Conceptual Academy

Physics

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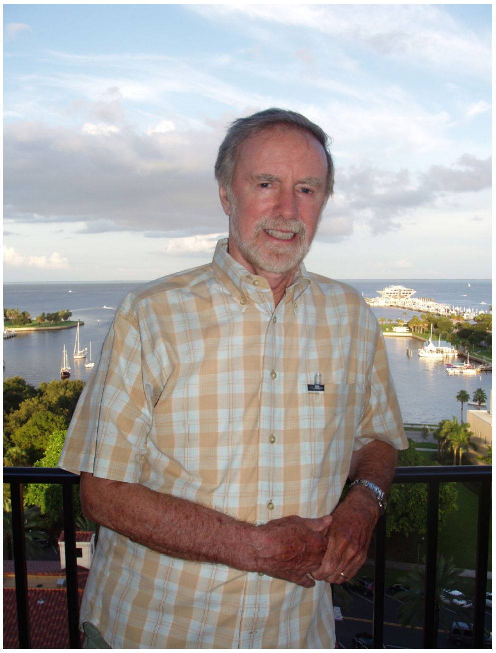

To the Instructor and Student

In most American schools, physics has usually been the last course in a science sequence. This policy goes back to the 1800s when farming was dominant and it was enormously important that personal hygiene be learned in school. Biology was the course that taught hygiene. A second year was devoted to chemistry, at a time before the electron was known, when students learned to mix and measure substances. For those reaching the senior year a more rigorous course in applied mathematics was taught—physics.

Today we view this sequence differently. Physics is the simplest of the sciences. How so? Look to the number of vocabulary terms found within any science textbook. By far, a textbook in physics shows the fewest terms, followed by chemistry, and then biology, which is the most complicated of these sciences. When physics is presented not as applied mathematics but as the study of the fundamental rules of nature, it becomes quite relevant to everyday life—while serving as a building block to the more complex sciences of chemistry and biology. The *Conceptual Academy Science* sequence is physics first, chemistry second, and then followed by biology. Physics deals with such basic topics as motion, energy, electricity and magnetism, light, sound, and nuclear processes all providing a necessary foundation from which a student can reach for his or her personal stars.

I present physics as a study of nature's rules. Learning to comprehend the basic rules (laws) of physics is a tall order. Honing that comprehension further can be the goal of a follow-up physics course. A grand mistake is trying to "do it all" in a first course, which results in the dreaded INFORMATION OVERLOAD. As a teacher, I have vowed not to inflict on my students undue exhaustion that results from much-too fast acquisition of knowledge. Suitable pacing of knowledge acquisition is a defining feature of Conceptual Academy.

Within physics, mathematical equations can be used as recipes for problem solving. But, more importantly, they can also be used as guides to clear thinking. The conceptual approach emphasizes the latter. Just as a music student learns to hear the music behind a musical score, a physics student learns to discern the relationships depicted within a mathematical equation. An example is Newton's second law of motion, $a = F/m$, which relates the acceleration, a, acquired by a body of mass, m, to the net force, F, exerted on it. Remarkably, this one simple equation was fundamental to humans reaching the Moon in 1969. Interestingly, Galileo understood acceleration, force, and mass, but he failed to recognize how these three concepts are related. Why? Because he didn't have the equation $a = F/m$! This relationship, even today, is one of the most complex concepts a student faces in a study of physics. Again, suitable pacing of knowledge acquisition is vital. Once $a = F/m$ is understood, the student has achieved a respectable milestone. Applying this law to numerical outcomes is small by comparison and can await a follow-up course.

Good Energy!

Paul G. Hewitt

Conceptual Academy Physics

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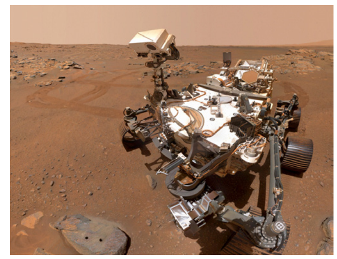


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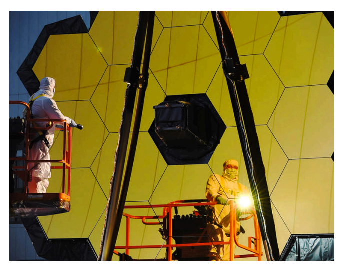
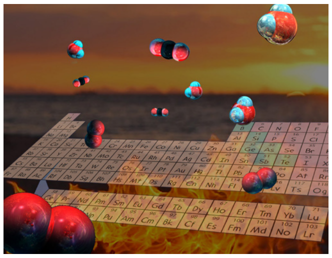




Introduction

About Science

THE MAIN IDEA

Science is the study of nature's rules

Science has given us much. Our modern world is built on it. Nearly all forms of technology—from medicine to space travel—are applications of science. But what exactly is this amazing thing called science? How should science be applied? Where did science come from? And what would the world be like without it?

Science is an organized body of knowledge about nature. It is the product of observations, common sense, rational thinking, and (sometimes) brilliant insights. Science has developed from group efforts as well as individuals' discoveries. It has accumulated over thousands of years and gathered from places all around the world. It is a huge gift to us today from the thinkers and experimenters of the past. Yet, science is not just a body of knowledge. It is also a method, a way of exploring nature and discovering the order within it. Importantly, science is also a tool for solving problems.

Science began back before recorded history, when people first discovered repeating patterns in nature such as star patterns in the night sky, weather patterns, and animal migration patterns. From these patterns, humans gradually learned to make predictions that gave them some control over their surroundings. Now *you* can learn more about science. Let's begin!

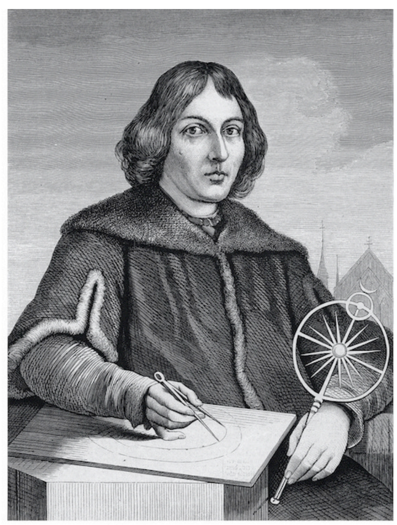
0.1 Copernicus and Galileo

When a sore throat keeps you home from school, you probably ask yourself, "How did I catch this cold?" You then speculate about how you could have been exposed to germs, and how you might avoid exposure next time. When a light goes out in your room, you ask, "How did that happen?" You might check to see if the lamp is plugged in, check the bulb, or even look at your neighbors' houses to see if there has been a power outage. When you think like this, you are searching for *cause and effect* relationships—trying to find out what events cause what results. This type of thinking is *rational thinking.* Rational thinking is basic to science.

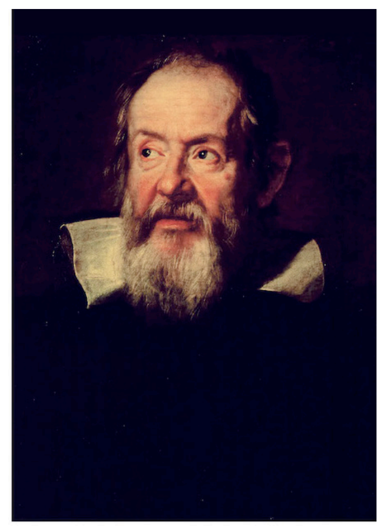
Today we use rational thinking so much and so often that it's hard to imagine other ways of interpreting our experiences. But it wasn't always this way. At times, people have relied more on superstition and magic to interpret the world around them—or have simply failed to ask, "Why?"

Rational thinking became very popular in Greece in the 3rd and 4th centuries BC. From there it spread throughout Rome and other parts of the Mediterranean world. When the Roman Empire fell in the 5th century AD, advancements in science came to a halt in Europe. Rational thought was replaced by the Dark Ages. But during this time science continued to advance in other parts of the world. The Chinese and Polynesians were charting the stars and the planets. Arab nations developed mathematics and learned to make glass, paper, metals, and certain chemicals. Finally, the Greek philosophy of rational thinking was brought back into Europe by Islamic people who entered Spain during the 10th to the 12th centuries. Then universities emerged. When the printing press was invented in the 15th century, science made a great leap forward. This invention did much to advance scientific thought (just as computers and the Internet are doing today).

Up into the 16th century most people thought the Earth was the center of the universe. They thought the Sun circled the stationary Earth. This thinking was challenged when the Polish astronomer Nicolaus Copernicus quietly published a book proposing that the Sun is stationary and that the Earth revolves around it. These ideas conflicted with religious teachings and were banned for the following 200 years.



Nicolaus Copernicus
(1473 - 1543)



Galileo Galilei
(1564 - 1642)

READING CHECK

How did Galileo study nature's behavior?

But about 100 years after Copernicus, the Italian physicist Galileo Galilei revived the Copernican view. Galileo used experiments, rather than speculation, to study nature's behavior. Galileo was arrested for popularizing the Copernican theory and for his other contributions to scientific thought. Yet a century later his ideas and those of Copernicus were accepted by most thinking people.

Scientific discoveries are often opposed, especially if they conflict with what people want to believe. Every age has its intellectual rebels who are persecuted, condemned, or suppressed at that time. But later they seem harmless and are often essential to the elevation of human conditions. To quote the Belgian poet Count Maurice Maeterlinck: "At every crossway on the road that leads to the future, each progressive spirit is opposed by a thousand men appointed to guard the past."

0.2 Scientific Methods

In the 16th century the Italian physicist Galileo and the English philosopher Francis Bacon developed a formal method for doing science—the **scientific method**. Although their method is not the only one, all scientific methods are based on rational thinking and experimentation. Some or all of the following steps are likely to be found in the way most scientists perform their work:

READING CHECK

What do all scientific methods have in common?

1. **Observe** Closely observe the physical world around you. Recognize a question or a puzzle—such as an unexplained observation.

2. **Question** Make an educated guess—a hypothesis—that might resolve the puzzle.

3. **Predict** Predict consequences of the hypothesis.

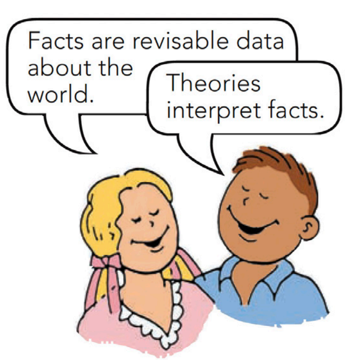
4. **Test predictions** Do experiments to see if the consequences you predicted are present.

5. **Draw a conclusion** Formulate the simplest general rule that organizes the three main ingredients: hypothesis, predicted effects, and experimental findings.

A scientific **hypothesis** is an educated guess. When a hypothesis has been tested over and over again and has not been contradicted, it may become known as a **law** or *principle.* A scientific **fact**, on the other hand, is something that competent observers can observe and agree to be true. For example, it is a fact that amputated limbs of certain crabs can grow back. Anyone can watch it happen. It is not a fact—yet—that a severed limb of a human can grow back.

Scientists use the word theory in a way that differs from everyday speech. In everyday speech a theory is the same as a hypothesis—a statement that hasn't been tested. But in science, a **theory** is a vast combination (synthesis) of facts and well-tested hypotheses. Physicists speak of the quark theory of the atomic nucleus. Chemists have the theory of chemical bonding. Geologists use the theory of plate tectonics, and astronomers speak of the theory of the Big Bang.

Theories are a foundation of science. They are not fixed, but evolve. They pass through stages of refinement. For example, since the theory of the atom was proposed 200 years ago it has been refined many times in light of new evidence. Some people argue that scientific theories can't be taken seriously because they change. Those who understand science, however, see that theories grow stronger as they evolve to include new information.



FOR YOUR INFORMATION

Here's an analogy for how science works. You're in a closed room with no windows and no light. It's pitch dark. You're **wondering** if there might be a cat somewhere in the room. So, being **clever**, you open a can of smelly tuna. No cat arrives. Does this mean there is no cat in the room with you? (No.) Or might it be better to say the **probability** of there being no cat is high? (Yes.) Say, a cat shows up. How then might you **determine** its color? Or do we accept that some things just remain **unknowable**? Or do we invent new **technology** to help us see past our **limitations**? At the heart of all science is a **curiosity** to learn the nature of things for what they are and not for what we might wish them to be. Better understanding those things helps us to care for those things. This include cats and all creatures of this planet, including ourselves.

0.3 Scientific Hypotheses

A scientific hypothesis is one that is testable. A test or series of tests can determine whether a hypothesis is valid. A hypothesis that is not testable is not scientific. It is **pseudoscience**—fake science with no tests for validity In scientific work, most hypotheses turn out to be wrong. Scientists have to be patient though, and keep testing their ideas for accuracy.

A well-known scientific hypothesis that proved to be incorrect was that of the greatly respected Greek philosopher Aristotle (384–322 BC). Aristotle claimed that heavy objects naturally fall faster than light objects. This hypothesis was considered true for nearly 2000 years—mainly because of respect for this great man. Also, air resistance was not recognized as an influence on how quickly objects fall. We've all seen that stones fall faster than leaves fluttering in the air. Without investigating further it is easy to accept false ideas.

Galileo very carefully examined Aristotle's hypothesis. Then he did something that caught on and changed science forever. He *experimented.* Galileo showed the falseness of Aristotle's claim with a single experiment—dropping heavy and light objects from the Leaning Tower of Pisa. Legend tells us that they fell at equal speeds. In the scientific spirit, one experiment that can be reproduced outweighs any authority, regardless of reputation or the number of advocates. Albert Einstein put it well when he stated, "No number of experiments can prove me right; a single experiment can prove me wrong." In science, the test of knowledge is experiment.

READING CHECK

What is the test of knowledge in science?

Although Aristotle was wrong about falling objects, his hypothesis was scientific. That's because it was testable. In Aristotle's time, experimentation hadn't caught on. Even the claim that the Moon is made of green cheese is a scientific hypothesis, because the claim is *testable*. The hypothesis was tested and proved wrong with the lunar landings that began in 1969.

The scientific method is effective in advancing knowledge. But many scientific advances involve trial and error, experimenting without guessing, or just plain accidental discovery. The trained eye, however, is better at noticing questions in the first place and making sense of evidence. More than a particular method, the success of science has to do with an attitude common to scientists. This attitude involves inquiry, experimentation, and being humble before the facts. A good scientist can admit to being wrong when wrong.

CONCEPT **CHECK**

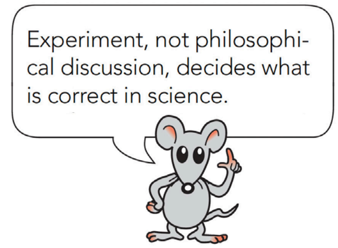
Which statements are *scientific* hypotheses?

a. Better stock market decisions are made when the planets Venus, Earth, and Mars are aligned.
b. Atoms are the smallest particles of matter that exist.
c. Albert Einstein was the greatest physicist of the 20th century.

CHECK YOUR ANSWER All statements are hypotheses, but only statements *a* and *b* are scientific hypotheses—because they are testable. Statement *a* can be tested (and proven wrong) by researching the performance of the stock market during times when these planets were aligned. Statement *b* not only can be tested, but has been tested. Although it is untrue (many particles smaller than atoms have been discovered), the statement is nevertheless a scientific one. Lastly, statement *c* is an assertion or opinion. Greatness is a quality that cannot be measured in an objective way.

0.4 Scientific Attitude

The curious mind works hard to make sense of what it experiences. How then to satisfy that curiosity? We can make up fanciful explanations. Or we can do as Galileo did and rely on the results of experimentation. When we follow Galileo's lead, we are satisfying our curiosity through science. In following this path, we quickly come to see value in a set of attitudes.



For example, we must accept our experimental findings even when we wish they were different. We must strive to distinguish between the results we see and those we wish to see. This is not easy. Most people can easily fool themselves. Furthermore, none of us has the time or resources to test every idea. Thus, we tend to accept the word of someone we trust. But who do we trust? To reduce the likelihood of error, the science-thinking individual trusts those whose findings are testable—if not in practice, then at least in principle. Ideas that cannot be tested are regarded as "unscientific."

READING CHECK

What kind of ideas are unscientific?

The fact that scientific statements will be thoroughly tested helps keep the science-thinking individual honest. Sooner or later, mistakes (or deception) are discovered. A scientist exposed for cheating doesn't get a second chance in the community of scientists. Honesty, so important to the progress of science, thus becomes a matter of self-interest. There is little bluffing in a game where all bets are called.

We have discovered that the physical universe is guided by a relatively small set of rules, such as gravity, electromagnetism, and nuclear forces. The application of these few rules to the gadzillion atoms and molecules of the universe, however, results in significant complexity. A living organism is a prime example. Science has done a remarkable job at unraveling many of the mysteries arising from this complexity. But given the vast complexity of the universe, what we know today is pale to what remains to be learned.

This leads to another key aspect of the scientific attitude. We can be proud of what we have learned, but it's important to remain *humble* for all that we still do not understand. This includes not just the unknowns, but the even greater number of unknown unknowns. An "unknown unknown" is that which you don't even know you don't even know. A good example is the idea of dark energy. From astronomical observations starting in the 1990s we learned of a universal force we now call *dark energy*. It permeates the universe but we still don't know what it is—it's a known unknown. Prior to the 1990s, dark energy was an unknown unknown, which means we were less than clueless. It's as if the more we learn, the more we learn we don't know. This pushes the mindful scientist to remain humble.

Lastly, there is this idea of *uncertainty*. It's human nature to want things to be simply black or white. Is it this? Or is it that? Given the complexity of the natural universe, however, most discoveries fall within a gray spectrum of fairly certain to most uncertain. Climate scientists, for example, have identified carbon dioxide to be a powerful greenhouse gas, which means it helps to keep the planet warm. This is fairly certain. As humans produce more carbon dioxide, this means the planet will become warmer, which brings a change in climates. This is fairly certain too. But how exactly might climates change? This is less certain. To the scientist, uncertainty is inspiration for further study. The scientific attitude embraces uncertainties because they are ever-present and part of the fabric of this complex universe.

FOR YOUR INFORMATION

To many who influence public opinion, including politicians, uncertainty is cause for ignoring the issue. Why? Because uncertainty is uncomfortable, and who would vote for a politician who makes them uncomfortable? The politician might say: "If people want black and white, then give them black and white." This attitude is NOT scientific.

0.5 Science and Technology

Science and technology are different from each other. Science is concerned with gathering knowledge and organizing it. **Technology** is the engineering of that knowledge for practical purposes. Plus, technology provides the instruments scientists need to conduct their investigations.

Technology is a double-edged sword. It can be both helpful and harmful. We have the technology, for example, to extract fossil fuels from the ground and then burn the fossil fuels to produce energy. Energy production from fossil fuels has benefited society in countless ways. On the flip side, the burning of fossil fuels damages the environment. It is tempting to blame technology itself for problems such as pollution and resource depletion. These problems, however, are not the fault of technology any more than a stabbing is the fault of the knife. It is humans who use the technology, and humans who are responsible for how it is used.

Remarkably, we already possess the technology to solve many environmental problems. Today we are posed to see a switch from fossil fuels to more sustainable energy sources. We recycle waste products in new and better ways. In some parts of the world, progress is being made toward limiting the human population explosion, which unchecked could worsen almost every problem faced by humans today. Difficulty solving today's problems results more from social inertia than failing technology. Technology is our tool. What we do with this tool is up to us. The promise of technology is a cleaner and healthier world. Wise applications of it *can* improve conditions on planet Earth.

READING CHECK

What is the promise of technology?

We bath in radiation whenever we venture outside. Some places more so than others.

Risk Assessment

Technology comes with risks as well as benefits. When the benefits are seen to outweigh risks, a technology can be accepted and applied. X-rays, for example, continue to be used to diagnose disease despite their potential risk for causing cancer. The benefits outweigh the risks. Of course, when the risks of a technology outweigh its benefits, it should be used sparingly or not at all.

A difficult ethical problem arises when a technology benefits one group of people but poses risk to a different group of people. Dumping raw sewage into the local river may pose little risk for a town located upstream, but for towns downstream the untreated sewage is a health hazard. Technologies involving different risks for different people raise questions that are often hotly debated. Which medications should be sold to the general public over-the-counter and how should they be labeled? Should food be irradiated to eliminate the food poisoning that has consistently killed thousands of Americans each year? Or are the unknown potential hazards of food irradiation sufficient cause for banning food irradiation?

People seem to have a hard time accepting the fact that zero risk is impossible. Airplanes cannot be made perfectly safe. Processed foods cannot be completely free of toxicity, for all foods are toxic to some degree. You cannot go to the beach without risking skin cancer no matter how much sunscreen you apply. You cannot avoid radioactivity, for it is naturally in the air you breathe and the foods you eat, and has been that way before humans first walked the Earth. Even the cleanest rain contains radioactive carbon-14; our bodies do as well. You might hide in the hills, eat the most natural foods, practice obsessive hygiene and still die from cancer caused by radioactivity. The probability of eventual death is 100%. So far, no one is exempt.

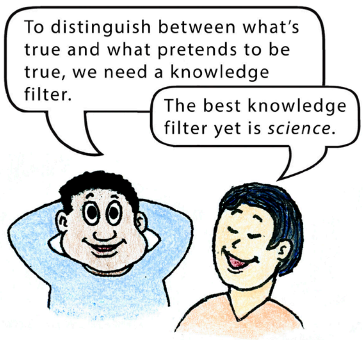
Science helps to determine the most probable results. As the tools of science improve, risks can be evaluated more and more accurately. Acceptance of risk, on the other hand, is more of a social issue than a scientific one. If society were to demand zero risk from its technology, this goal would not only be impractical, but selfish. Any society striving toward a policy of zero risk would consume its present and future economic resources. A society that accepts no risks receives no benefits.

0.6 Skepticism and Denialism

Skepticism is being doubtful over unsubstantiated claims. Skepticism is integral to the scientific process. A good scientist is a good skeptic. Sorting out the few kernels of wheat from the large pile of chaff requires much effort and cautious inference.

Denialism is being unfairly resistant to substantiated claims, often motivated by ideology or strong beliefs, where commitment to the belief takes precedence over the evidence. Belief comes first, reasons for belief follow, with reasons skewed to ensure that the belief survives intact.

There have always been groups of people skeptical about issues such as the Holocaust, the 1969 Moon landing, tobacco, climate change, and vaccines. The list is seemingly without end. Keep in mind the word *some*



when identifying skeptics and deniers. Some people hold that the Earth is flat, while other people consider Earth as round—in fact, spherical. Importantly, what is the *percentage* of each? More often than not, deniers make up a small percentage of people.

Emotional motivation often fosters denial when a policy is seen as distressing or distasteful. As an example, if your dentist tells you that you need a root canal, you may not want to believe the evidence and reasoning. You are emotionally motivated to deny the report. So, you go for a second opinion, and perhaps a third—which is quite reasonable. You are gathering data to evaluate. But at a certain point, if all of the credible dentists you visit are in consensus about your diagnosis, you will be wise to set your emotions and short-term preferences aside, and try to understand the dental science of your tooth.

Think of a less wise approach: You interview 1000 dentists until you find one who declares no root canal is needed. You then heed the advice that no root canal is needed. Further, you praise and elevate that dentist's credentials because finally you found someone who knows how to listen to your underlying needs. You convince yourself there are always two sides to a story. You think of yourself as a crafty renegade for bucking a system that's clearly corrupt and self-interested. What you would be doing here is known as "cherry picking" the evidence. Cherry picking evidence means that you knowingly or unknowingly only consider evidence supporting your case, no matter how outlying that evidence is. Cherry picking evidence is a common way to deny the validity of scientific claims.

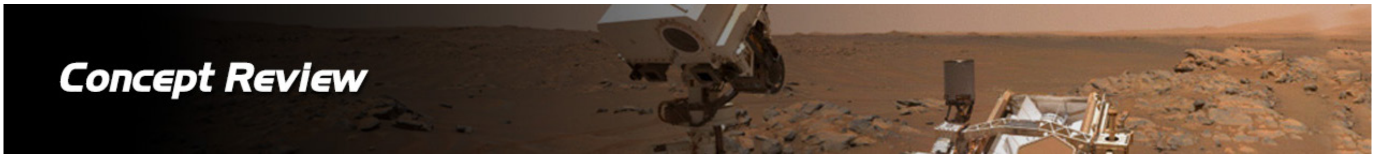
READING CHECK
What is meant by "cherry picking"?

The physical world, knowable to a large extent through science, offers *real* rewards, joys, sustenance, and plenty of hazards too. The human population is booming like never before. This means we are taxing the environment that sustains us like never before. Can we ultimately use what we learn from science to address our modern challenges and to accomplish great things? If we've been to the Moon and back, then the answer is a resounding yes.

CONCEPT CHECK

Why are long term problems, like over-population, easier to deny than short term problems?

CHECK YOUR ANSWER It's common for people today to think short term. I'm hungry. I want to buy that car. A problem that develops over a longer time scale, such as too many people in too small a space—overpopulation—is more difficult to grasp, especially if you live in a sparsely populated area. Addressing long-term problems requires a focus on the future and commitment to a sustainable way of life. This is a greater challenge.



Concept Review

Introducttion

Summary of Terms

Denialism Being unfairly resistant to considering substantiated claims.

Fact A phenomenon about which competent observers can agree.

Law A general hypothesis or statement about the relationship of natural quantities that has been tested over and over again and has not been contradicted. Also known as a *principle.*

Hypothesis An educated guess; a reasonable explanation that is not fully accepted as factual until tested over and over again by experiment.

Pseudoscience Fake science that has no tests for its validity.

Science The collective findings of humans about nature, and a process of gathering and organizing knowledge about nature based upon experimental evidence.

Scientific Method An orderly method for gaining, organizing, and applying new knowledge.

Skepticism Being doubtful over unsubstantiated claims.

Technology Method and means of solving practical problems by applying the findings of science.

Theory A synthesis of a large body of information that encompasses well-tested hypotheses about certain aspects of the natural world.

Review Questions

1. Throughout the ages, has acceptance or resistance usually been the general reaction to new ideas about established "truths"?
2. Outline the steps of the scientific method.
3. Distinguish among a scientific fact, a hypothesis, a law, and a theory.
4. How many experiments are necessary to invalidate a scientific hypothesis?
5. Must a statement prove correct to be a scientific hypothesis?
6. In science, what kind of ideas are generally accepted?
7. Why is honesty a matter of self-interest to a scientist?
8. How do scientists regard "not knowing" in general?
9. Clearly distinguish between science and technology.
10. Who uses and who is responsible for how technology is applied?
11. In daily life people are often praised for maintaining some particular point of view, for the "courage of their convictions." A change of mind is seen as a sign of weakness. How is this different in science?
12. In daily life we see many cases of people who are caught misrepresenting things and who soon thereafter are excused and accepted by their contemporaries. How is this different in science?
13. In answer to the question, "When a plant grows, where does the material come from?" Aristotle hypothesized by logic that all material came from the soil. Do you consider his hypothesis to be correct, incorrect, or partially correct? What experiments do you propose to support your choice?
14. What is probably being misunderstood by a person who says, "But that's only a scientific theory"?
15. Make an argument for bringing to a halt the advances of technology. Make an argument that advances in technology should continue. Contrast your two arguments.

Answers to Odd-Numbered Questions

1. Resistance.

3 Whereas a fact is generally a close agreement by competent observers of a series of observations of the same phenomenon, a hypothesis is an educated guess, which when verified may become a law. A scientific theory is a synthesis of a large body of information that encompasses well-tested and verified hypotheses.

5. No. It need only be testable.

7. The scientist is in an arena where falsehood will sooner or later be found, and discredit that scientist.

9. Science has to do with gathering and organizing knowledge; technology puts that knowledge into practice and provides the tools needed for finding more.

11. A change of mind is a strength of science, enabling refinements in theories.

13. Aristotle's hypothesis was partially correct, for material that makes up the plant comes partly from the soil, but mainly from the air and water. An experiment would be to weigh a pot of soil with a small seedling, then weigh the potted plant later after it has grown. The fact that the grown plant will weigh more is evidence that the plant is composed of more material than the soil offers. By keeping a record of the weight of water used to water the plant, and covering the soil with plastic wrap to minimize evaporation losses, the weight of the grown plant can be compared to the weight of water it absorbs. How can the weight of air taken in by the plant be estimated?

15. The answers to these are open ended.