Originally published in The Technology Teacher*, April 2002, by the International Technology Education Association*

From Smoke Signals to Cell Phones: Tracing How Technologies Evolve

How many famous inventors can you name? We often give credit to people like Thomas Edison for inventing the electric light bulb, the Wright brothers for inventing the airplane, and Alexander Graham Bell for inventing the telephone. Do you suppose that these people, smart though they were, just all of a sudden got the ideas for their "inventions" with no help from anyone else? Do you think that the Wright brothers just sat down at a drawing board one day and designed their airplane from scratch?

No, of course you don't! Because no matter how smart inventors are, they almost always stand upon the shoulders of other smart people who have gone before them. There is a reason it has taken humans hundreds of thousands of years to finally acquire the amazing and almost magical technologies that surround us today. That reason is because it was very, very hard to get started!

Let us look, for example, at how people have kept track of time over the ages. Before people starting organizing themselves into complex civilizations around five or six thousand years ago, it was good enough to just have calendars to keep track of days and years, and use the position of the Sun in the sky to keep rough track of the time of day. But with more formal governments and religions, and the need to gather people in one place for scheduled events and rituals, everybody needed to agree on exactly what time of day it was. And now, much of modern life has come to depend on precise time. Transportation, communication, manufacturing, electric power and certainly space exploration technologies are dependent on super-accurate clocks.

But put yourself back at the beginning. How do you make a clock if no one has ever kept time before? Where do you even begin?

As you can see from Table 1 on the next page, it took an awfully long time for timekeeping technology to get going. But once it did, advances were very rapid, with each "inventor" building on the best design that went before and solving maybe just one or two more problems to make a more advanced technology for keeping time.

Other modern technologies have similar histories. Advanced technologies that are used to explore the Universe are really the latest products in the history of finding better and better ways to perform a particular function or solve a problem.

Space Exploration State-of-the-art

In addition to extremely accurate timekeeping, some of the kinds of technologies necessary for space exploration are these:

Propulsion (locomotion): For a spacecraft, the propulsion technology is how the spacecraft gets from Earth orbit to another destination in the solar system and beyond, and to make course correction or orbit insertion maneuvers. Examples are ion propulsion, chemical propulsion, and solar sails.

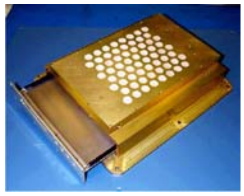
Ion engine used on the Deep Space 1 spacecraft

Table 1. A Brief History of Timekeeping*

Dates	Type of device	Accuracy
~3500 BC	Egyptian sun clock, obelisk structure that cast shadow	Not very accurate. Didn't work at night or on cloudy days.
~1500-30 BC	Egyptian sundials, various designs	Not very accurate. Didn't work at night or on cloudy days.
~325 BC	Greek, water clock, which was a simple vessel with a small hole for water to drip through	Water flow was not constant.
~100-500 AD	Greek and Roman, water clocks with mechanical parts to make water flow more constant.	Although improved, water flow is difficult to regulate, so clock was not very accurate.
500-1500	Europe, various sundials, not much technological advancement in any fields	Not very accurate. Didn't work at night or on cloudy days
1088	Chinese, elaborate mechanical water clock tower 30 feet tall	Water flow is difficult to regulate, so clock was not very accurate.
~1300-1600	Mechanical clocks that used a weight to pull on a gear type mechanism, generating an oscillation.	Difficult to regulate rate.
1500	First spring-powered mechanical clocks, allowing them to be smaller that weight-driven clocks and portable. First watches.	Slowed down as spring unwound.
1656	Christiaan Huygens, a Dutch scientist, made the first pendulum clock, regulated by a mechanism with a "natural" period of oscillation.	Error of less than 1 minute per day, later refined to less than 10 seconds per day.
1675	Huygens developed the balance wheel and spring assembly, which could be used in small watches	Error of about 10 minutes per day, good for a small clock or watch.
1721	George Graham improved the pendulum by compensating for changes in the pendulum's length due to temperature variations.	Accurate to 1 second a day
1761	George Graham's marine chronometer won the British government's 1714 prize for a means of determining longitude while at sea.	Kept time on board a rolling ship to about one-fifth of a second a day, nearly as well as a pendulum clock could do on land, and 10 times better than required.
1889	Siegmund Riefler's clock with a nearly free pendulum.	Accurate to one hundredth of a second a day.
1921	R. J. Rudd's Shortt clock, with two pendulums, one that has nothing to do but swing undisturbed, and another to give the master pendulum the gentle pushes needed to maintain its motion, and also to drive the clock's hands.	Even more accurate than Riefler's clock, replacing it as supreme timekeeper in observatories.
1930s to present	Quartz clocks and watches, which use the natural constant vibration of a quartz crystal when subjected to an electric field and placed into an electric circuit.	Most accurate timekeepers yet, but still rely on mechanical vibration whose frequency depends on crystal's size and shape.
1949	First atomic clock, based on the natural frequency at which atoms and molecules absorb and emit electromagnetic radiation. Ammonia was used as the regulating molecule.	Not much better than the best quartz clocks.
1957	Atomic clock based on the Cesium atom.	Much better than ammonia.
1967	Cesium atom's natural frequency becomes the official unit of time: the second defined as exactly 9,192,631,770 oscillations or cycles of the cesium atom's resonant frequency replacing the old second that was defined in terms of the earth's motions.	The best primary cesium standards now keep time to about one-millionth of a second per year. The second becomes the physical quantity most accurately measured by scientists.
2000	Laser-cooled clocks, that use laser beams to nearly stop the natural motion of the atom so that it's vibration can be measured more accurately.	If this clock ran for three billion years it would lose less than 1 second!

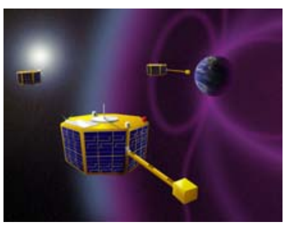
*Source: National Institute for Standards and Technology, "A Walk Through Time," http://physics.nist.gov/GenInt/Time/time.html .

Communication: These technologies enable the spacecraft to communicate with Earth or with other spacecraft. New types of communication antennas are very lightweight, have no moving parts, and can send and receive huge amounts of data very rapidly.



Communication antenna on Earth Observing 1 Spacecraft: Fast, lightweight, and no moving parts!

Power (energy): Power technologies supply electric power to all the spacecraft systems that need it, including the computer, communication antenna, science instruments, and motors that move and point instruments and antennas.



High-tech solar panels are attached directly to the three tiny Space Technology 5 spacecraft

Navigation: Navigation is the technology the spacecraft uses to know where it is and to keep on course. Advanced navigation systems enable the spacecraft to check and correct its course autonomously (needing no commands from Earth).

Imaging: Imaging technologies collect the information that allows the spacecraft to carry out its science goals. New imaging devices detect not only the light we see with our eyes, but a good part of the electromagnetic spectrum we don't see, including microwaves, ultraviolet, infrared, x-rays, or gamma rays.

How Far Have We Come?

Here's something for you to do.

Pick one of the five categories of technologies needed for space exploration, and trace its history from the beginning (however you want to define it), as Table 1 does for timekeeping. See if you can reconstruct how one invention grew out of the previous ones.

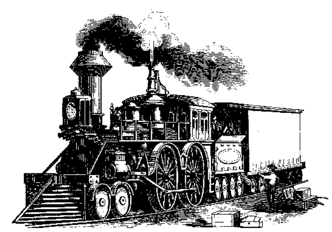
Make a table like Table 1. Then, write a brief narrative history. As the technology you're investigating evolved, what successful parts of the design were kept and what was added or changed to solve problems or improve the older technology? Try to include some illustrations.

The Internet is a good place to begin your investigation. Just go to your favorite Web search site and type in search terms like "history of cameras" or "history of the telephone." Of course, the library is always an excellent source of material on history.

To get you started, here are some rough ideas of some of the "milestones" along the way in the development of the five technologies from which you may choose:

Propulsion or locomotion:

Stripped down to bare essentials, propulsion technologies are simply trying to solve the problem of getting from one place to another. For thousands of years, people just rode on the backs of large animals to get around. We may not wish to define this means of solving the problem as technology. However, the first wheel might be considered the beginning of locomotion technology. But what of the energy source itself that propels someone or something from place to place? What is the history of the use of such means of locomotion as wind power, steam power, gasoline power, solar power, and nuclear power?

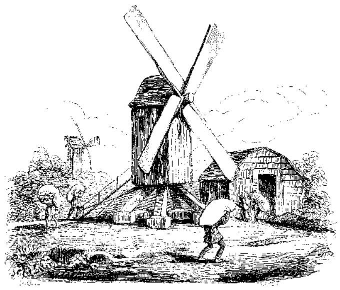


Communication:

How have people communicated with each other over long distances? Drums, smoke signals, and the Pony Express were early communication "technologies." Where did the state of the art of communication go from there? Where is it now and how long did it take to get here? You will probably find that more has changed in the past 25 years than in all the history before that.

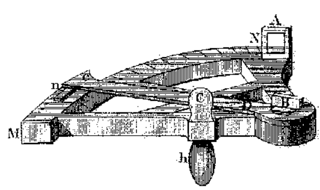
Power:

These days, power usually means electricity. Before we learned to convert water, wind, sun, fossil fuels, and atomic energy to electricity, we used other forms of power. Most of these involved burning fuel directly (like in a steam engine) or using muscle power (whether human or non-human) to drive some sort of machine. What are the early forms of power that humans harnessed to their own purposes? How did the technology of generating and storing electricity evolve? What are some of the advanced technologies now used on spacecraft to generate and store power?



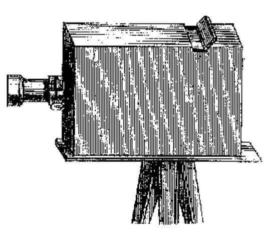
Navigation:

The first time people wandered a few miles from home in pursuit of their four-footed dinner, they had to navigate to find their way back home. When they set out in boats on the seas and lost sight of land altogether, that's when they really had to develop some navigation knowledge and technology. How did people navigate before they had any instruments? What were first instruments of navigation and how did they evolve over the centuries? What do ships and planes use now to help them navigate? How do spacecraft that are destined for other bodies in the solar system navigate?



Imaging:

We might think of the Chauvet cave paintings in France as the first applications of imaging technology. But besides copying by hand onto stone or canvas or paper what people saw with their eyes, at some point somebody discovered that images of reality could be made by directly capturing the light reflected from a scene and recording it on some kind of material. What are some early attempts to do this? How was it done? How has the technology of photography developed? What are some of the special things about the imaging techniques used on today's spacecraft?



Pushing Ahead

The New Millennium Program is the effort by the National Aeronautics and Space Administration (NASA) to test in space the latest, most advanced technologies in these five, as well as other, areas to see whether they can withstand the harsh conditions and perform the difficult tasks of space exploration. The space program is thus helping to accelerate the evolution of technologies that will increase our knowledge of the Universe and help us understand and take better care of our own home planet.

Send Us Your Timelines!

We in NASA's New Millennium Program would love to see the timelines you create in this activity. If your teacher will send them to us from your class (photocopies are fine), we will send a NASA poster for your classroom. Send timelines to:

NASA New Millennium Program Outreach
Jet Propulsion Laboratory
Mail Stop 301-235
4800 Oak Grove Dr.
Pasadena, CA 91109

This article was written by Diane K. Fisher, science writer and developer of The Space Place (http://spaceplace.nasa.gov), a fun web site about space science and technology. It is provided through the courtesy of the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration's New Millennium Program.