NANO 101:

Introduction to Nanoscale Science, Engineering, and Technology for Educators

NISE network
NANOSCALE INFORMAL SCIENCE EDUCATION

Welcome to Nano 101! In this presentation, we're going to go over key concepts for engaging the public in the new field of nanoscale science, engineering, and technology. Since that's a mouthful, we'll often just use "nano" for short.

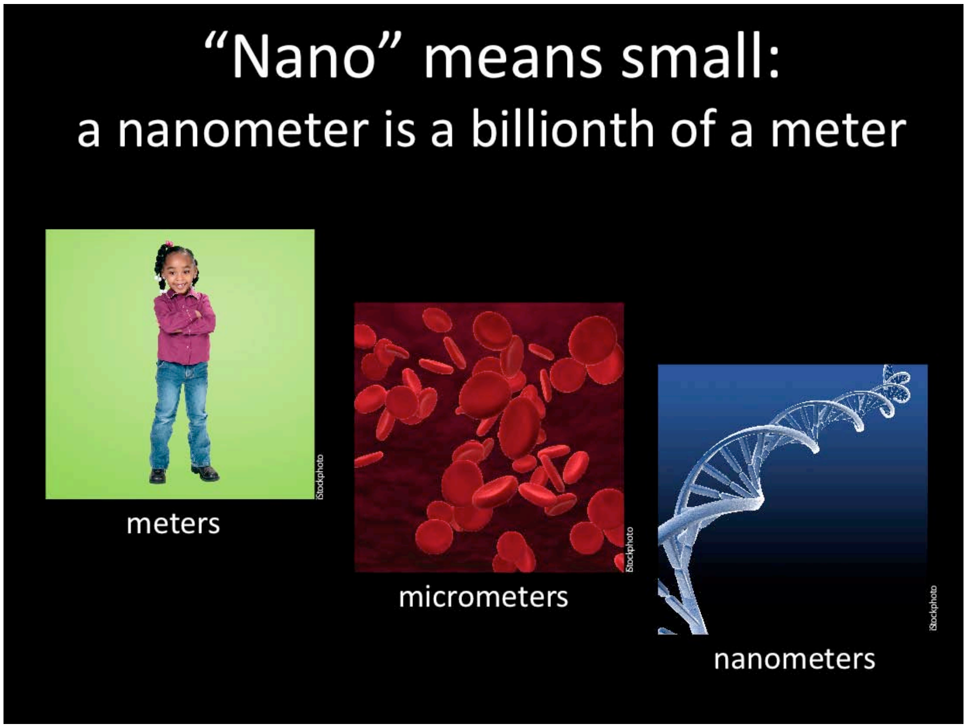
Big Ideas

1. Nano is small and different
2. Nano is studying and making tiny things
3. Nano is new technologies
4. Nano is part of our society and our future

We'll cover four big ideas related to nano:

- Nano is small and different.
- Nano is studying and making tiny things.
- Nano is new technologies.
- Nano is part of our society and our future.

Let's get started with the basics: Nano is small and different. For this idea, we'll go over what "nano" means, and talk about some of the ways that nanometer-sized things can behave differently and act in surprising ways.



Nano- is a prefix, like mega- or micro-. You've probably heard of megabytes or microscopes. "Nano" means "one-billionth." When we put nano in front of something, it means one-billionth of that thing. So a nanometer is a billionth of a meter and a nanosecond is a billionth of a second.

In the field of nanoscale science, engineering, and technology, researchers measure things using nanometers.

A billionth of a meter is very, very, very small! To visualize how small that is, let's start with a meter.

If I hold out my arm, a meter is about the distance from my nose to the end of my fingers. A 6-year-old child is about one meter tall—like the girl in the picture on the left.

The picture in the middle is of a red blood cell. A red blood cell is about a millionth of a meter, or one micrometer across.

A nanometer is one thousand times smaller than a red blood cell.

The picture on the right is a DNA molecule. DNA is two nanometers wide. That's two-billionths of a meter!

So nano researchers are working on the scale of atoms and molecules.

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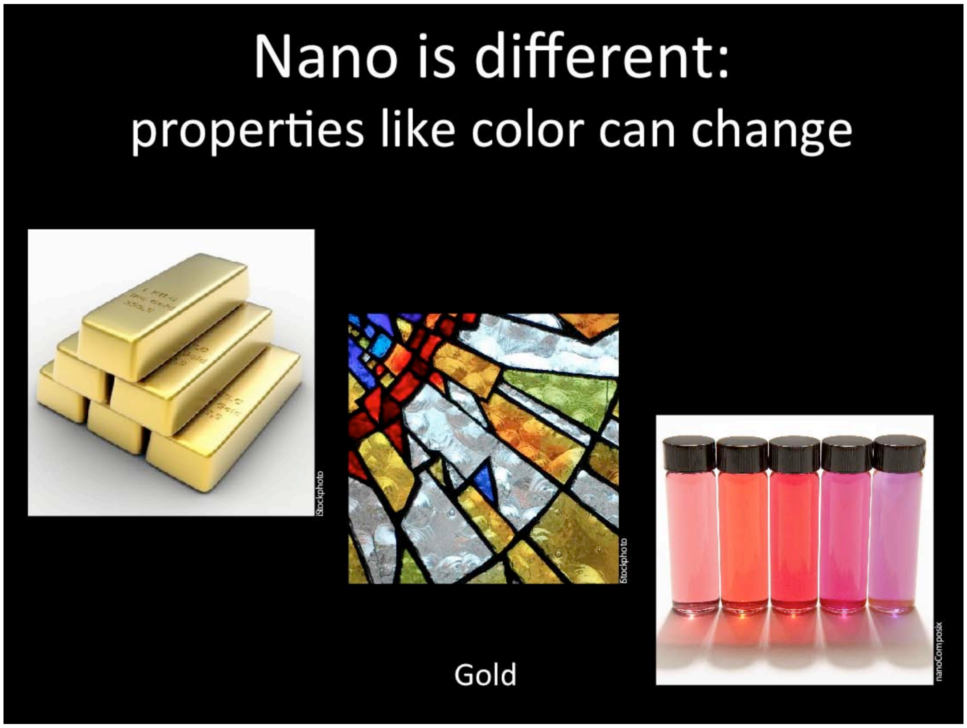


Some things behave differently when they're nano-sized than they do when they're bigger.

For example, things can look different.

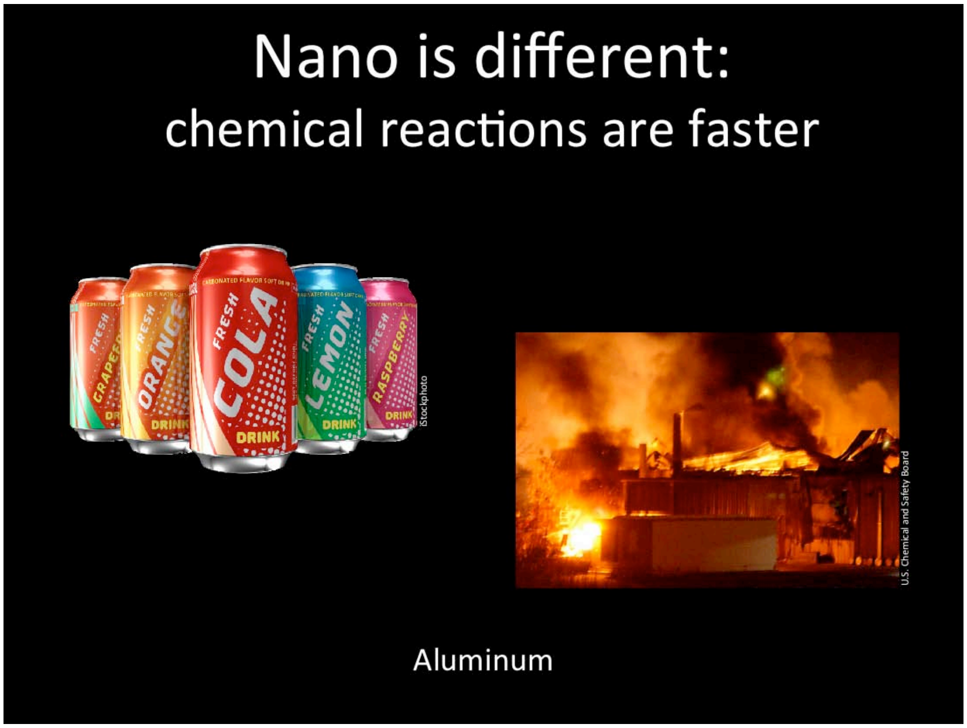
We're familiar with gold on the macroscale, in lumps big enough to see and measure in meters, centimeters, or millimeters—like the gold bricks in the picture on the left. Bulk gold is shiny and golden and has other metallic properties.

But on the nanoscale gold takes on different properties. Nanoparticles of gold—meaning pieces of gold small enough to measure in nanometers—reflect light differently.

Nano gold in solution, like the photo on the right, can look red or purple. These vials are different colors are because the gold nanoparticles they contain are different sizes.

The picture in the middle is of a stained glass window. Nano gold gives some red glass its beautiful ruby color. Gold has been used since the Middle Ages to make red stained glass.

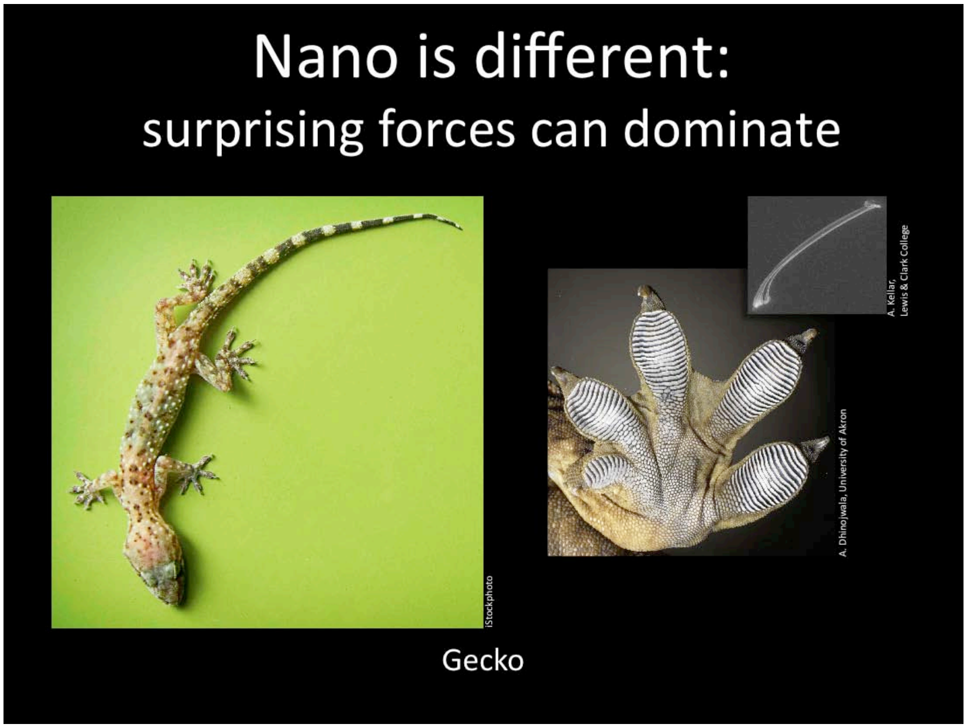
RELATED ACTIVITY: Exploring Materials—Nano Gold



Other properties can also change at the nanoscale.

When a material is nano-sized, chemical reactions often go faster. That's because reactions occur on the surface of objects, and nanoscale objects have a lot of surface area per unit of volume. Aluminum, used everyday in drink cans, can be explosive when the aluminum particles are nano-sized!

RELATED ACTIVITY: Exploring Properties—Surface Area



Different forces can dominate at the nanoscale, making things behave in unexpected ways.

For example, geckos can climb up walls and across ceilings, but there's no glue on the bottom of their feet! Instead, millions of tiny, nano-sized "hairs" form bonds with the wall. These tiny structures, called *setae*, are only about 200 nanometers wide. Molecules in the setae are attracted to molecules in the wall, and they form a temporary bond. While each bond is weak, there are enough setae that the intermolecular forces overcome the force of gravity. To move, the gecko tilts it foot, breaking the bonds.

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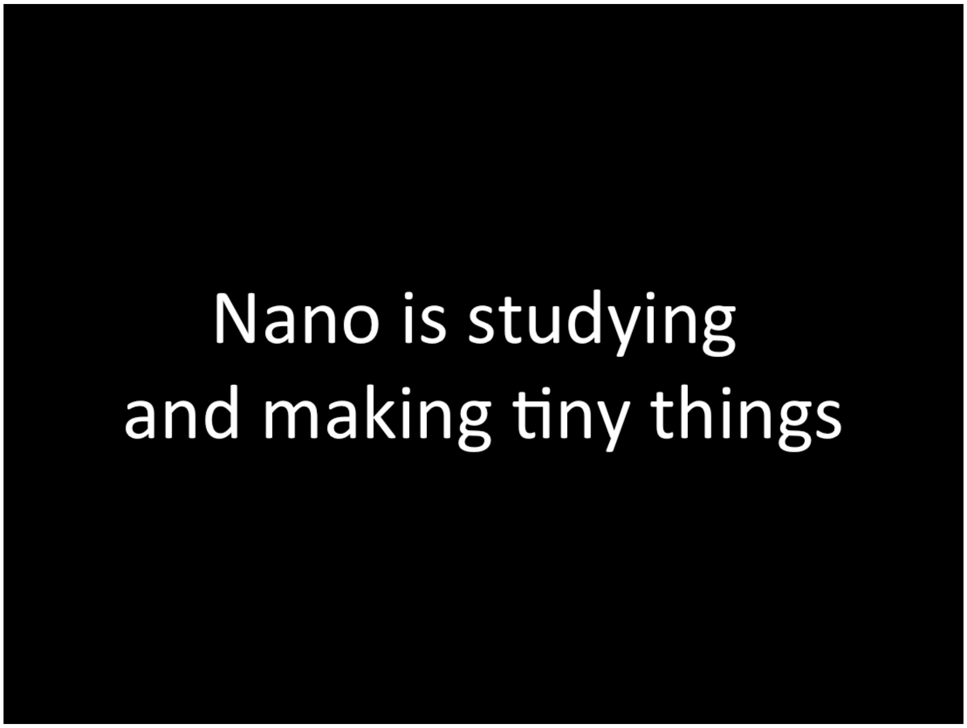
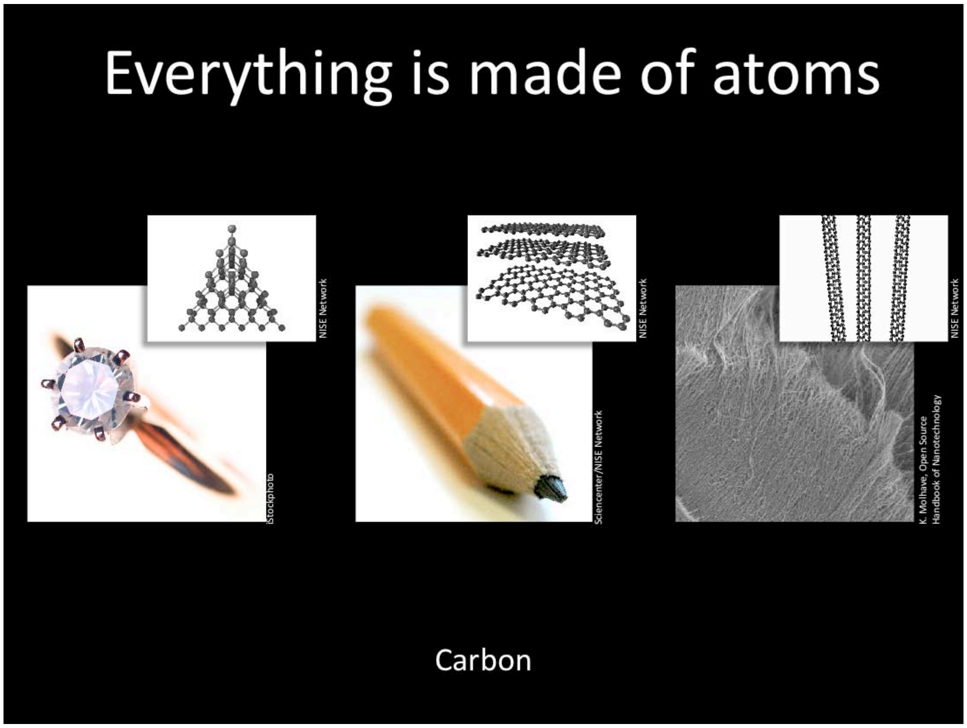


So now we realize that nano-sized things are very small, and that things can be pretty different on the nanoscale.

Let's talk more about what's happening the field of nanoscale science, engineering, and technology—what researchers study and make at this super-small scale.



This field includes the study of some of the most basic things on earth: atoms and molecules.

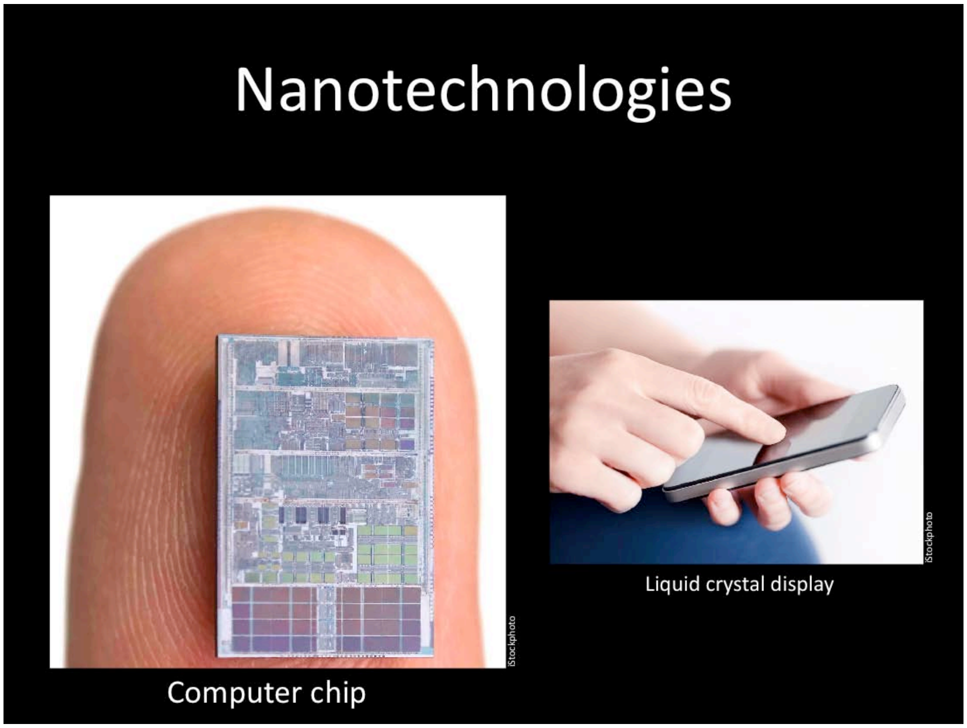
You know that everything on Earth is made of tiny building blocks called *atoms*. Atoms are tiny particles smaller than a nanometer. The way that these tiny building blocks are arranged helps determine the properties, or behavior, of a material.

These three pictures all have something in common. They're all made of carbon atoms. Carbon atoms can form diamond, the hardest natural material known on Earth, like you see in the picture of the ring on the left. But they can also form a much softer material, graphite (or pencil "lead"), like you see in the picture in the middle.

Both diamonds and graphite are made entirely from carbon atoms. They have different properties because the carbon atoms are arranged differently. Diamonds are hard and shiny because they have a sturdy molecular structure. Graphite is soft and slippery because its carbon atoms are stacked in sheets.

Carbon can also form nanometer-sized structures, including *carbon nanotubes* and *buckyballs*. (You can see carbon nanotubes in the picture on the right.) Like larger forms of carbon, these tiny objects have special properties due to the way their carbon atoms are arranged. Researchers are studying how to grow these nanoscale forms of carbon, and use them to build nanotechnologies.

RELATED ACTIVITIES: Exploring Materials—Graphene, Exploring Structures—Buckyballs



Nanotechnology takes advantage of special properties at the nanoscale to create new materials and devices. Electronic gadgets are a good example of nanotechnology we use every day. Actually, our gadgets are enabled by a variety of different nanotechnologies.

In one common example, many cell phones and laptops have displays that use nano-sized liquid crystals. These liquid crystal displays let us create thinner, lighter devices. You can see an example of a smartphone with an LCD in the picture on the right.

On the left, there's a picture a computer chip sitting on a fingertip. Look how small the features on it are! There are even smaller features that are way, way too small to see. Intel makes computer chips with tiny features that are only around 30 nm across. 60 million transistors this small can fit on the head of a pin! This is about as small as we can go with current manufacturing techniques. To make even smaller, faster chips, we'll need new technologies and new ways of fabricating chips.

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To study and make tiny nano-sized things, researchers often use special tools and equipment. Sometimes they work in special labs called *clean rooms* that have a controlled environment.

One important tool is called an *atomic force microscope*, or AFM. AFMs use a super-sharp tip to move across a nanoscale surface. To make an image, researchers move the tip of the AFM back and forth across the sample many times. A computer combines the data to create an image.

AFMs are very powerful. They can even detect and make images of individual atoms! Some can also be used to move tiny things around, allowing researchers to make nano-sized structures. Researchers can put individual atoms into place using an AFM!

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But making things out of individual atoms is pretty painstaking. Researchers are also looking at other ways to build nano-sized things.

One promising area of research is *self-assembly.* Self-assembly is a process where things grow themselves. This happens all the time in nature. For example, water molecules self-assemble into ice crystals and fall to the ground as snowflakes.

This is a video loop of a snowflake self-assembling in a laboratory.

Some researchers are working on finding ways to get other kinds of structures to self-assemble. IBM has already had computer chips on the market that were created (in part) through self-assembly of silicon crystals.

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Nanoscientists are inspired by other things in nature, too.

One example is the Blue Morpho butterfly. Blue Morpho butterflies get their iridescent color from tiny nano-sized structures in their wings. The nanostructures are colorless, but they're precisely spaced so they reflect blue light back to your eyes.

Scientists are using similar colorless nanostructures to create low energy displays.

RELATED ACTIVITY: Exploring Structures—Butterfly

We've already seen some examples of the ways nano has been incorporated into existing technologies such as computers and smartphones. Now let's look at some of the other existing and new technologies where nano plays a role.

Nanotechnologies could transform the ways we create, transmit, store, and use energy. Some scientists think nanotechnology will allow us to build ultra-efficient transmission lines for electricity, produce more effective and inexpensive solar cells, make cheap, efficient biofuels, and improve the safety of nuclear reactors. More research and investment is needed before nano energy solutions can be developed or widely distributed, but here are a few examples.

Thin-film solar panels (like you see in the photo on the left) are made of bendable nano-layers of material. These small, portable panels can provide a personal power source anywhere in the world. They produce almost as much electricity as traditional photovoltaic panels.

Fuel cells (like you see in the photo on the right) convert chemical energy into electrical energy without combustion, so they're a clean, efficient way to generate power. As more efficient catalysts are developed using nanoparticles, the use of fuel-cell cars may become more widespread.

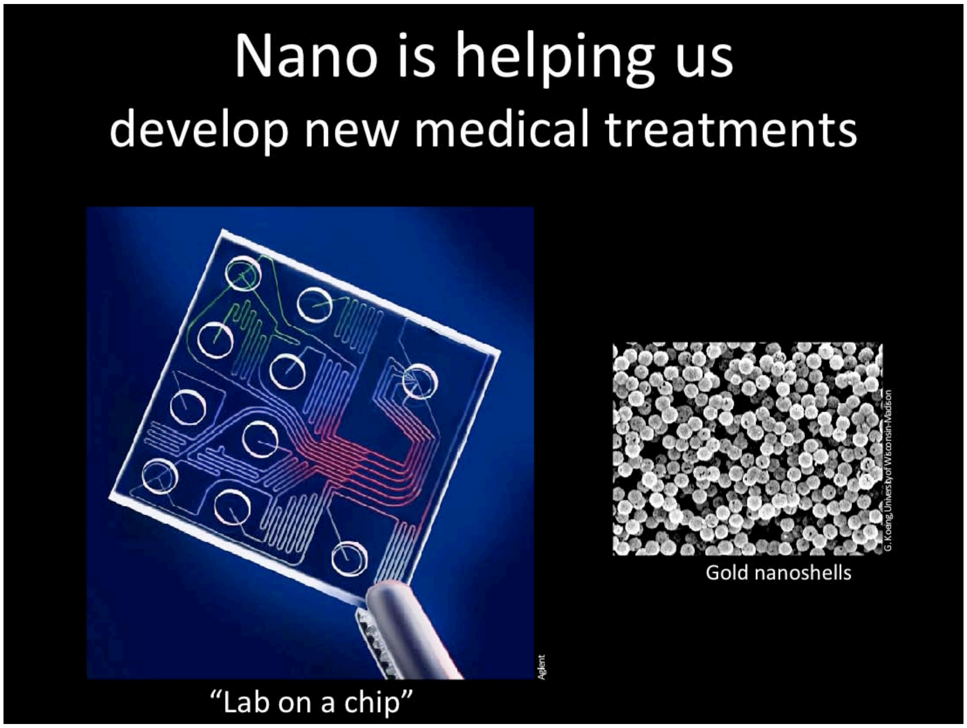
RELATED ACTIVITY: Exploring Materials—Thin Films

Another new use for nanotechnologies is in water filters.

On the left you can see a picture of a water filter that’s packaged like a tea bag! It can be taken anywhere in the world and stuffed into the neck of an ordinary water bottle for use.

On the right, you can see a picture of another portable nanotechnology water filter. Many water filters can get out relatively big things like dirt and bacteria, but only filters with very small pores can remove tiny things like viruses and salt ions.

RELATED ACTIVITY: Exploring Size—Ball Sorter



Nanotechnology might also lead to improvements in healthcare.

In the picture on the left, you can see a "lab on a chip." In the future, small chips the size of a postage stamp may take only a drop of blood and a few minutes to run a whole variety of medical tests. These "labs on a chip" will owe their efficiency to their micro-sized channels and nano-sized sensors.

The photo on the right shows nano-sized silica beads coated in gold. These gold nanoshells might one day be used to treat cancer! Therapies using gold nanoshells are currently in clinical trials with humans. In the therapy, the nanoshells injected in the blood and used with near-infrared light to heat and kill tumors with very little harm to nearby tissue.

RELATED ACTIVITIES: Exploring Fabrication—Gummy Capsules, Exploring Materials—Nano Gold

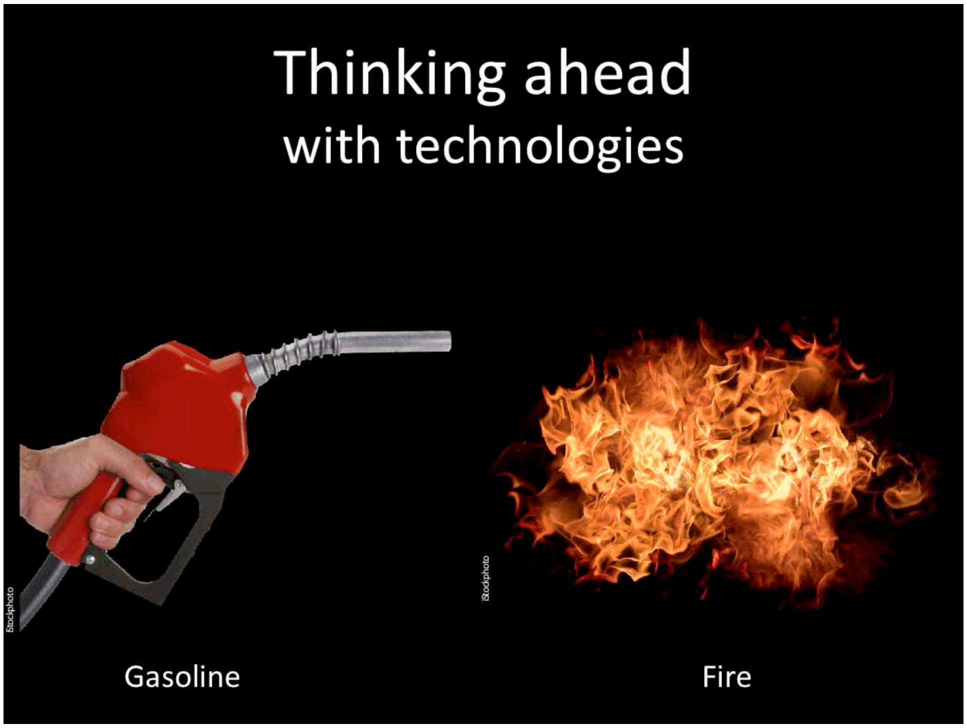
Nanotechnology might also help us to create innovations we can hardly imagine today.

For example, some scientists think nanotechnology might allow us to create an elevator to space! The idea of a space elevator has been around a long time, and some scientists think nanotechnology may make it possible. Tiny carbon nanotubes are super-strong for their size, so they could be used to create a cable between a base station on earth and an anchor in space.

Another possibility is quantum computers. Today's computers use a binary system, where every bit of information is either a 0 or a 1. We might be able to greatly increase computer memory and processing power by using quantum bits, which can exist in more than one state simultaneously (both a 0 and a 1, for example).

RELATED ACTIVITIES: Exploring Nano & Society—Space Elevator, Exploring Nano & Society—You Decide

Nanotechnology is already part of our lives, and it will become even more important in the future. Think about how new technologies, like the personal computer or cars, have changed our lives. Scientists think that nanotechnology could transform our lives just as much!



All technologies involve costs, risks, and benefits.

Let's consider fire, one of the oldest technologies. Fire is good when we want to get warm or cook our food. But fire can also burn things down. We think ahead and protect ourselves from the risks related to this useful technology. We build fires in a contained space, and we have fire extinguishers and a fire department to help us if a fire gets out of control.

Another example of a familiar technology is gasoline. Gas is toxic and flammable, but it's also useful. So we have regulations for producing, transporting, and using it safely.

Just like other technologies, nanotechnology has potential to provide great benefits, but we also have to think about potential risks and how to protect ourselves. And we'll have to think about the kind of future we want and how nanotechnology can be part of that.

Everyone has a role in shaping nanotechnology. Companies and governments decide which technologies to invest in and how to regulate them. Individuals can help shape nano research and development by deciding whether to use products containing nanotechnology.

Each of is already making decisions about whether or not to use nanotechnologies, though we may not always know it.

Many products containing nanotechnology can already be found on the shelves of sports stores, supermarkets, and electronics stores. Nano-sized silver particles are one of the most common nanomaterials used in consumer products. There are socks, for example, that use nanosilver to kill the bacteria that make feet smell. Some people wonder what might happen when the nanosilver particles enter the water supply when you wash them.

Another example is sunblock. Many sunblocks contain nano-sized particles of zinc oxide or titanium dioxide. Manufacturers don't have to label whether the sunblock contains nano-sized particles, so many people are using nanoparticle sunblock without realizing it.

So nanotechnology is part of our lives today, and it will continue to be part of our lives in the future.

RELATED ACTIVITIES: Exploring Products—Sunblock, Exploring Products—Nano Fabric

Our values inform the technologies that we choose to make and use. As we develop and use new nanomaterials and technologies, we can consider how to do so in a way that's equitable and responsible. We can try to maximize the benefits of nanotechnology and minimize the risks. And we can try to share the risks more equally across different people.

We all have a role in shaping our nano future, as individuals and as a society. Companies and governments decide which technologies to invest in and how to regulate them. Individuals can help shape nano research and development by deciding whether to use products containing nanotechnology.

We've covered a lot! As a reminder, we've been through four big ideas:

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