INTERACTIVE

FUN²

INNOVATIVE

INSPIRE

TEACHER'S REFERENCE GUIDE

MathAlive!

Presented By **Raytheon**

A GUIDE TO THE MATHEMATICS EXPLORED IN THE EXHIBIT

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INTRODUCTION

Welcome to **MathAlive!** This guide is designed as a resource for teachers who are interested in more information about what specific mathematics concepts are explored in the exhibit, and how they are presented. It is designed to help with planning a field trip, allowing you to identify relevant math in advance of your visit, so that students can get the most out of the experience based on what they are currently learning. It will also help when encouraging students to experience the exhibit with their families, allowing you to suggest specific "don't miss" exhibitry and activities.

A map of the exhibit identifies all the activities, organized by thematic gallery (sports, video games, robotics, etc.). For each of the exhibit's interactive displays (approximately 40 in total), this guide provides the following:

- A brief description of the experience
- The main idea
- The "math at work"
- Curricula connection
- Standard/strand
- Sources

For some, additional suggested activities are provided to create a more enriching experience.

Also, be sure to download the exhibit's Teachers Activity Guide, which can be found at www.mathalive-me.com.

We hope you and your students enjoy **MathAlive!**

MathAlive! is made possible by Raytheon.

MathAlive!... Overview of the Exhibit

Designed to be one of the most interactive and inspiring exhibitions exploring the world of mathematics ever to tour.

MathAlive! is designed to inspire, to spark the imagination, to reveal not only math at work, but the endless possibilities of math. Primarily designed for kids in grades 3-8, the exhibition brings to life the real math behind what kids love most – video games, sports, design, music, robotics, and more – and creates interactive and immersive experiences that bring to life the math at work in each, whether in design, application or use.

In this 5,000 square foot exhibition, visitors will ride snowboards in a 3-D experience, design (and play) their own video games, capture their 360-degree images in a unique interactive, even design a custom skateboard for "pop" — the quick, snapping motion that allows a board to do the best tricks. Through nearly 40 unique, interactive experiences, the exhibit takes math from its native form into the applied worlds of design, engineering, technology and science.

They'll explore and operate simulations of NASA's latest robotics, including the Robonaut 2 and the Curiosity Mars Rover. They'll design a Supertall skyscraper and learn how engineers work to make a city hum while taking on different engineering roles to design a more sustainable infrastructure.

The exhibition also includes content of specific interest to Middle Eastern audiences. Visitors learn about historical achievements by noted figures from the region; explore math at work today in innovative applications in the region - as well as hearing from those shaping the future; and experience interactives with math within the cultural backdrop of Arab-centric imagery, landmarks, customs, culture and language.   The exhibition is presented in dual language, with text and graphics displayed in Arabic and English.

This innovative exhibit responds to the movement toward greater focus on STEM development and STEM career awareness, and inspiring kids to make math a priority, reaching them in that window of vulnerability when math gets more challenging and kids begin to lose interest.

The exhibition is designed to help math teachers answer the age-old question: "Will I ever use all this math they're teaching us?"

Visitors are accompanied by fun and quirky virtual guides, and along the way they'll meet and hear professionals, visionaries and inspiring personalities talk about math in their work across fields kids are most interested in exploring. The exhibit addresses all math strands and subjects for upper elementary and middle school, and neatly aligns with standards for educator planning.

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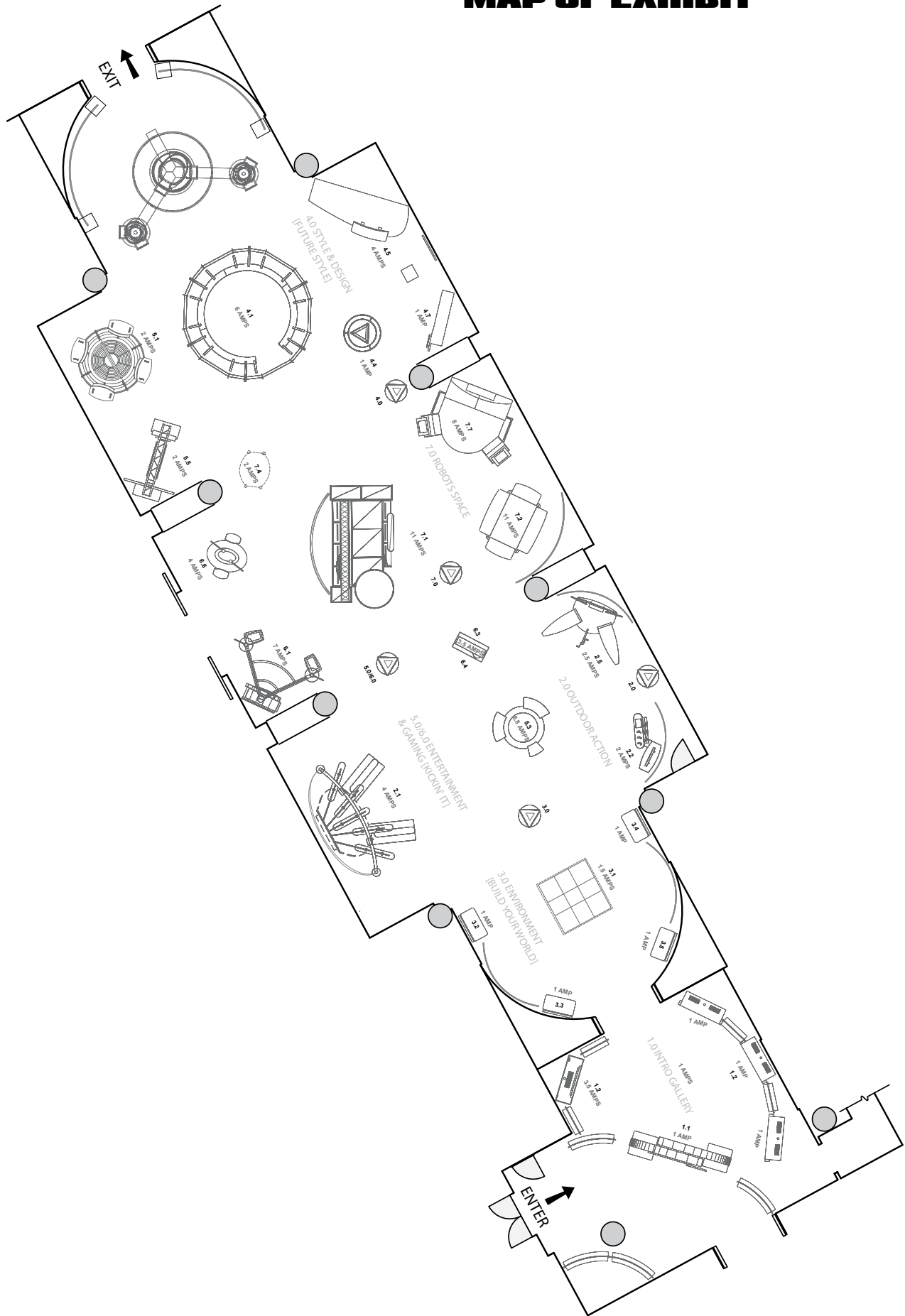
TEACHER'S REFERENCE GUIDE TO EACH ACTIVITY IN THE EXHIBIT

The following outlines provide an explanation of the interactive experiences, the main idea behind each, the math at work, and samples of the text on panels or screens that accompany each. Where personalities are featured in each gallery, sample narrative is provided; the personalities appear in videos, on touch screen displays and on graphics panels.

1. INTRO GALLERY – Marquee Title and Entry Passage

An overarching passage introduces the exhibition. A freestanding video introduces the BotZ characters who "hand you" the magical math goggles that allow you to see the math behind all actions and objects you encounter in the exhibition. Enter a darkened space punctuated by a dynamic montage of bold, vibrant images which dissolve and cycle to reveal the underlying math graphically, emphasizing how math is a part of the world around us, and that math opens doors and takes you places.

Who are the BotZ:
Three character guides who act as a cool and creative team throughout the exhibition, using humor, clear communication, and useful tools to help visitors discover how math relates to the world around us. The BotZ introduce how the interactive activities work, with fun exchanges and small details that bring out their personalities and relationships. Each Bot has expertise in at least two subjects covered by the exhibition galleries, so a Bot helps explain the featured mathematical concept in many of the activities. They provide humor, communication, and helpful tools or devices.

2. *OUTDOOR ACTION... ADVENTURE SPORTS*

2.1 *Boardercross... Snowboard Experience*

Description:
Race others in a snowboard ride. Jump onto a pivoting snowboard and twist and torque your body, angle your board, and fly over obstacles while you race against other players. Watch the action on an immersive screen to coordinate your body movements along with the action.

Main Idea:
This interactive gives visitors a better understanding of angle size and provides concrete comparisons of different sized angles. The idea of "acute" angle is emphasized.

Text Panel:
> *On Your Mark...*
> *1. Press START.*
> *2. Swerve to avoid obstacles.*
> *3. Watch your speed and your angle each time you turn.*

Math at Work:
Precision
The straighter your path down the slope, the faster your speed.
Swerving to avoid obstacles slows you down. Too wide and you lose speed. Too tight and you risk wiping out.
The angle of your turn will likely be less than $90°$ — an acute angle.
Think ahead to finish first — always hit the turn at the best angle.

Curricula Connection:
This interactive provides practice in identifying angle types, including acute, right, and obtuse angles.
It connects with students' study of the measurement of angles.

Standard/Strand:
- Geometry: Use visualization, spatial reasoning, and geometric modeling to solve problems; draw geometric objects with specified properties such as side lengths or angle measures. (NCTM Standards, grades 6-8)
- Draw and identify lines and angles, and classify shapes by properties of their lines and angles. (Common Core State Standards)
- Measurement: Understand measurable attributes of objects and the units, systems, and processes of measurement. (NCTM Standards, grades 6-8)

Ideas for the Visit:
Encourage the players to talk with each other about strategy as they do their runs down the slope. As they describe their strategies, encourage them to communicate about the size of the angles that were most effective, using mathematical terms like "acute" and "obtuse" and connecting them with everyday language like "sharp" and "wide" angles.

Sources:
NCTM Standards (Geometry, Measurement)
Common Core State Standards (Geometry)

2.2 *Ramp It Up... Build a Skateboard with POP*

Description:
At a virtual design station, using real skateboard parts as the interface, design a skateboard that performs an Ollie and set the variables to perform the best tricks with your board. Determine the best shape and length of your board; choose the best wheel size and position of the trucks. A skateboard is a kind of lever and the wheels and trucks act as fulcrums. Test the ability of your board to perform an Ollie.

Main Idea:
Two variables can be manipulated and tested in combination to get closer to the optimal effect.

Text Panel:
> *Get Rolling*
> *1. Touch the screen to start.*
> *2. Select your height to determine the length of your board.*
> *3. Touch a board to choose the shape you want.*
> *4. Touch one of the wheel sets to select your wheel size.*
> *5. Determine the position of your trucks.*
> *6. Hit TEST to see your board do an Ollie.*

Math at Work:
Optimization
Set the variables to perform the best tricks with your board.
- The diameter of your wheels affects how high the nose of the skateboard rises when you push down on the tail.
- The trucks are the fulcrums of your board. A fulcrum is a fixed point where something pivots, or turns, like a seesaw. Optimize your board by placing the trucks in the best location.
- Hit the ground quickly with the tail of your board and it has more energy to move forward.

Curricula Connection:
The understanding of "variables" is crucial to algebraic thinking and should be developed starting in the elementary grades and continuing into formal algebra.

Algebra Standard:
1. Investigate how a change in one variable relates to a change in a second variable. (NCTM)
2. Develop an initial conceptual understanding of different uses of variables. (NCTM)

Sources:
NCTM Standards, grades 3-8

2.5 *Pedal to the Peak…* **Mountain Bike Challenge**

Description:
Compete against others in a mountain bike race. Jump on a stationary bike, or use a hand pedal. As you pedal, match the shaded areas on two linked graphs. One graph represents speed on one axis and time on the other, while the other graph shows distance on one axis and time on the other. The more accurately you match the areas shaded around the lines plotted on the graphs, the higher your score.

Main Idea:
Line graphs can show changes in distance over time and changes in speed over time. These two graphs are interrelated.

Text Panel:

Riders Ready
1. It's not all about speed.
2. Pedal to match the graph.
3. Stay as close to 100% as you can.

Math at Work:
Graphing
A GRAPH is a mathematical diagram designed to show a functional relationship.

(Shown with accompanying graphs)
This graph shows how far your bike travels within a set amount of time.
Time is recorded on the x axis and the distance on the y axis.
The graph shows that even if the bike stops, time continues to pass.

This graph shows how fast your bike goes within a set amount of time.
The time it takes your bike to move is shown on the x axis and its speed on the y axis.
When you stop, your speed drops to zero.

Put both graphs together and you can see the accumulation of distance over time.

This is CALCULUS, the mathematical study of RATES OF CHANGE. Calculus is used to calculate everything from changing conditions in a race to predicting and explaining the economy.

As you pedal, you can see a percentage. This shows the AVERAGE DEVIATION — the average of the DISTANCE your path strays from the line.

Curricula Connection:
Analyzing graphs of speed and distances is essential to both algebra and physical science courses. These graphs provide an ideal way for connecting science and math, because "telling the story of the graph"

necessitates an understanding of the phenomenon of motion.

Standard/Strand:
Algebra Standard
1. Use graphs to analyze the nature of changes in quantities in linear relationships. (grades 6-8)
2. Explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope. (grades 6-8)

Ideas for the Visit:
Keep the focus of this activity on "graph matching" (rather than going as fast as possible) by calling students' attention to how closely they stay on the path.

Sources:
NCTM Standards, Algebra, grades 6-8

2.6 *Featured Personalities in OUTDOOR ACTION:*

- Eric "Tuma" Britton, Professional Skater/Instructor, Venice, California

- Liza Brooks, Co-owner and Technical Director at True Snowboards, United Kingdom

  I hated math until I studied ENGINEERING.
  *My **dyslexia** wasn't diagnosed until I went to college. No matter how hard I worked in English class, I didn't see the results. I did well in math but it felt so irrelevant.*

  It's all about PRECISION.
  As a vibrations engineer, I investigate the natural frequency of materials. Snowboards and snow each have their own frequency. When the two frequencies match — when they're both at their resonant frequencies — the snowboard hits SPEED WOBBLE.

  Speed wobble is what happens when a board reaches a certain speed and wobbles out of control. To prevent this happening, you can add carbon fiber. The carbon fiber stiffens the board and changes its natural frequency.

  Math is a universal language.
  I can read through a scientific article in Japanese and follow the math even though I don't understand the words.

- Skip Garibaldi, Mathematician and Rock Climber from Emory University, Atlanta, Georgia

  While in college I thought I was going to be a computer scientist.
  Every year I took part in math competitions. They were hard and I wasn't very good, mostly because I didn't practice. But I enjoyed them and slowly realized that I would enjoy a job doing math.

  Math doesn't need fancy lab equipment.
  Being a mathematician gives you a lot more independence than most other jobs. All it takes is your brain and maybe paper and a pencil. You can do math anywhere — while out on a hike, lying on a beach, or back in camp after a day of climbing.

  Stick with it.
  It's never too late to turn things around. I didn't do so well in math class. Then, when I was 15, I started doing my homework. After that, class got a whole lot easier.

Like rock climbing, math requires focus.

- Hind Hobeika, Swimmer and Inventor

3. *BUILD YOUR WORLD...* ENVIRONMENT

3.1 *Supertall... Skyscraper Design Studio...* The Engineered City

Description:
Visitors design their own 'supertall' skyscraper by making several choices about the building's function, structure and design. Once the design choices are made, the visitor will test a model of the building. If the design passes the test, it will be 'built,' triggering an animation on the stacked monitors that simulates time-lapse photography of construction of their building. It ends with a high quality, full-color concept rendering. The skyscraper display is surrounded by stations where visitors take on different engineering roles as they design a more sustainable infrastructure for a city.

In This Area:

Systems Engineering
Engineers design virtual models, so they can test how the building will withstand various forces. The engineers study the test results, change one variable at a time, and re-test. They do this over and over to optimize the design.
So now, you get to design and test your own model of a supertall. Let's boot up the Design App and get started.

3.2 *Easy on the Gas...* Transportation

Description:
As the city keeps growing, the TRANSPORT network has to ensure traffic circulates efficiently.
At this design challenge station, try to come up with a plan to reduce gridlock and fuel consumption.

Main Idea:
Mathematics enables us to simultaneously consider several "what if" questions about the impact of several variables.

Math at Work:
Modeling
Complicated problems have a large number of factors, or VARIABLES. Engineers, mathematicians, and other experts create a MATHEMATICAL SIMULATION, or MODEL, to help find solutions.
They use the model to adjust the variables and observe the effects. This helps them identify the factors that are most important and understand what happens when the QUANTITY, or amount, of each variable changes.

Curricula Connection:
Algebra in 8th and 9th grades includes an emphasis on modeling. Working with transportation systems is an important application of modeling.

Standard/Strand:
- Algebra: Use mathematical models to represent and understand quantitative relationships.
- Model and solve contextualized problems using various representations, such as graphs, tables, and equations. (NCTM, grades 6-8)
- Model with mathematics: Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace. (Common Core State Standards)

Ideas for the Visit:
Ask students to predict which variables might make the biggest difference in terms of energy savings. Also ask them which variables might be easiest to influence through public service announcements.

Sources:
NCTM, grades 6-8
CCSS, Standards for mathematical practice

3.3 *Power Play...* Energy

Description:
Reducing ENERGY USE keeps down costs and improves air and water quality. A major storm is racing toward the city. Which essential services need a constant supply of power? At this design challenge station, minimize disruptions in power supply during extreme power surges by coming up with plans such as when and how to apply rolling blackouts to maintain essential services.

Main Idea:
Examining real-time graphs of electrical use provides engineers with immediate mathematical information that is used to maintain the functioning of the grid in emergencies.

Math at Work:
Real-time Graphing
A real-time graph shows the total amount of electricity used in the city.

During an emergency, electrical workers consult a real-time graph to determine how much power needs to be cut to maintain essential services.

By reading the graph, workers can flip power switches on and off to see the impact of their actions. They keep consumption within the allocated kilowatt range and all the services keep running.

Curricula Connection:
The science of energy conservation is connected with the ability to read and interpret graphs that change in real time. Science laboratory "probes," such as those that measure temperature, motion, or electrical energy usage, demand that students use real-time graphs.

Standard/Strand:
- Algebra: Explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope. (NCTM, grades 6-8)

Ideas for the Visit:
Ask students to "tell the story" of the graph that they see unfolding.

Sources:
NCTM, Algebra, grades 6-8

3.4 *Going Viral...* Communications

Description:
Find out how much server space is needed when your video goes viral through digital networks. At this design challenge station, work through a linear animation that demonstrates the powers-of-ten formula through digital communication.

Main Idea:
Exponents are a key way of expressing the size of numbers and provide a way to simplify calculations involving very large and very small numbers.

Exhibit Text:
Access arrival predictions on the go.
GPS, digital mapping, and mobile phones are used to collect information in different areas:
- *the actual location of a bus or train*
- *the distance from there to your stop*
- *other planned bus stops along the way*
- *information about traffic and road conditions.*

All this information gets factored into a mathematical formula, called an ESTIMATION ALGORITHM, and is then delivered straight to your device to help you determine the best route.

Math at Work:
Exponentials
Astronomers use huge numbers to describe distances in space. Physicists use tiny numbers to describe the size of atoms. Math provides a simple way to express numbers that are extremely large or small without having to use a long string of zeroes. Using POWERS OF 10 provides an easy-to-read shorthand. The EXPONENT — the little number beside the 10 — tells you the place value. Negative exponents are used to show values less than 1, and positive exponents are used to show numbers greater than 1.

$10^3 = 1000$
$10^2 = 100$
$10^1 = 10$
$10^0 = 1$
$10^{-1} = 0.1$
$10^{-2} = 0.01$
$10^{-3} = 0.001$

Curricula Connection:
High school study of math and science depends upon having a solid understanding of exponents.

Standard/Strand:
- Number and Operations: Develop an understanding of large numbers, and recognize and appropriately use exponential, scientific, and calculator notation. (NCTM, grades 6-8)
- Expressions and Equations: Know and apply the properties of integer exponents to generate equivalent numerical expressions. (CCSS, grade 8)

Sources:
NCTM, Number and Operations, grades 6-8
Common Core State Standards, Expressions and Equations, grade 8

3.5   *Test the Waters... Water*

Description:
Make the city's river water safe enough for swimming. At this design challenge station, virtually test water samples, and using data provided, determine whether the natural balance of the river's ecosystem has been restored to safe levels for swimming.

Main Idea:
Very small numbers can be expressed in multiple ways, using the notions of "parts per million" decimals and scientific notation.

Math at Work:
Giardia is a bacterium that causes diarrhea. Swallow contaminated water from a pool or a river and you may get sick. Just ONE PART PER MILLION (ppm) of *Giardia* in a glass of water is harmful.

One part per million is tiny. If you put four drops of ink in a 55-gallon water barrel and mix it thoroughly, the ink concentration would be one part per million.

A liter of water weighs 1 kilogram (kg)
1 kilogram (kg) = 1000 or 10^3 grams (g)
1 milligram (mg) = 1/1000 or 10^{-3} grams (g)

A milligram is one ppm — or one millionth — of a kilogram.

You can write this three different ways:

$$\frac{1}{1,000,000} \quad \text{or} \quad 0.000001 \quad \text{or} \quad 10^{-6}$$

Quick ways to write tiny amounts:
- Bacteria vary in size from 5×10^{-4} mm to 5×10^{-3} mm (0.0005mm - 0.005mm)
- A wavelength of green light is 5.5×10^{-7} m (0.00000055 meters)

Curricula Connection:
High school study of math and science depends upon having a solid understanding of exponents. Understanding of parts per million is especially important in the study of biology, as well as in the emerging field of nanotechnology.

Standard/Strand:
- Number and Operations: Develop a deeper understanding of very large and very small numbers and of various representations of them. (NCTM, grades 9-12)
- Expressions and Equations: Write and evaluate numerical expressions involving whole-number exponents. (grade 6)

Sources:
www.nanomedicine-explorer.net
NCTM Standards, Number and Operations, grades 9-12
CCSS, Expressions and Equations, grade 6

3.6   Featured Personalities in BUILD YOUR WORLD:

- Rondi Davies, Geologist and Champion Marathon Swimmer, New York

    As a geologist, I study how the Earth works.

    Since I was a young kid, I've loved swimming and being outdoors.
    Marathon swimming unites my two passions.

A Big Challenge
In the 1970s, the Hudson River in New York was too polluted for swimming. After decades of cleanup work, the river is now swimmable most days.

To raise awareness about water quality, I organized a 120-mile, seven-day swim between eight bridges on the Hudson. There were 21 swimmers and we swam 13-20 miles every day.

Calculations
To figure out how long we should swim each day, I had to calculate
- when the ebb tide started
- the average speed of the current during the ebb tide
- the speed of each swimmer.

- Tanya Martinez, Electrical Engineer, Albuquerque, New Mexico

- Yemarshet Yemane, Engineer and Business Owner, Ethiopia

I work on systems that deliver CLEAN WATER to communities.
When I was in 10th grade, my favorite math teacher went to the U.S. to study ENGINEERING. Right then, I decided to become an engineer.

I was good at math and studied civil engineering, water supply, and sanitation overseas. Now I have my own business designing water projects and supervising the construction of water systems.

Every aspect of my work involves math.
Many projects start with creating a dam to store water. The water is treated and then distributed to residents through a system of pipes.

I use MATH to calculate everything from the volume of water stored in the dam to the size and length of pipes to the costs of labor and materials.

The MATH you study in school is used to DESIGN and BUILD your home, the roads you use every day, your family car, your computer, even your video games.

- Francisca Rojas, Communication/Migration Specialist, Cambridge, Massachusetts

In the 1980s, when my family moved from Chile to Washington, DC phone calls home to Chile were expensive. Today, wireless technology and the Internet help everyone stay connected. Calling relatives and friends in Chile several times a week is affordable, and we can video chat any time.

Math helps us understand the world from social and cultural perspectives.
I'm curious to discover how wireless technology is changing how cities work. As a social scientist, I use math to analyze numbers and discover PATTERNS and TRENDS. For instance, did you know that New Yorkers call the Dominican Republic more than any other international destination?

I've always been fascinated by how cities work.
Transit authorities in Boston and New York City use cell phones and computers to collect DATA — in the form of NUMBERS and PATTERNS. My job is to talk to people about how they use mass transport. By interpreting and explaining all the data, I can help transit agencies build more efficient systems.

- Azza Faiad, Biofuel Researcher

- Mahmoud Shattel, Alternative Energy Pioneer

- Zaha Hadid, Architect

4. *FUTURE STYLE... STYLE AND DESIGN*

4.1 *Style Revolution... 360-degree Photo Shoot*

Description:
Step onto a photo stage, pose and have your image captured in 360 degrees, using the same freeze-motion technique made famous in contemporary action movies. On a monitor, manipulate your image and choose to play back your shots in either a clockwise or counterclockwise sequence.

> *It's Showtime*
> *1. Sign up here and get your secret code.*
> *2. Step into the ring.*
> *3. Be ready to strike a pose.*
> *4. Exit after the cameras go off. Find your pictures at an open workstation.*

Main Idea:
There is an inverse relationship between the number of cameras taking photos and the size of the angles between the cameras.

Math at Work:
Sequencing
Each camera is in a fixed position. The distance and the angle between each pair of cameras are equal.

If there are x cameras,
the angle (y) between each pair of cameras is

$$\frac{360}{x} = y$$

The more cameras you use, the smaller the angle between each pair of cameras.

All the cameras shoot at exactly the same time. The computer puts the camera images together IN SEQUENCE to create a seamless animation in 360°.

Curricula Connection:
The study of geometry, number, and measurement are integrated in this interactive.

Standard/Strand:
- Geometry: Make and test conjectures about geometric properties and relationships, and develop logical arguments to justify conclusions. (grades 3-5)
- Measurement: Understand, select, and use units of appropriate size and type to measure angles, perimeter, area, surface area, and volume. (grades 6-8)

Ideas for the Visit:
Walk around the perimeter of the circle and ask one student to call out the angle size between steps while another keeps track of the number of "steps." The number of steps multiplied by the angle size should equal 360 degrees.

Sources:
NCTM, Geometry, grades 3-5
NCTM, Measurement, grades 6-8

4.4   *Make It Fit...* Tessellations

Description:
Work with edge-lit acrylic shapes on a backlit table lined with mirrors. Move shapes to create tessellating patterns that fit together and repeat without gaps or overlaps.

Main Idea:
Identifying the attributes of certain two-dimensional shapes which, in combination, tessellate or fit together without any overlaps or gaps.

Math at Work:
Tessellations
Shapes TESSELLATE when they fit together perfectly like a tiled floor, without overlapping or gaps.
In any shape that tessellates, the angles at any corner — or vertex — add up to 360°.
Find different tessellating shapes inside patterns. Some shapes, like pentagons, octagons, and hexagons, have equal angles but cannot tessellate on their own.

Curricula Connection:
Geometric shapes can be used in combination to create pleasing artistic patterns that have defined mathematical properties.

Standard/Strand:
• Geometry: identify, compare, and analyze attributes of two- and three-dimensional shapes and develop vocabulary to describe the attributes. (NCTM, grades 3-5)
• Reason with shapes and their attributes. (CCSS, grade 3)

Ideas for the Visit:
Encourage students to create their own tessellations with different combinations of shapes. A variation of this activity can be continued with pattern blocks once students return to the classroom.

Sources:
NCTM, Geometry, grades 3-5
CCSS, Geometry, grade 3

4.5   *Nature's Numbers...* Nature's Patterns

Description:
Spectacular patterns from the natural world with a mathematical foundation are featured. At the attached workstation, discover how to calculate numbers in the Fibonacci sequence.

Main Idea:

Some number patterns can be represented by a ratio that has interesting geometric properties.
Math at Work:
Ratio
Like a fraction, a RATIO is a way to compare two values or numbers.

The ratio of the sides of this rectangle is 8:5,   or $\dfrac{8}{5}$ = 1.6.

This rectangle is called a GOLDEN RECTANGLE because the ratio of two adjacent sides is approximately 1.618, a number called the GOLDEN RATIO.

All golden rectangles can be divided into a square and a smaller rectangle that is also a golden rectangle. This can be repeated over and over again.

Drawing a curve through the corners of the squares forms a LOGARITHMIC SPIRAL, a strong but compact shape often seen in nature.

The Ancient Greek mathematician Euclid first showed this calculation around 300 B.C.E. About 2,000 years later, in 1835, the German mathematician Martin Ohm described it as "golden." Ohm never explained why he chose this term.

The Fibonacci Series
This number sequence is often found in nature. It is seen in the growth patterns of leaves on a branch or in the chambers in a nautilus shell. The series is named after an Italian mathematician called Fibonacci who lived from around 1175-1250.

Try to discover the next Fibonacci number in the puzzle on screen.

Golden Numbers
1. Select the numbered rectangle that comes next.
2. Watch the Fibonacci series fill up.

Curricula Connection:
This interactive connects number theory, namely the relationship in the golden ratio, with geometry.
It enables students to make connections between different areas of mathematics.

Standard/Strand:
• Number and Operations: Understand and use ratios and proportions to represent quantitative relationships. (NCTM, grades 6-8)
• Understand ratio concepts and use ratio reasoning to solve problems. (CCSS, Grade 6)
• Geometry: Use geometric models to represent and explain numerical and algebraic relationships. (NCTM, grades 6-8)

Ideas for the Visit:
Encourage students to find as many examples of the golden ratio as they can in the panels in this interactive. Where else might they expect to see the golden ratio in nature?

Sources:
NCTM, grades 6-8, number and operations and geometry strand

4.7 *Shadow Play...* Shadows

Description:
Artist KUMI YAMASHITA uses the light shining on this seemingly random arrangement of numbers to throw shadows that produce the unexpected.

<u>Shadow Play</u>
Press here and step back to find out what is revealed.

4.8 Featured Personalities in FUTURE STYLE:

• Theo Jansen, Artist and Designer, Netherlands

Beach Beasts
To create wind-powered kinetic sculptures that look and behave like fantasy animals, Dutch artist THEO JANSEN fuses physics, engineering, technology, and his imagination to make robotic STRANDBEESTS or beach animals.

These mesmerizing creatures come to life through Theo's mastery of computer math programs. By running the data he can work out essential details, such as the size and movement of the Strandbeests' legs.

• Nzinga Knight, Fashion Designer

• Ayah Bdeir, Interactive Artist and Engineer

5. *KICKIN' IT...* ENTERTAINMENT

5.1 *Mix It Up...* Giant Musical Instrument

Description:
Adjust the controls at several mixing desks to add or subtract one of the instruments on a giant super-instrument into a continuously looping soundtrack. Watch the instrument light up as it plays a pre-recorded track. Explore the mathematical relationship involved in rhythm as well as the relationship between pitch and frequency in music.

Main Idea:
Fractions play a vital role in understanding music.

Math at Work:
<u>Fractions</u>
Rhythm is repeated patterns created by the length of the notes and the time between them. Notes are grouped into equal periods of time called MEASURES. Rhythm is what makes music move and flow.

Each type of note is a different FRACTION of the whole measure.

In a measure with 4 beats you might hear:

• a whole note	Each whole note is 4 beats long.	4 beats x 1 = 4 beats.
• 2 x 1/2 notes	Each 1/2 note is 2 beats long.	2 beats x 2 = 4 beats.
• 4 x 1/4 notes	Each 1/4 note is 1 beat long.	1 beat x 4 = 4 beats.
• 8 x 1/8 notes	Each 1/8 note is 1/2 beat long.	1/2 beat x 8 = 4 beats.
• 16 x 1/16 notes	Each 1/16 note is 1/4 beat long.	1/4 beat x 16 = 4 beats.

Or a combination of any of these that adds up to 4 beats, e.g.
1 1/4 note + 2 1/8 notes + 1 1/2 note
(1 beat + 1 beat + 2 beats = 4 beats)

Curricula Connection:
Fractions are a major area of study in upper elementary grades, and this exhibit provides a familiar context for making sense of equivalent fractions.

Standard/Strand:
• Number and Operations: Develop understanding of fractions as parts of unit wholes, as parts of a collection, as locations on number lines, and as divisions of whole numbers. (NCTM, grades 3-5)
• Recognize and generate equivalent forms of commonly used fractions, decimals, and percentages. (NCTM, grades 3-5)
• Use equivalent fractions as a strategy to add and subtract fractions. (CCSS, grade 5)

Ideas for the Visit:
Challenge students to find as many combinations of notes as they can to make a 4-beat measure (e.g., 4 sixteenth notes plus 2 quarter notes plus 2 eighth notes).

Sources:
NCTM, Number and Operations, grades 3-5
CCSS, Number and Operations, grade 5

5.3 *Flicker Fusion...* Make a Movie

Description:
Artful figures are attached to a circular platform visible through viewing windows. Turn a dial and watch the figures as the platform rotates. Create a perfect animation by choosing the optimum frequency of rotation and optimum frequency of flashing light.

Main Idea:
The idea of frequency, both with respect to number of light flashes per second and with respect to number of times a platform rotates, is explored. This is a particular type of ratio, namely the number of flashes per second.

Math at Work:
<u>Frequency</u>
The smoothness of the image depends on
      1. the FREQUENCY, or number of times, that the light flashes per second
      2. the speed, or FREQUENCY, at which the platform rotates in a given period of time.

When the rotating platform moves at slower speeds, you clearly see the light flash and the individual figures. As you increase the speed, the image becomes smoother. This is because at around 24 flashes per second the light begins flashing too fast for the eye to see. Above that rate, the animation appears perfectly smooth.

Because the flashing light and spinning platform are synchronized, the figures move forward one position each time the light flashes. The platform appears to stay in place.

Curricula Connection:
Rate of change is an important topic in algebra as well as in science, and this interactive provides grounding for the study of rate of change.

Standard/Strand:
- Algebra: Identify and describe situations with constant or varying rates of change and compare them. (NCTM, grades 3-5)
- Understand ratio concepts and use ratio reasoning to solve problems. (CCSS, grade 6)

Sources:
NCTM, Algebra, grades 3-5
CCSS, Number and Operations, grade 6

5.5 *Step Up...* **Color Motion**

Description:
Step up and move in front as your motion is captured in silhouette forms. As you move, watch rainbows and effects fan out from your reflected silhouette.
Discover how mathematical functions can be used to create moving color effects.

Main Idea:
Transformations in real time. Move your body and watch the changes on screen.

Math at Work:
Binary
How does this work?
A camera linked to a computer program assigns a binary number — numbers made up of 1s and 0s — to your silhouette. That number corresponds to a color, or frequency, in the color spectrum. The background number always equals zero.

The program compares each pixel on the silhouette with the pixel above, below, or beside it. If there is no pixel, it means you moved and created a new outline. The program assigns the edge of the new silhouette a new number and color.

Adding the silhouette images together creates an animation in real time.

5.6 *Featured Personalities in KICKIN' IT:*

- Ajay Kapur, Musician and Computer Scientist, California Institute of the Arts, Valencia, California

  My life revolves around my two passions: computers and music.
  Ever since my parents bought me my first computer, I've been glued to a screen. Soon after, I got a red Pearl drum kit and I've never stopped beating the drums, the walls, the dinner table.

  As a musical scientist I constantly ask myself "How?"
  How does a sitar make that sound? How does a drum resonate? How do people play music together? How can I design programs that enable computers to improvise with human musicians?

  Jamming 21st century style
  KarmetiK, the robotic orchestra I direct, is made up of musicians, composers, scientists, engineers, and artists who use their hands, heads, lights, lasers, gestures, and computers to communicate with each other and with robots.

  Music and math are a lot alike.
  They both have their own language made up of symbols and numbers. Rhythm, harmony, and tempo can all be explained using math. Although math might seem hard at first, don't give up.

  Like music, it gets better with practice.

- Dr. Naif Al-Mutawa, Comic Book and Television Series Creator

6. *GAME PLAN... VIDEO GAMES AND OTHER GAMES*

6.1 *Game Developer*

Description:
Race against a timer to design and program a game object at a touch screen workstation using a 3-D model. Choose from a set of variables that determine the object's properties and movements. Launch your character into the game and see how the properties you assigned the object affect its survival.

Main Idea:
Graphing can happen in 3-dimensional space, using positive and negative numbers on the X, Y, and Z dimensions to locate and move an object.

Text Panel:
Test and Modify
1. Design your rickshaw.
2. Launch it to see how it performs.
3. Modify your design and re-launch.

Math at Work:
3-D Mapping
Computer designers and programmers use 3-D mapping to navigate an object in space.

There are three axes — x, y, and z. All three contain negative and positive numbers. The x, y, and z axes intersect at zero.

You can tilt an axis and rotate an object through 360˚ to view it from different perspectives and angles.

CAD — Computer-Aided Design — programs use math to create three-dimensional drawings. CAD is used in design, construction, engineering, and to build mathematical models.

Standard/Strand:
- Geometry: Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life. (NCTM, grades 5-8)
- Investigate conjectures and solve problems involving two- and three-dimensional objects represented with Cartesian coordinates. (NCTM, grades 9-12)

Sources:
http://sketchup.google.com/ (free CAD tool often used in secondary school math)
NCTM, grades 5-12

6.3 *Crack the (Binary) Code*

Description:
Five large switches correspond to the first five binary bits, or digits 16, 8, 4, 2, and 1. Turn the switch on to indicate "1". Turn it off to indicate "0". Challenge yourself to create binary equivalents of the "Target Number". See how many codes you can crack. The target number is in Base 10. Translate it into Base 2 (binary).

Main Idea:
There are different number systems used for different purposes: Binary or base 2 is commonly used in computer programming.

Text Panel:

(Don't Get) Lost in Translation
The target number is in Base 10. Translate it into Base 2 (binary).
• To display a 1, slide the switch to ON.
• To display a 0, slide the switch to OFF.

Math at Work:
Bases
BASE 10 or the decimal system is the most commonly used number system. The numbers in the decimal system are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9.

The position of the numbers determines their value,

```
100  +  10  +  1
3        2       1      =      321
100x3   10x2    1x1
```

BASE 2, or the binary number system, uses only two digits, 1 and 0.
The value of binary digits also relies on their position.

```
8  +  4  +  2  +  1
1      1      0      1      =      13 in the Base 10 system
1x8    1x4    0x2    1x1
```

Base 2 is used in computing because an electrical circuit is either switched "on" or "off."
1 = "on"
0 = "off."

Curricula Connection:
Mathematics is rarely connected with computer science in elementary and middle school. This interactive provides an important opportunity to connect number theory (mathematics) with real life applications in computer science.

Standard/Strand:
• Number and Operations: Recognize equivalent representations for the same number and generate them by decomposing and composing numbers. (grades 3-5)

Ideas for the Visit:
Encourage students to be code-breakers: Ask one student to write a binary numeral that represents a base 10 numeral between 1-100. Other students "break the code" by translating to the base 10 system.

Sources:
http://illuminations.nctm.org/LessonDetail.aspx?id=L245
NCTM, Number and Operations, grades 3-5

6.4   *Flip It…* **Probability**

Description:
Zero out the counter on a monitor. Strike a pressure point to flip a disk inside a tube. The result of the flip is recorded with a camera. Repeat several times. A display shows your results. Compare these with the results for the flips and for the entire life of the exhibition (or some combination). The more times the coin is flipped, the closer the probability moves to 50%.

Text Panel:

Heads or Tails?
1. Press the reset button.
2. Punch the button to flip a disk.
3. Compare your results with the running tally.

Main Idea:
Coin flipping is an important context for understanding independent events: The probability of a fair coin coming up heads remains ½ no matter how many times it is flipped.

Math at Work:
Probability
Each time you flip a coin there are two possible outcomes: heads or tails.

The probability for each outcome = 50%.

Each flip of the coin is an independent event. Flip it 5 times and you may get 5 heads. Flip it 500 times and your results will come much closer to the expected frequency of 50%. The greater the number of flips, the closer you get to 50%.

Plot your results on a graph to show how many times you get "heads" when you flip a coin 10 times. If many people do this, the results form a bell curve. Most results center around 4, 5 and 6, with the greatest concentration at 5.

Curricula Connection:
Probability is an important part of the study of many types of data. For example, understanding genetics depends on understanding the notion of independent events.

Standard/Strand:
• Data Analysis and Probability: Use proportionality and a basic understanding of probability to make and test conjectures about the results of experiments and simulations. (NCTM, grades 6-8)

Ideas for the Visit:
Within a minute, every student in the class can flip a coin 10 times and record the results to make their own distribution. Does this distribution resemble a bell curve?

Sources:
pbskids.org/cyberchase/games/probability/
NCTM, grades 6-8

6.5   Game Box Kids

Description:
Real game play on video games created by kids. In interviews, the game designers and developers talk about the math they used and learned in order to create their games.

7.   ROBOTICS AND SPACE

7.1   On Target... NASA Robot

Description:
A viewing camera is mounted to the end of a Robotic Arm that extends from a 3-D version of the International Space Station. A cupola provides work stations along with views of the surrounding space station. Control the robotic arm movement and camera as they check three different locations on the outside of the Space Station. Stay within your time limit.

Main Idea:
The coordinate system is a clear way of locating objects in 2-D space.

Text Panels:

> *Far Out Friends*
> *Living in space can be dangerous. Taking a walk outside a vessel is risky. Robots protect the human crew by carrying out hazardous jobs as well as taking care of routine maintenance tasks.*
>
> *On Target*
> *Move the robot along the robotic arm to check three different locations on the outside of the Space Station. Stay within your time limit. Each time:*
>
> *1. Enter the number of moves and the direction — FORWARD or BACK — to reach the Target location.*
> *2. Angle the camera and zoom in or out to read the Target code.*
> *3. Enter the code to check the status of the Target.*
>
> *DEXTRE*
> *The dual-arm, remote-controlled DEXTRE is the robotic handyman on board the International Space Station. Dextre can make repairs outside by attaching to a giant robotic arm.*

Math at Work:
Numbers
To move the robotic arm you have to figure out HOW FAR it is from your STARTING POINT to the TARGET.

If you move FORWARD along the number line from 1 to 8, the distance you move is 7.
You can figure this out in more than one way:
You can SUBTRACT 1 from 8:   8 – 1 = 7
Or you can think about what you need to ADD to 1 to get to 8:   1 + 7 = 8

The distance from the starting point to the target will always be a positive number, but you need to think about the direction that you travel.

If you move FORWARD from -8 to -1, it is 7.
And moving FORWARD from -3 to 4 is 7 too.
Even if you move BACKWARDS along the number line from 4 to -3, that's also 7.
Seven is what you get if you count the steps from 4 to -3. It's also what you get if you subtract: 4 - (-3) = 7.
Take the mystery out of subtracting negative numbers by counting steps — you should get the same results.

Curricula Connection:
The coordinate system involves geometry and making/communicating about mathematical representations.

Standard/Strand:
• Geometry: Make and use coordinate systems to specify locations and to describe paths. (NCTM, grades 3-5)
• Find the distance between points along horizontal and vertical lines of a coordinate system. (NCTM, grades 3-5)
• Graph points on the coordinate plane to solve real-world and mathematical problems. (CCSS, grade 5)
• Investigate conjectures and solve problems involving two- and three-dimensional objects represented with Cartesian coordinates. (grades 9-12)

Sources:
http://illuminations.nctm.org/LessonDetail.aspx?id=L280
NCTM Standards, Geometry
CCSS Standards, Geometry

7.2   Curiosity Mars Rover

Description:
Control the movements of a virtual Curiosity Mars Rover on a flat tabletop touchscreen as it moves across the Mars landscape. Enter a series of commands and maneuver past obstacles to collect rocks for analysis.

> *Get Ready to Rock*
> *1. Touch START MISSION.*
> *2. Enter direction and number of moves.*
> *3. Each time you change direction, also enter the number of moves.*
> *4. Hit LAUNCH to run the sequence. Does the Rover reach the rocks?*
>
> *25 Minutes to Mars*
> *Because of the massive distance between Mars and Earth — ranging from about 45 million to 400 million kilometers (about 249 million miles) depending on how far apart the two planets are at a given moment — there's a gap of approximately 25 minutes between the time a message is sent from Earth and the time it reaches Mars.*

Main Idea:
Programming a robot involves carefully planning a sequence of steps. In programming, mathematical language is used to make communication clear and efficient.

Math at Work:
Programming
Curiosity Rover, like all robots, is a specialized computer that can move independently and perform tasks. Like any computer, robots have to be programmed by human beings. Math is the basic language used in all computer programs.
Using a series of commands, the program moves the Rover from its starting point. The information entered — the number of moves and the direction — is the INPUT. The OUTPUT is the response you see when the

Rover moves across the landscape.
Program the Rover to turn through 45, 90, 135, 180, 225, 270, 315, and 360 degrees.

Curricula Connection:
A variant of the Logo programming language, designed to enable children to learn rudimentary programming and its connection to math, is highlighted in this interactive.

Standard/Strand:
• Geometry: Specify locations and describe spatial relationships using coordinate geometry and other representational systems. (NCTM, all grades)

Ideas for the Visit:
Elementary students enjoy practicing "commands" by directing each other to physically move a certain number of steps and turn in a given direction. Put a target on the floor and encourage them to "program each other" while they wait for a turn to program the Curiosity Rover.

Sources:
illuminations.nctm.org/LessonDetail.aspx?id=L396
http://www.mathsnet.net/logo.html

7.4 *Robot Rally...* **Robot Artifact Display**

Description:
Winning entries from the First Robotics or other robotics competitions are on display.

7.7 *Picture This...* **Hubble Telescope**

Description:
At "universe" viewing stations, select a short-exposure photograph taken from the Hubble telescope. Initially, the image is almost completely black apart from 2 or 3 dots of light. By adding and averaging (co-adding) multiple images of the same length of the same shot of the universe, you increase the accuracy and clearness of the image. A counter on the screen tracks the number of images being averaged. Your final image shows a dense, bright, multi-colored star field. Experiment with "sampling" and mathematical formulas that lead to extraordinarily detailed images captured in space.

Better Vision
1. Select a short-exposure image.
2. Co-add a batch of 100 additional images and compare with the original image.
3. Co-add a batch of 1,000 images and compare with the original image.

Main Idea:
The greater the number of images, the more that "noise" or variation can be minimized.

Math at Work:
Co-Adding
A single short-exposure image taken of deep space is grainy and dark with only a few bright spots visible. The longest exposure shot that the orbiting Hubble telescope can take is about 5,000 seconds, or about 1 hour 23 minutes.

To get a better picture, astronomers stack together hundreds, even thousands, of short-exposure images of the same location. They then average the images together, pixel by pixel, in a process called "co-adding."

Co-adding images produces a sharp, rich, colorful final image with a combined exposure of hours, even days.

Eight hundred exposures taken over the course of 400 Hubble orbits around Earth were co-added to create this Hubble Ultra Deep Field Image. The total exposure time was 11.3 days.

Mathematically, co-adding is expressed in a formula that relates the statistical noise in one image (s) to the final statistical noise (N) in the number of co-added images (S).

$$S = \sqrt{\frac{s}{N}}$$

Curricula Connection:
The idea of "sampling" in math and science is highlighted here: The basic concept is that multiple samples produce a better approximation of the phenomenon. In this case, the more astronomical time sample photos that are taken and added together, the better the image.

Standard/Strand:
• Data Analysis and Probability: Understand how sample statistics reflect the values of population parameters, and use sampling distributions as the basis for informal inference. (NCTM, grades 9-12)
• Technology plays an important role in statistics and probability by making it possible to generate plots, regression functions, and correlation coefficients, and to simulate many possible outcomes in a short amount of time. (CCSS, grades 9-12)

Sources:
NCTM, Data Analysis and Probability, grades 9-12
CCSS, Statistics and Probability, grades 9-12

7.8 **Featured Personalities in ROBOTICS AND SPACE:**

• Robonaut 2, Dexterous Humanoid Robot, NASA

> *The state-of-the-art humanoid Robonaut 2 works side-by-side in space with human astronauts. Skilled at using tools to do work that involves fine hand control and movement, R2 is a DEXTEROUS crewmate.*
>
> *This new-generation robot has an added advantage over earlier robot prototypes. As well as being a valued onboard colleague, R2 can work in space without a pressurized suit or oxygen supply. Like a rover, R2 is designed to move across the lunar or Martian landscape collecting rock samples and gathering data.*

• Dennis Hong, Robotics Engineer, Blacksburg, Virginia

> ***When I was 7 years old, I went to see Star Wars.***
> *All those spaceships and robots in the movie took my breath away. That day, I decided to become a ROBOT SCIENTIST.*
>
> ***How does C3PO do chores?***
> *In my lab we think about the different ways robots MOVE, how we can make them LOOK AND ACT like humans, and how they can interact with and help humans.*
>
> ***I consider myself an expert in SYSTEMS INTEGRATION.***

To build and design a robot, it's crucial that everyone can "SPEAK MATH." I work with a brilliant team with expertise in mechanical designing, software development, and robot vision.

The most fun part of our work is testing our ideas.
When one of us comes up with a smart theory, we put it to the test. First we design an experiment, then we design and build a robot and try it out. If it works, we know it's a good idea and we keep going. If not, we try again.

- Robin Murphy, Robotics Engineer, College Station, Texas

When I was a kid I was convinced that one day I would live on a space station and do useful things.
At college, I studied mechanical engineering and then computer sciences. I fell in love with computers when I realized I could use them to solve all kinds of problems.

I was in hog heaven when I started working on ARTIFICIAL INTELLIGENCE.
A.I. is based on ideas of how people think, make decisions, and solve problems.
Computer scientists convert these ideas into MATHEMATICAL SYMBOLS.

Emergency helpers
Robots can go places that human rescuers like firefighters, police, or medical personnel cannot go. For instance, a robot can determine if a building is structurally sound. This makes it a valuable addition to the larger emergency response team.

The first time I used robots in a real situation was in New York City after 9/11. Since then, my robots have helped in the aftermath of hurricanes, mine collapses, and mudslides.

- Farouk El-Baz, Astronomer

- Kathryn Gray, Student and Supernova Searcher, Fredericton, Canada

In summer we have STAR PARTIES.
My dad's an astronomer. Every year he takes us camping with other astronomers, off somewhere where the sky is dark enough to really see stars.

A supernova is an exploding star that blinks on and off as it burns and dies.
So far, dad has found six supernovae. When I was 10, I heard about a 14-year-old girl who found one and I thought, "HEY, I CAN DO THAT!"

Dad put me to the test. I looked through his images of galaxies and found five of his six supernovae — that's an 80% success rate.

Scrolling through pictures of different galaxies, I spotted a blinking star in the fourth picture.
It was a new supernova. I became the youngest person ever to find one.

Since then, I've looked at over 2,500 more photos.
When I think I've found a supernova, I use MATH to plot it on a GRAPH based on its brightness. So far I haven't found a second one but I'm still looking!

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