected by publishers is a very difficult part of research. Scientists are people who get dejected and discouraged just like everyone else.

Case Study 2 Dark Matter

Understanding Content

1. (a)
2. (a)
3. (b)
4. (a)
5. Rubin and Ford's data can be explained one of three ways. First, their measurements could be wrong. Second, our understanding of gravity could be wrong. Third, there could be some kind of dark matter that has mass but does not interact with light.

Exploring Context

1. The decision to rework a theory or to wait for more data is a personal one. If a researcher has more confidence in the observations than the theory then they will invest their energy is developing a new theory. If the researcher has more confidence in the theory then they will wait for more observations.
2. Inventing new things to explain observations is a difficult decision. Scientists are trained to reject speculative ideas that have no proof, but scientists are also creative problem solvers. If the observations are best explained by inventing something then that is the appropriate response. The other component to this response is to generate predictions that would either affirm or negate the invention.
3. Scientists are not always trying to find evidence for radical ideas. Vera Rubin was trying to make simple observations of a nearby galaxy when she noticed that something in her data was strange. Many scientific experiments involve simply gathering more data to support current theories.
4. Science is cumulative. In order for Rubin to make her observation, there had to be many technical developments and theoretical discoveries to understand what should be seen. Rubin used Ford's new spectrometer to observe the spectral shift from stars. She was able to use theories by Newton, Doppler, and Hubble to interpret her observations.
5. Scientists are people. Personality conflicts and societal barriers can interfere with the advancement of science. Fritz Zwicky was brilliant but he was difficult to get along with so many scientists ignored his results. Vera Rubin was a woman working in a male-dominated field so she faced more resistance than her work warranted.

Case Study 3 Element 118

Understanding Content

1. (c)
2. (d)
3. (b)
4. (b)
5. The Berkeley investigation led to a retraction of the paper and the discovery claim. Victor Ninov was fired and the other members of the team were reprimanded for not checking his work more carefully.

Exploring Context

1. Creating super-heavy elements is one way to test our current model for matter. The goal is not to actually create new material but to expand our knowledge of what holds atoms together.
2. Scientists feel pressure just like everyone else. They know that a big discovery will give them recognition and job security. Labs also feel similar corporate pressure: discoveries lead to prestige and stable funding.
3. Synthetic elements are not officially named until the scientific community feels there is sufficient evidence. Three atoms is not a large enough sample to generate confidence.
4. One of the lessons learned from this situation is that no one person should have control of the data. Other researchers must be able to replicate the results independently.
5. Shank was probably really embarrassed and very angry that this happened in his lab. He might also feel personally offended depending on his relationship with the researchers in question.

Case Study 4 Neptune

Understanding Content

1. (c)
2. (d)
3. (b)
4. (a)
5. New planet discovered right where predicted!

Exploring Context

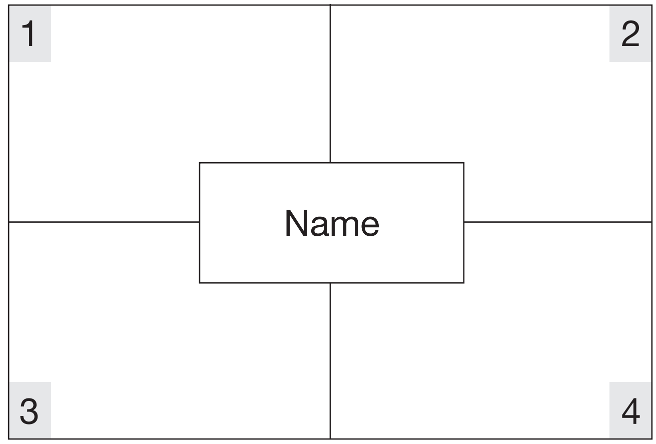
1. Galle and Le Verrier deserve the credit for discovering Neptune because they were the first to recognize what it was. Credit for the discovery is important because it validates the efforts of the researchers and, in this case, determines who gets to name the planet.
2. New theories have to provide valid explanations for all previous observations as well as the anomalous ones. To abandon Newtonian mechanics because of one anomaly is a pretty drastic step.
3. The precession of Mercury did not lead to the discovery of another planet because in this case it is the theory that fails. The orbit of Mercury can only be explained with the better model for gravity provided by Einstein's general theory of relativity.
4. Both Le Verrier and Adams were frustrated by the disinterest of astronomers. Adams kept pushing for attention while Le Verrier simply moved on to another observatory until he found an astronomer willing to listen.

APPENDIX

Adapting the Frayer Model for Inquiry

We will use the basic structure of a Frayer Model to help students organize their inquiry (see following page for a template used in Activities 1 & 2). In the central box is the name of the object being examined while in each of the four quadrants is a category of information about the object.

This model can be used at any grade level for a multitude of purposes. It lends itself to a variety of teaching strategies including individual work, think-pair-shares, collaborative learning and can be used for both small and large group work.



The Frayer Model is a simple graphic organizer originally designed to help readers decipher words and concepts.

An 11x17 version of the Frayer Model is on the CD-ROM.

Types of lessons possible

1. Ice breaker: *Use an eclectic collection of items to pique curiosity.*
2. Motivational opener: *Use items to introduce a new unit.*
3. Thinking and Inquiry Activity: *Use items to stimulate questions and lead students to think deeply about their world.*
4. Consolidation Activity: *Use items related to topics recently studied.*

Prior to lesson

- Photocopy Frayer Models, with each quadrant clearly labelled.
- Assemble the items or images that you wish the students to examine.
- Prepare larger versions for the wrap-up portion of the activity.

Suggested items to examine

The options are only limited by what you have available and what you hope to achieve. Here are some suggestions organized by discipline:

- Biology: *bones, fossils, seeds, flowers, leaves, sea shells, plants, sea sponges*
- Earth Science: *rocks, fossils, sand, minerals, lava, drift wood*
- Chemistry: *glassware, powders in vials, elements, safety or measuring equipment*
- Physics: *simple machines, electric devices, optical instruments*

Lesson Wrap-up

After circulating through each station, students consolidate the ideas generated for one station and present the completed graphic organizer to the class.

Frayer Graphic Organizer

2

4

Name

1

3

02 Perimeter Inspirations

Process of Science

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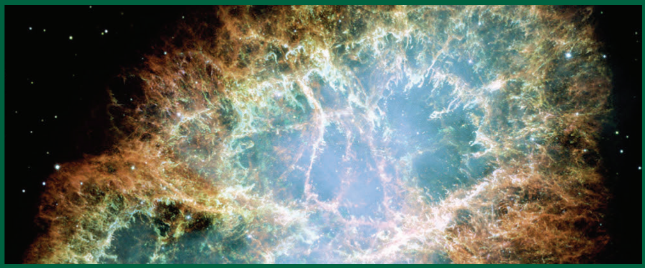

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