SOCIETY OF PHYSICS STUDENTS SOCK

Science Outreach Catalyst Kit 2013

2013: Sensors, Detectors and Meters… Oh My!

A set of hand-on experiments and activities designed to address the question: How do we know…?

This manual was produced as part of the SPS Interns program. For more information about the unique experience of being an SPS Summer Intern, see

http://www.spsnational.org/programs/internships/

More information about the SPS SOCK program, including electronic versions of the manuals and materials lists from 2001 – 2013, is available here

http://www.spsnational.org/programs/socks/index.htm

For more information about the Society of Physics Students, see

www.spsnational.org

or email us at sps@aip.org or sps-programs@aip.org

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Table of Contents

The SPS SOCK and SPS Chapter Outreach 4

Welcome! from the SPS 2013 SOCK Interns 5

About Our Partner, NIST 6

Planning an Effective Outreach Event for your Chapter 7

Checking for interest in your chapter 7
Planning an outreach event 7
Next steps 8
Follow up after an event 9
Outreach is a customized activity for each chapter 9

How to use the SPS 2013 SOCK 10

What's in the SPS 2013 SOCK 11

Activities to Explore Measurements & Standards 13

Activity 1: Measurement and Units – What is the length? 14

Resources – Measurement and units –what is the length? 18

Activity 2: Explorations in time (supplemental) 19

Activities to Explore Sensors & Detectors 22

Background material for using the sensor kit 23

A Brief Introduction to Circuits 23
The Modular Sensor Device 24

Activity 3: Sensor Activity: Introducing Sensors (Beginner level) 30

Activity 4: What does a sensor sense? (Intermediate level) 32

Activity 5: Qualitative Sensor Investigation (Beginner and Intermediate) 35

Activity 6: From sensor to meter, on to calibration and prediction (Advanced level) 36

Activity 7: Quantitative Frequency Predictions (Advanced - optional) 38

Appendices: SPS 2013 SOCK Resources and Materials for Outreach 40

Appendix 1: Resources and References 41

Appendix 2: Building your own base sensor unit from scratch 42

Appendix 2: Handouts and Worksheets 45

The SPS SOCK
and
SPS Chapter Outreach

Welcome! from the SPS 2013 SOCK Interns

Congratulations!

Your SPS chapter is now the proud owner of a 2013 SOCK. This Science Outreach Catalyst Kit should serve you well in your outreach efforts; a good core if you're just starting out, and a fresh infusion of ideas otherwise. The theme of this year's SOCK centers on the ideas behind detection and measurement of physical phenomena. For the first time, SPS has partnered with the National Institute of Standards and Technology (NIST) to design and test several activities that make these topics come to life. The essential question of this SOCK is, "How do you know….about nature?" In physics class, we make many claims about what we know about the universe. Many of the things we know have come about due to advancements in sensor technology, expanding our ability to detect signals from the physical interactions that are happening all around us (and sometimes inside of us!).

Our everyday lives are saturated with sensors. Chances are that your pockets contain a suite of sensor technology that would have been unthinkable just a decade ago. In this outreach kit, we will make use of some of that technology. Measurements, units, and standards are used throughout our human experience. NIST is the go-to place for standards and references that are used in science labs, industry, and consumer commerce. Science and technology depend on having a universal language for communicating about quantities, just as they are necessary for commerce. A liter of milk must be a liter of milk in all parts of the world in order to ensure fair exchange. With this outreach kit, you can make the importance of standard units and common measurement come alive for younger students.

There is a lot going on in this SOCK! There are lots of gadgets, pieces and parts to keep up with. Your chapter should take some time to explore and think about the contents. Even with all these pieces and parts, we have barely begun to explore the possibilities of the materials we've provided you, so we're confident you can blaze new trails through these fascinating topics. We want to hear about it! Send us reports, blow-by-blows, pictures and video. How did it go? What worked? What did not go so well? Tell us so that we can make future SOCKs even better.

We, the SPS SOCK Interns and the SPS National staff, thank you for taking part in this grand experiment. You can always reach out to us at sps@aip.org. Now go and do some science! You and your participants will have a lot of fun. And maybe, just maybe, you might learn something.

Thanks all,

Caleb Heath, University of Arkansas
Nicole Quist, Brigham Young University
SPS SOCK Interns 2013

University of Maryland Physics Camp participants with Nicole and Caleb (lower right)

About Our Partner, NIST

Founded in 1901 and now part of the U.S. Department of Commerce, the National Institute of Standards and Technology (NIST) is one of the nation's oldest physical science laboratories. Congress established the agency to remove a major handicap to U.S. industrial competitiveness at the time—a second-rate measurement infrastructure that lagged behind the capabilities of England, Germany, and other economic rivals. Today, NIST measurements support the smallest of technologies—nanoscale devices so tiny that tens of thousands can fit on the end of a single human hair—to the largest and most complex of human-made creations, from earthquake-resistant skyscrapers to wide-body jetliners to global communication networks. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

http://www.nist.gov/

Did you know…[1]

- NIST scientists have earned three Nobel Prizes in the last 11 years?
- Closed-captioning for people with impaired hearing, now featured on all TV sets, was co-invented at NIST, earning it an Emmy Award in 1980?
- NIST led the development of performance standards and placement recommendations for smoke detectors, now in 94 percent of American homes and saving thousands of lives, or that half of home fire deaths occur in the 6 percent of homes with no smoke alarms?
- Many of the tools and materials used in modern dentistry—from the panoramic X-ray to composite fillings to an array of adhesives—originated at NIST through a partnership with the American Dental Association that began in 1928?
- More than 3,000 law-enforcement officers have been spared from death or disabling injury as a result of NIST-developed standards for ballistic-resistant body armor ("bullet-proof" vests)?
- NIST's Internet Time Service is used by NASDAQ members to time-stamp hundreds of billions of dollars' worth of stock trades and other financial transactions conducted every business day?
- About 2.6 billion times a day, or 30,000 times a second, NIST's Internet Time Service sets computer clocks and other networked timekeeping devices, such as those used to synchronized telecommunications systems?

[1] These and other fun facts about NIST can be found on the NIST.gov website.

Planning an Effective Outreach Event for your Chapter

The SPS SOCK is designed to be a starting point for science outreach carried out by your chapter in your community. The SPS 2013 SOCK contains the equipment and instructions for a few activities, but we also include suggestions and tips for planning a successful outreach event.

Checking for interest in your chapter

Before organizing an outreach activity, talk with your chapter to determine willingness to participate. Outreach requires a commitment of time for the events as well as preparation, but there are many benefits for students who participate! Presenting physics to younger students or even peers can be really fun! More importantly, when physics students present challenging concepts in order to educate and excite others about physics, the students learn while teaching! Taking the time to perform professional service provides immediate rewards in the "WOWs" that you get from the group, but also long lasting rewards when students can list service and leadership experiences on their resumes.

Planning an outreach event

Talk to your chapter advisor

Before contacting the schools and organizations to schedule any events, you should talk with your chapter advisor about the idea. Your advisor may have advice and access to resources that will help support your ideas. Also talk with your physics and education department faculty to see if there are already existing outreach programs at your school in which your chapter might participate. You want the support of faculty mentors in your outreach efforts!

Take out, or stay in?

In your discussions with advisors on campus, you will need to decide whether your chapter should go out into the community or to other groups on campus, or if your chapter should invite those groups to you. Both of these are meaningful ways to present sciences outreach activities, and what you do should depend on your chapter's interest, space and time.

Determine which lessons to present in outreach events

Once you have discussed the possibilities with advisors and your chapter, you are ready to plan some demonstrations and activities. What activities you present during an outreach event should be based on the budget and available materials and supplies, time and location constraints, and interest of the volunteers. Check around the department for items that you might be able to borrow if budget and supplies are an issue.

Next steps

Find willing participants!

Once you have decided to hold an outreach event, consulted with advisors, and decided on your program, it is time to find willing participants. Contact the math, science, and technology teachers in your local school districts to let them know you are interested in putting on science events for their students. Also, consider contacting local youth organizations such as Boy and Girl Scouts, 4H, and YMCA to see if they have any interest; these groups are often willing to come to you.

Get all the details

When scheduling an event, make sure to get all the specifics. When dealing with any group, on campus or in the surrounding community, you need to know:

- name of a contact person
- contact information for that person (email AND phone, address)
- anticipated number of students
- age of students
- any special requests for science topics to be covered

When taking your outreach off campus, you will need to know something about the space:

- the general layout of the space where you will present your outreach
- availability of electrical outlets and/or water/sink (if needed)
- availability of any other equipment that you might use and not want to carry (for example, extension cords, power strips, projectors, etc. – all dependent upon the particulars of the presentation)
- time constraints (allow time for participants to get settled and for a meaningful program closing/wrap-up)
- any special considerations or special needs of the participants. Try your best to address these concerns ahead of time, and if you need help, talk directly to the teacher or participant.

Ensure adequate transportation to and from the event for volunteers

Whether going in one vehicle or traveling separately, if your chapter is leaving campus it is a good idea for the outreach leader to confirm the travel arrangements with each volunteer. You should check with your advisor to make certain that you are abiding by any school policies that govern student travel, since SPS students are representing the department as outreach volunteers.

Send Reminders

It is a good to send reminders to volunteers about upcoming events. An email or text message reminder is never a bad idea. You might consider making a flyer for each outreach event or keeping an outreach calendar in the student lounge or some other common area where volunteers congregate. Also, it is a good idea to check-in with your event contact person a few days before the event to verify that everything is in order.

Practice!

Test all activities/experiments/demos at least twice! Make sure all the volunteers are familiar with the lessons and equipment. Verify that everything is ready and prepare your equipment the day before. Rehearse the order of presentation and **write it down**. Make sure all presenters have an order of events beforehand.

Be prepared!

Pack up and do a complete inventory check well before the departure time if going off campus. Be sure to take a small "repair kit" and other supplies like pens, paper, scissors, extra batteries and tape.

Follow up after an event

Make sure that every outreach event is a learning experience, not just for the participants, but for your chapter members as well. Below we list a few things that you should do ***after*** an outreach event:

- Debrief and evaluate: Do a post evaluation of your outreach event to discuss how things went and how to do better next time.
- Repair and or reset: Make an inventory of any supplies that were used up and will need to be replaced for the next event and repair any broken equipment immediately following an outreach event. Waiting until just before the next event to check the status of supplies or repair equipment is a bad idea.

Outreach is a customized activity for each chapter

The above notes are for any general outreach program for a chapter. When using the SPS SOCK, we encourage you to modify the lessons to best fit the needs of each specific outreach event that you have planned. We encourage volunteers to find personal experiences, real life examples and questions to help teach these principles. We have included example questions and real life connections that can be used as a starting place.

We hope this kit helps you to start or expand your outreach program and truly serves as a **catalyst** for the development and use of new activities.

Above all, physics should be fun, so have fun!

How to use the SPS 2013 SOCK

The SPS 2013 SOCK is intended to be used as a "starter kit" for chapters that do not have a lot of experience with outreach events, or for chapters that do have experience but are looking to have more directed, hands-on activities for groups. While the activities are intended to convey some lesson or concept about physics, the hope is that participation in the activities will be fun for both the participants and the presenters and, for both groups, stimulate interest in the study of physics.

It would be impossible to complete all of the activities in the SPS 2013 SOCK in a single outreach event. If your chapter has an ongoing relationship with a classroom or group, you might consider doing a series of activities at each meeting. For a single outreach event, you should plan for no more than 45 minutes -1 hour of activities. By reading through this manual with the SOCK contents, you will get an idea of which activities will work best for your outreach events.

Things to consider

Determining which of the SPS 2013 SOCK activities to select for your outreach event will depend on:

- Time allotted for the activity. All time estimates are ±10 minutes at best. The best way to gauge time is to run through the activity with someone who has not seen it before.
- Age group or grade level of the participants.
- The space you have available (for example, some activities work best with tables and others in open spaces).
- The science background of the class and/or preference of the teacher. Some teachers prefer activities that align with their curriculum so they may request that you cover certain topics.
- Size of the group of participants. Small groups can sometimes go more in-depth with activities, but can take longer unless you have enough volunteers to station one presenter with each small group. Presenting to a larger group sometimes goes a little faster since there is less opportunity for interaction with individuals, but you may need more transition time between activities. If you do end up having several small groups, you may need to purchase additional materials to ensure that each group has what they need.

Using time effectively

We have included estimated times for each of the activities, but the time ranges can vary significantly depending on the participants skill level and the experience of the presenters. We recommend:

- Plan for extra time for an opening and closing so that volunteers can introduce themselves and participants have time to ask questions – *about 10 minutes at the start and at the end.*
- Read through the activity carefully and do a few practice runs of the activities before the outreach event. Note: In the practice note any additional equipment or supplies that might be needed for the activity.

What's in the SPS 2013 SOCK

The SOCK, most of which is actually packed inside a large denim SOCK, should contain the following components. Please check the contents carefully and alert the SPS National Office (sps@aip.org) about any missing parts. *Small electronic components are mounted on cardboard for easy handling.*

Table 1: Contents of the SPS 2013 SOCK (Packing list)

✓	Quantity	Item	✓	Quantity	Item
	3	Modular "Theremin-like" electronic device (a.k.a. sensor base unit)		2	Sand Timer
	3	Resistor Component		30	UV beads
	3	Potentiometer Component		4	25ft rope
	3	Light Sensor Component		1	10" bungee cord
	2	Pressure Sensor Component		1	Protractor
	3	Bend Sensor Component		1	Thermometer
	2	Moisture Sensor Component		50	Pennies
	2	Temperature Sensor Component		1	Laser Pointer/UV LED
	1	Multimeter		1	SOCK Guide Book
	1	Multimeter Manual		1	Oral Syringe
	1	Set of 6 Measuring Sticks		3	Sets of Polarizers
	1	Digital Scale		3	9V Battery
	2	Nanoseconds (0.3m optic fiber)		8	Test Clip
	2	Tape Measure			

Other items that will be useful with the SPS 2013 SOCK (not included)

- Extra 9 volt batteries (the battery life will be limited – so batteries should be checked prior to each outreach)
- Large flip chart or poster board (for measurement activity)
- Extra protractors
- Stop watches or digital timers

Recommended vendors for supplies in the SPS 2013 SOCK (in case you need replacements or supplements)

Most materials in this SOCK can be acquired from local electronics supply stores, hardware stores, hobbyist stores, office-supply stores, and general retailers. However, some special materials may be difficult to find this way. We have provided below a list of online retailers that stock the materials necessary to construct or supplement an SPS 2013 SOCK. These retailers can provide a competitive price for locally available goods, and often have options for bulk orders.

- Mouser Electronics http://www.mouser.com/

A general electronics supplier capable of providing many components, including but not limited to the following: breadboards, copper-clad board ("pcb"), hook-up wire, resistors, capacitors, thermistors, photoresistors, 555 timers, speakers, test clips, battery snaps, and more.

- Harbor Freight Tools http://www.harborfreight.com/

A brick-and-mortar tool and hardware supply store. Items of interest include tape measures, rope, elastic cords, and inexpensive multimeters.

- The Fiber Optic Store http://thefiberopticstore.com/

Supplier for the fiber optic cable to make “nanoseconds”.

- EMF Safety Shop http://www.lessemf.com/

A provider of electromagnetic shielding products, including VELOSTAT® and conductive fabric and thread.

- DealeXtreme http://dx.com/

For various gadgets, including digital scales, UV LED/Laser pointers, and miniature thermometers.

Fun extras (not required, but certainly good additions)

The most advanced of the sensor activities included in this kit require some additional tools. Fortunately, most are available in the form of free or low-cost apps and software. In addition, there are many tablet and smartphone apps that allow you to directly access the sensors built into your device.

Sound Analysis Tools

For the advanced sensor activities, suitable for late middle school/high school groups, it is necessary to accurately measure the frequency of the sound generated by the sensor base unit. If you have access to an oscilloscope, you can actually measure and show the base unit’s electrical output, but a cheaper and more portable solution is a sound analysis application available on smart phones. You want to look for terms like “sound analyzer” or “frequency analyzer”. Some music tuners may also work, but others have only a limited or fixed range of frequency detection. Whatever you choose should be able to handle a large frequency range, at least up to 14000 kHz. We did not check all platforms, but for Android we had good success with an app called Spectrum Analyze.

Sensor Tools

While not necessary for any activities, sensor apps for smart phones can be useful for demonstrating the number and types of sensors located in a smartphone or tablet. These can include light intensity sensors, accelerometers, magnetic field sensors, and many others. Some even offer graphing capabilities. You should have no trouble locating such apps by searching for sensors.

Activities to Explore Measurements & Standards

Activity 1: Measurement and Units – What is the length?

Time estimate for the rope activity: 30-40 minutes (parts 1&2)

This is a great introductory activity to get students to think about how and why we measure things. It gives them an opportunity to play with non-standardized measurement tools and to realize through discovery the need for standard units of measure.

Objectives

Participants will be able to…

- Understand the development of and need for standards for measurement
- Understand the use of constants

Materials

- Set of ropes
- Set of sticks in assorted 'stick lengths' (Note that the sticks should not be shown to participants ahead of time!)
- Tape measure
- Elastic cord
- 'nanoseconds'-30cm lengths of fiber optic cord
- LED (not included, for optional part 3)

Preparation

Make sure that all the ropes in your kit are approximately (±2cm) the same length. This should be done in a location that is out of sight of the classroom participants! We have made every effort to put four equal length ropes in every SPS 2013 SOCK but please double check before presenting this to the class.

Procedure

Part 1 - Measuring discrepancies

1. Divide students into groups. Give each group a different stick. Do not hold the sticks near each other, or otherwise arrange them so that the students can easily compare lengths. That comes later.
2. Have each group measure a length of rope and record the length in 'stick lengths' to the nearest tenth. Do not give them instructions on how to make the measurements, encourage them to come up with creative ways to accurately determine the length of the rope using their stick. Examples: some students fold the stick end over end down the length of the rope, some groups stretch the entire rope as tightly as possible and slide the stick along the rope, some groups hold the stick fixed and "inch-worm" the rope along the stick, etc.
3. Ask a representative from each group to record their measurement. It is useful to have a large poster or a chalk/white board for students to record their results so that the whole class can see the results.
4. There should be a discrepancy between the groups. Discuss this with the group. And then select two groups to compare rope lengths, preferably the group with the "shortest" rope and the "longest" rope.

5. Have the students from each group stretch out the two ropes side by side for comparison.

6. Ask the students what is going on. Why are the measurements different? Eventually lead the students to consider comparing the stick lengths if they don't get there on their own.

7. Have students compare the various sticks and discuss the problem. What if everyone had a ruler of a different length? Why is it important for scientists (and others) to use rulers that all match?

Discussion Questions

- Why do we measure things?
- What is a standard?
- Would it be a problem if everybody used a different definition of *meter*?
- How do we decide how long a 'stick' should be? How did we decide what a meter should be? Who makes these decisions?
- The best standards are based on things that don't change. These are called constants. Do you know any?

Part 2 – Exploring an importance of standards

8. Now that students know standards are important, start a discussion about how standards might be determined. You might start with, "Which stick is the right stick?"

9. Display the elastic cord by stretching it overhead and ask what the students think of using this stretchy cable as a "stick". Would it make a better "stick" that the sticks they used? Discuss why or why not, and bring up the idea of having an artifact (like an actual stick) to use as a reference for measurement. You can demonstrate the downside of this by stretching the cord, explaining how even really good artifacts (like the old platinum bar that was *the meter*) can physically change. Is there anything that doesn't change that we can base standards on?

10. Eventually turn the discussion to things in nature that do not change, and **bring up the speed of light if participants do not**. This is a physical constant of nature (so far as we know!). The speed of light in vacuum does not change like the elastic cord. It is good to write it down in both metric and standard English units for bigger impact.

    - The speed of light is approximately: 3×10^8 *m/s* (300,000,000 *m/s*) or 670 THOUSAND miles per hour (670,616,629 miles per hour).
    - This well-known standard speed allows us to calculate distances if we know time. For example, it takes light from the sun over 8 minutes to travel to the Earth.

11. Explain how the length of a meter is now determined using the speed of light (although we still use rulers when need approximations!). It is the distance that light travels in 1/299,792,458 of a second. Have them try to imagine what a small fraction of a second that really is. This is an extremely small number, so it is difficult for most people to imagine, and often using orders of magnitude is the best way to get the point across.

Fun Facts – light speed, time and distance

- One three hundred millionth of a second is the time it takes light to travel about one meter.
- One common expression of distance in 'time speak' is the **light year**. Though is sounds like a unit of time, it is really a unit of distance since it is the distance traveled by light over the period of time defined by one year (365 days), or 9.4605284×10^{15} meters.
- We know that the sun is about 92,960,000 miles (149,600,000 km) away. Because the speed of light is so well defined, we know that it takes 8.3 minutes for light from the sun to reach the earth.
- The average time that it takes for an ordinary "blink of the eye" is about 0.3s or 300,000,000ns! That is 3 hundred million nanoseconds for a single blink! In this time, light travels about 90,000,000 meters!

Part 3: Connecting the speed of light with distance (optional – add 10 minutes)

In the SPS 2013 SOCK, there are 2 lengths of fiber optic cable. Each of these lengths represents the distance light travels in a nanosecond. If you shine an LED on one end and see it exiting on the other end, it is easy to imagine the beam of light traveling and imagine how fast it does so.

12. Discuss how far light travels in some fraction of a second---a nanosecond ($1\times 10^{-9}\, s$)
13. Bring out the nanoseconds and distribute them. Describe them as the distance light travels in one nanosecond. Let students explore the fibers with an LED.
14. Use the nanoseconds to measure some objects.

Nanosecond fun facts

- One nanosecond is one billionth of a second.
- 3 nanoseconds is the time that it takes light to travel one meter.
- A peregrine falcon is one of the fastest moving animals in all of nature. It can dive through the air at the astonishing rate of 322 km per hour. That is 322 thousand meters every second or about 200 miles per hour. But in the short time of one nanosecond, it travels only 0.1 micrometers. That distance is 500 times smaller than the size of an average speck of dust.

Optional Activity involving distance – for more advanced students (calculators recommended)

15. Ask the students to calculate the distance to the moon. It takes a laser 2.56 seconds to go to the moon and back.

Thinking about connection between distance and time

- How do we know how far it is to the moon? Past lunar missions left complex mirror systems on the moon. Scientists bounce laser off these mirrors to learn more about the moon, including how far away it is from the earth. *Answer: the moon is approximately 384,400 km (384,400,000 m) away.*
- You can further explore the metric distance units by putting together the two 150cm measuring tapes to make a 300cm length. You could call this "light-0.01-microsecond" in an analogy to the idea of a "light-year". This distance is the distance traveled by light in 0.01 microseconds or 0.00000001 seconds. If you put all of the 25 ft. rope sections together, the sum of their lengths is approximately 30m, or about one light-0.1 microseconds. You might try to have the group imagine how many ropes you would have to connect to have a length equal to a "light-second", or the distance traveled by light in one second. *The answer is… you would need enough rope to wrap around the earth more than seven times!*

Part 4: Further Exploration - Introducing the Metric System (optional – add 10 minutes)

The metric system is an internationally decided upon system of measurement. It is easy to use because it is connected with prefixes indicating a decimal change. Despite many students' formal unfamiliarity with the metric system, the metric system is used by everyone in the world for at least one measurement: time. The second is the standard unit for time in the metric system. Other common standard units are as follows, along with a table of commonly used prefixed. Adding a prefix to the symbols changes the magnitude by a decimal factor.

16. Discuss and explore metric lengths (see resources below)—Get students to answer the question (and show you),"About how long is one meter?" Give examples (height, lengths) of the sizes of common objects big and small in metric units.

A review of Metric Units

Table 2: Metric Unit review		
Quantity	**Unit**	**Unit Symbol**
Distance/Length	Meter	m
Time	Second	s
Mass	Kilogram	kg
Volume	Liter	l
Temperature	Kelvin or Celsius	K or °C
Electric Current	Ampere	A
Force	Newton	N
Frequency	Hertz	Hz
Electric Resistance	Ohm	Ω
Energy	Joule	J
Electric Potential	Volt	V
Power	Watt	W

Metric Prefixes

Table 3: Metric units – common prefix review				
Prefix	**Symbol**	**Factor**	**Power of ten**	**Words**
tera	T	1,000,000,000,000	10^{12}	trillion
giga	G	1,000,000,000	10^{9}	billion
mega	M	1,000,000	10^{6}	million
kilo	k	1,000	10^{3}	thousand
hecto	h	100	10^{2}	hundred
		1	10^{0}	
deci	d	0.1	10^{-1}	tenth
centi	c	0.01	10^{-2}	hundredth
milli	m	0.001	10^{-3}	thousandth
micro	μ	0.000001	10^{-6}	millionth
nano	n	0.000000001	10^{-9}	billionth
pico	p	0.000000000001	10^{-12}	trillionth

Resources – Measurement and units –what is the length?

- If possible you can show a photo of the original artifact used as the standard for a meter, housed at NIST, and found online here: http://physics.nist.gov/cuu/Units/meter.html and http://www.nist.gov/pml/div683/museum-length.cfm

Activity 2: Explorations in time (supplemental)

Time estimate for this activity: 15-20 minutes

Time is a fundamental physical quantity, and yet historically, time proved to be an elusive measurement for many scientists. Galileo managed with a pendulum clock, but now extremely accurate time measurement is essential for our increasingly technological world. Over time (pardon the pun) scientists and engineers have developed a variety of ingenious ways to measure time. In this activity, we test an “old school” time measurement device to compare with more modern and accurate time measurement techniques.

Objectives

Participants will be able to…

- explain the need for instruments to measure time accurately and precisely.
- compare the precision of different kinds of time measuring devices.
- describe the effects of certain activities on the perception of time.

Materials

- Sand timers
- Stopwatches*
- Pencils and paper*
- (optional) Water clocks – made with disposable cups and push-pins*

*not included in SPS 2013 SOCK supplies

Preparation

- If making water clocks, collect materials and do some pre-calibration of the drip timer.

Procedure

Part 1- Measuring Time

1. Divide students into groups.
2. Begin with a discussion about time. What is it? Why do we measure it, and how? What is a clock? Bring up observations of regular natural phenomena – things that happen with regularity. This should bring up ways of measuring time that do not involve a technological device. For example, the motion of the sun, moon, and stars. Can students think of other ways to mark time using “natural clocks”?
3. Pass out stopwatches and/or sand timers to the groups.
4. Start the stopwatch and quickly turn over the sand timer. Stop timing when the sand has fully emptied into the bottom bulb and record the result. The sand timers are supposed to count out two minutes. How close are they?

5. Turn over the sand timer and repeat the procedure in step 3. Does it take the same amount of time to empty the top bulb as before? You will likely have a discrepancy of several seconds depending on which end of the sand timer is being used. What might cause this?

Part 2: Our perception of time

6. Begin a discussion with the question: "Do you think you could get by without a clock?" Have students consider what life would be like if we did not mark time in some way. Why do we mark time in the first place? How does marking time help us as a society? Help students think about ways that our perception of time can be faulty. A boring class can seem to last forever, but a fun time seems over far too quickly. Yet time still passes at the same rate. Clocks of all sorts, from wristwatches to atomic clocks, aid us in keeping track of time. But how well can you keep track of time without a clock?

7. Divide participants into pairs and give each pair a stopwatch. One partner should run the stopwatch and one should be the thinker/feeler for trial 1.

8. Trial 1- How long is 30 seconds?
   Have the person with the stopwatch say "Go!" and begin timing. The other person then waits for what they think (or "feel") is 30 seconds and then says "Stop!", at which time the person with the stopwatch stops the clock. Have the thinker/feeler record his or her observations on a piece of paper (see next page) and the timer record the actual time.

9. Repeat this exercise using a one minute time. Was the perceived minute longer or shorter than a real minute?

10. If there is enough time, have the participants switch roles and repeat the trial.

11. Trial 2 – using a *counting word* for time
   Repeat steps 8-10 exactly like in Trial 1, except have the person being timed count aloud using a placeholder word of their choice (like "one Mississippi, two Mississippi').

Discussion Questions

- Was it easier to "feel" 30 seconds or 1 minute?
- Was your 30s or 1 minute more accurate when you counted?
- Why do you think it is important for us to have some better way to mark time than just "feeling" or counting?

Table 4: Data for "Feeling time"		
Trial 1: thinking about how long – without using any counting words		
	Actual time	Notes
30 seconds		
1 minute		
Trial 2: thinking about how long – using a counting word		
30 seconds		
1 minute		

Note that copies of this data table suitable for copying and passing out are in Appendix 2

Part 3: Measuring time using a physical process: the Water Clock (optional)

12. You can also compare sand timers or stopwatches with other kinds of "artifact clocks". A simple water clock, for example, can be made by using a push-pin to punch a small hole in the bottom of a disposable cup and suspending the cup above a container to catch the water. Use the stop watch to find out the time that it takes for one drop of water to drop from the cup into the container.

Things to think about: Discussion Questions

- What natural phenomenon provides the most accurate way to measure time?
- What makes the stop watch better than the sand timer?
- What is the smallest amount of time that we can measure?

Activities to Explore Sensors & Detectors

Background material for using the sensor kit

The SOCK sensor activities rely on the use of an electronic device, based on the fundamental physics of electrical circuits. For background, we include basic information on electric circuits and electronics. This material is generally covered during the first year of introductory physics, but the hope is that this background will serve as a quick reference or refresher. **Most of this information is beyond the scope of what would be presented at most outreach events. The exception might be a high school or advanced middle school classroom.**

A Brief Introduction to Circuits

- An **electrical circuit** is essentially a closed path along which electricity (in the form of free electrons) can travel. A circuit can contain several components. Examples include voltage sources (such as batteries), resistors, capacitors, and a wide variety of other electronic components.
-
- There are three essential quantities that we measure in circuits: **voltage**, **current**, and **resistance**.
- **Voltage** differences "drive" electrons to flow in a circuit. **Voltage** is measured in **volts** (V). A battery is an example of a chemical voltage source. If you imagine the electricity in a circuit in an analogy of water flowing through pipes, a voltage source would be like a pump.
- **Current** is the "flow" of electrons through an electric circuit. It is measured in **Amperes** (A). Continuing our water analogy, this would be like the actual movement of water in the pipes.
- **Resistance** describes the opposition to the current. Resistance is measured in **Ohms** (Ω). Analogous to the way friction affects the movement of objects, resistance affects the "flow" of current in an electric circuit. Materials with high resistance (like wood or plastic) are called insulators. Materials with low resistance (like most metals) are called conductors.
- There is a relationship between the quantities voltage, current and resistance called **Ohm's Law**. Ohm's Law describes the linear relationship between these quantities as Voltage = Current x Resistance, or in equation form:

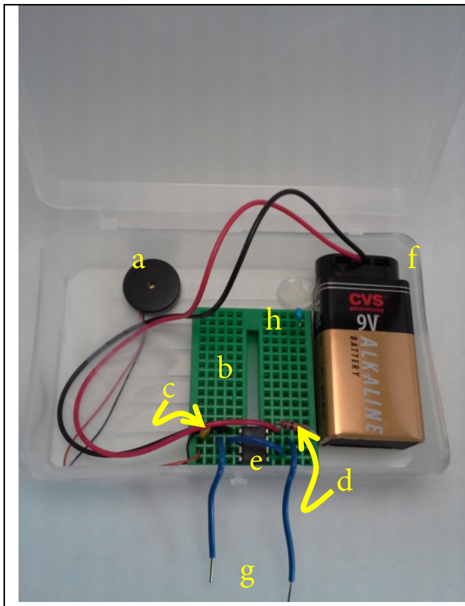
$$\mathbf{V = IR} \qquad (1)$$

The idea of resistance and its role in the physics of an electric circuit is worth discussing because the sensor portion of the SPS 2013 SOCK centers on an electronic circuit in which the overall resistance is variable, producing a varying audible output signal. Although this is a somewhat simplified version of how circuits work, the basic idea of the role of resistance is important for presenters.

The Modular Sensor Device

For the sensor investigations in the SPS 2013 SOCK, we have included three base sensor units. These "Theremin-like"[2] devices serve as the base component to which a variety of sensors can be connected (one at a time). The base unit is an electronic circuit with a speaker that produces sound (audible signal). The frequency of the sound changes with changes in the resistance in the circuit. The modular sensors provide this variable resistance. The value of the electrical resistance of each of the sensor modules changes in response to some physical phenomenon, like temperature, pressure or light intensity. When resistance is low, the circuit output is high frequency and makes a high-pitched sound. When resistance is high, the frequency and pitch are lower.

The SPS 2013 SOCK includes components that are affected by changes in visible light, bend (deformation), pressure, moisture, and temperature. We also encourage you to develop your own sensors.



a. Piezo speaker
b. Plug-in circuit board
c. Capacitor
d. Fixed value resistor , "R1"
e. 555 timer chip
f. Battery Clip with batter
g. External sensor connection terminals
h. Extra capacitor for frequency adjustments – not connected to the circuit – this is a "spare part"

Note: the device is contained in a closed box. Once the battery is installed, it is not necessary to open the box, and student participants should be advised NOT to open the box during an outreach event. Access to the interior of the box should be limited to trained personnel (presenters) and should only be necessary if changing the battery or in the case of changing out the capacitor as described in the text. If students really want to see inside of the box, presenters might want to give them a look.

Figure 1: Inside the "soap box" base sensor unit, the "Theremin-like" device.

[2] An actual Theremin is a tone-generating electronic music instrument that was patented Russian scienсts, Leon Theremin, in 1928. The instrument is built with two high frequency oscillators and two antenae. The amplified output of the oscillators produce sound that is controlled by the non-contact motion of the player's hands near the antenae, one of which controls the pitch of the sound, and the other which controls the volume.

Basic function of the device

The base sensor unit is an astable multivibrator made using a 555 timer. This is a very common circuit used whenever a time dependent output signal is desired. We do not present here the details of the function of the 555 IC or the how these type of circuits work (the references section can point you towards more complete information).

The output of the 555 circuit is a square wave, which is translated into a sound wave by the speaker. During each cycle, the output voltage increases almost instantly to a fixed value, then drops to zero, from an "on state" to an "off state". The frequency of the output is the number of these cycles that happen during one second. The frequency of the output is dependent upon the values of resistance and capacitance in the circuit.

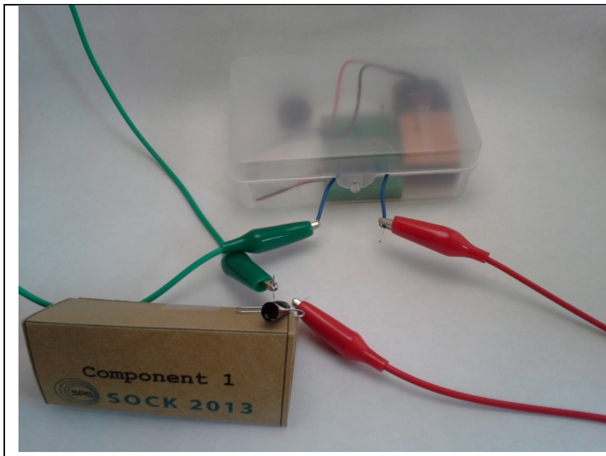


Figure 2: Component 1 connected to optical sensor using test clips

The frequency can be described mathematically in equation form:

$$f = \frac{1.4}{(R1+2*R2)*C} \quad (2)$$

where C is the capacitance of the capacitor, R1 is the value of the resistor connected on the circuit board and R2 is the resistance provided by the modular sensor component. R2 is the variable resistance that causes the variation in frequency output of the device.

The sensor base unit components

We refer to the sensor base as a "Theremin-like" device because when in use with the light sensor (photoresistor), waving your hands around the sensor (the same kinds of motions associated with an actual Theremin) results in varying tones emanating from the speaker. The sensor base unit is not actually a Theremin.

Table 5: Values of components

Component	Value
Capacitance, C *(orange component)*	0.01uF
Fixed Resistance, R1	10kΩ
Spare capacitor *(blue component)*	0.1uF

The sensor base unit is constructed simply, using off-the-shelf and inexpensive electronic circuit components. There are three in the SOCK, all ready to use once the battery is installed. In the case that something shifted during shipping or you encounter a problem, or need to rebuild or repair a base unit (or construct a new one), we provide instructions on assembling one from scratch in Appendix.

Modular Sensor Components

Each of the modular components is a resistor of some kind. Six of them are variable resistors. Five are sensor components with a resistance that depends on some physical phenomenon.

The components in the SPS 2013 SOCK have been mounted to a small piece of labeled cardboard. They are labeled with numbers because many of the activities ask students to explore the component without naming it in order to allow them to discover its purpose and/or function. The un-mounted components in the SOCK are shown in Figure 3.

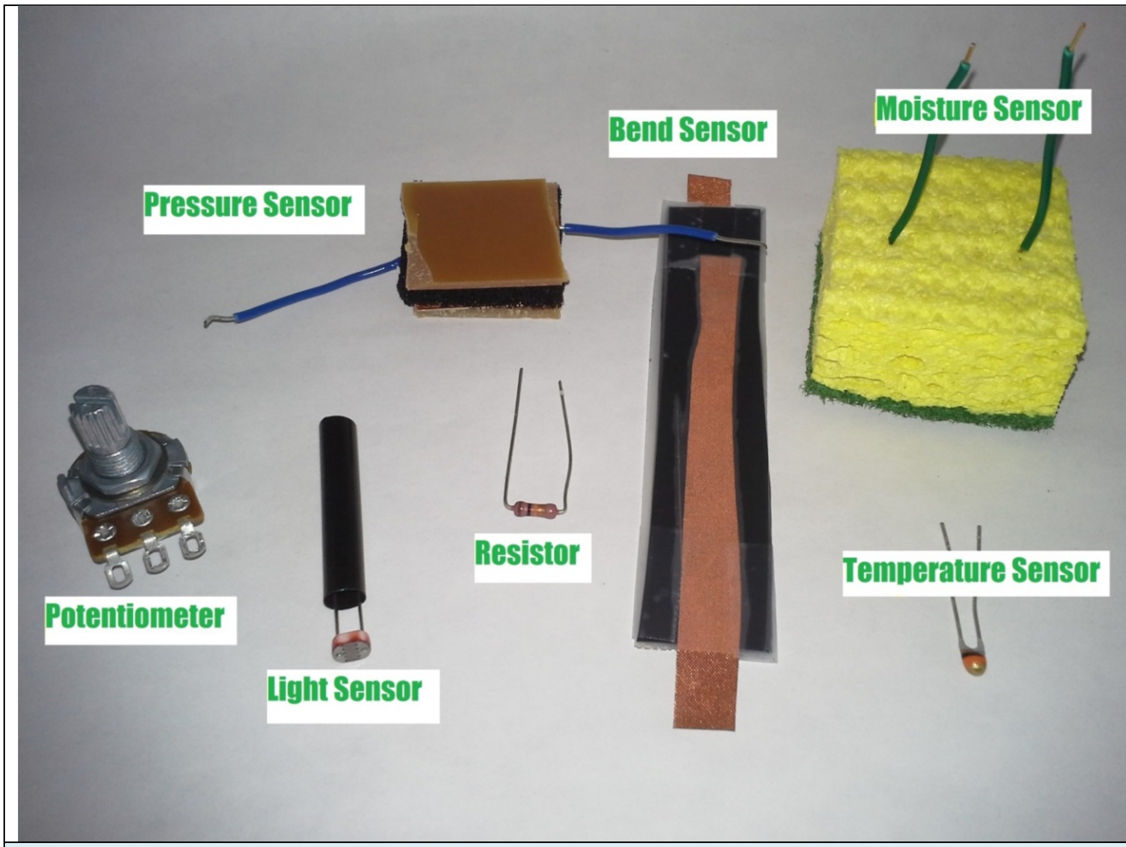


Figure 3: Sensor components to use with the base "Theremin-like" device

Note that the descriptions below are much more detailed than participants need to know for the activities!

- **Component #1 - Fixed Standard Resistor Component:** This is a fixed value 10kΩ resistor.

- **Component #2 - Potentiometer Component**: This is a 100kΩ potentiometer. The "pot" is a variable resistor. By turning the dial, the resistance value changes from an "off" position (where it is effectively disconnected) up to a max of 100kΩ. The dial is logarithmic, so you can adjust the resistance more precisely for low values than for high ones. To increase resistance, turn the dial counter-clockwise. To decrease the resistance (or turn off the connection), rotate clockwise. The potentiometer has three terminals, though we only use #2 and #3. The middle terminal is #2. If you point the middle terminal towards your chest, #1 is on the left and #3 is on the right.

- **Component #3 Light Sensor Component**: This is a CdS (cadmium sulphide) photoresistor, a light-dependent resistor. A property of this material is that its electrical conductivity increases (and thus its resistance decreases) when the intensity of light striking the surface of the material is increased. Placing the photoresistor in a small piece of black straw (as we have done) allows for better control of the amount of incident light on the diode surface.

- **Component #4 Pressure Sensor Component:** This component consists of two conductive plates of copper with a piece of conductive foam (normally used for shipping electronics) sandwiched between them. As the plates are pressed together, the distance between them decreases. This decreases the effective overall resistance. This sensor can be used to measure the pressure produced by the force of gravity and calibrated to become a scale.

- **#5 Bend Sensor Component:** This flexible component responds differently to being bent at different angles. It is actually a variation on a pressure sensor, and can be used in the same way (though it is more sensitive). It consists of two pieces of conductive fabric separated by insulating plastic. The resistance decreases the more you bend the component, as the two pieces of conductive fabric scrunch closer together.

- **#6 Temperature Sensor Component:** This component is an off-the-shelf commercially available thermistor, a resistor that varies with temperature. Though all resistors will change in resistance depending on their temperature, thermistors are designed to be especially sensitive to temperature changes. The thermistor included in the 2013 SOCK is of the NTC type, so that increased temperature results in decreased resistance.

- **#7 Moisture Sensor Component:** This component consists of a small piece of ordinary sponge with two wires inserted as electrical contacts. If ordinary tap water is slowly added to the sponge, the effective resistance is lowered since tap water is a conductor. Salt water is an even better conductor, while pure water (without salts or other dissolved components) is actually an insulator.

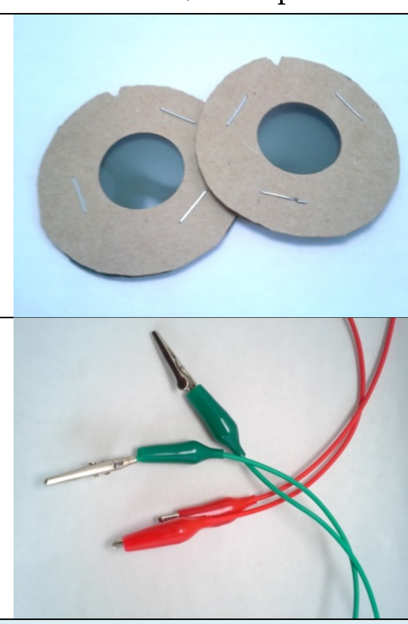


Figure 4: Pair of linear polarizers (top) and test clips (bottom)

Accessories for investigating the sensor functions

The SPS 2013 SOCK also comes with several tools used for investigating the function of the sensors.

- **Test Clips:** These are standard laboratory equipment, insulated wires with conductive clips on each end. They allow easy attachment of the various components to the base device input terminals and the multimeter.

- **Linear polarizer:** This is an accessory for the light sensor, and consists of a cardboard circle that holds a piece of polarized film. Together, the pair of polarizers allows you to control the light intensity. When one polarizer is directly on top of the other and the axes of the two films are aligned, a maximum amount of light passes through. If you rotate one of the polarizers with respect to the other so that the angle between the axes is increased, the intensity of the light transmitted decreases. At 90 degrees, the polarizer pair is almost impenetrable to light. This phenomenon is described with an equation known as Malus' law:

$$I = I_0 * cos^2\theta \quad (3)$$

where I is the intensity of the light transmitted, I_0 is the intensity of the light that first enters the polarizer and θ is the relative angle of the polarizer transmission axes.

- **UV LED/Laser Pointer:** This small flashlight-like device includes several different light sources. Use it to see what effect different kinds of light have the light sensor. The UV LED can also be used on the color changing beads, or to highlight the security strips on currency.

- **Pennies (50):** These coins can be used as standardized masses for the pressure sensors, as long as you note the year of each penny—the mass changed in 1982. See Table 6 for reference. Masses should be confirmed on the digital scale.

Table 6: Mass of pennies for calibration of the pressure sensor module

Year	Mass
Minted prior to 1982	• 3.1 – 3.2 g
Post 1982	• 2.5 g

- **Protractor:** This device measures the angles between two objects. It is used with both the polarizers and the bend sensors.

- **Oral Syringe or pipette:** This device is used with the moisture sensor. The volume markings on the side allow you to precisely control how much fluid is dispensed.

- **Thermometer/Compass:** This can provide the current temperature, and is thus most useful when used with the temperature sensor. It also includes a compass, which can detect the earth's magnetic field (bonus detector!)

Using a Digital Multimeter (DMM)

Some of the activities in the SOCK require the use of a multimeter, particularly when using the SOCK with more advanced students. This instrument provides several types of information about a circuit and its electrical components. We have provided one multimeter in each SOCK, though we encourage you to acquire more if possible. The instruction sheet for the multimeter is supplied with the SOCK. We encourage you to read this thoroughly before using the multimeter. For immediate reference, we provide some information in this section.

- The body of the multimeter contains an on/off switch, a digital readout, a selector dial, and three sockets for the probes.
- The two probes, red and black, connect to the multimeter by the socketed ends. The black probe should be plugged into the lowest of the three sockets, labeled COM.

- The red probe should be plugged into the middle socket. (The top socket is used for measuring high currents, and is unlikely to be needed for any SOCK activity. Consult the multimeter manual for further information.)

Figure 5: Digital multimeter included in the SPS 2013 SOCK

Measurements are made by connecting the metal probe tips to appropriate parts of an electrical component or the circuit. You can either touch the tips to the component in question, or you can connect the tips and components by using test clips. We recommend using the test clips when working with younger students, as it makes a better connection.

How to Measure Resistance

The quantity measured in the SPS 2013 SOCK is resistance. The DMM provided has several ranges for making this measurement, but does not autorange. **Measurements should be made when the component in question is not currently part of an active circuit. Disconnect the circuit before measuring.**

1. Turn on the multimeter.
2. Find the resistance settings, which are in the lower left corner of the dial, surrounded by a green border. It should also contain the symbol for ohms (Ω).
3. Turn the dial to the 200 Ohm setting.
4. Test the multimeter by touching the metal tips of the red and black probes together. The readout should show a value of 0 or very close to 0. (This means there is no resistance.) If this does not occur, your multimeter may be damaged. If you are not able to find a replacement in your department, contact SPS at sps@aip.org.
5. Connect a component to the two probes. If the display reads 1 on the far left, then the component has a resistance value greater than the range selected. If so, turn the dial clockwise to the next setting. Repeat until you have an accurate reading.

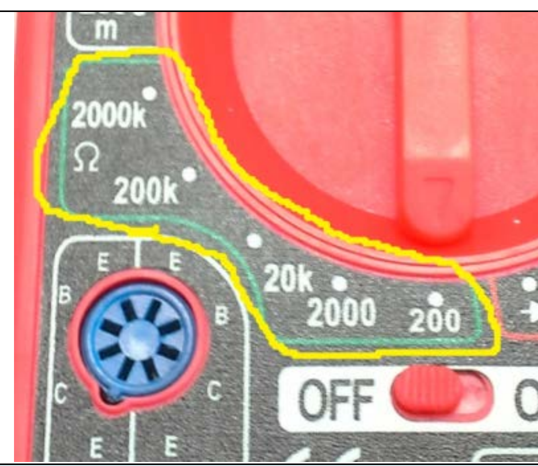


Figure 6: close up of Ohm meter ranges on the DMM. Dial is shown on the 200 Ohm setting.

Here's how to interpret your results: If the setting you've selected does not have a "k" (200 or 2000), the number on the readout is the value of the resistance in ohms. If the setting does have a k, the value on the display is in kilo-ohms. To get the value in ohms, just multiply by 1000. Once you are in the correct range (either ohms or kilo-ohms), changing the setting will change the accuracy of the measurement. That is, it will change how much it is rounded. Going up to the next setting if you already have an accurate reading will give you a less exact value.

Activity 3: Sensor Activity: Introducing Sensors (Beginner level)

Time estimate for this activity: 25-30 minutes

We begin our investigation of sensors by demonstrating one in action. By use of either hands-on or audience-guided (demonstrator-implemented) experimentation, participants will learn about the possibilities of measurement. This activity can be done alone with beginner level students or as an introductory exercise for more advanced students.

Objectives

After successful completion of this sensor activity, participants will be able to…

- Explain the concept of a sensor
- Identify a component and the phenomena to which it is sensitive.

Materials

- Sensor base unit ("Theremin-like" device)
- Light sensor component (Component # 3), one for each base unit
- Pens and paper*

**not included in the SPS 2013 SOCK*

Preparation

Decide whether to do a more demonstration-style presentation or more hands-on activity. If doing hands-on, the group will need to be divided into smaller groups, each of which can gather around a single base sensor unit. The SPS 2013 SOCK contains units. Batteries must be installed on the base sensor units before use.

Procedure

1. Open with a general discussion about sensors. Start by talking about how we have five senses. Discuss the information that we can detect using our sensors. The properly functional human body is equipped with two chemical sensors (tongue and nose), visible radiation sensor (eyes), infrared radiation sensor (skin), pressure sensor (ears), and another pressure sensor (skin). How do we know so much about our universe when we are limited to only these senses? *We use our understanding of nature to construct sensors that expand our ability to collect information beyond our five senses.*

Discussion Questions

- What is a sensor?
- What are some examples of sensors?
- Why do we need sensors?
- Does the human body have any sensors?

2. Bring out a base unit connected to the photo-resistor (Component #3). Briefly demonstrate that by moving your hands over and around the device, you can manipulate the sound produced by the device.

   Take care not to give away what is going on too soon! Invite speculation and exploration before telling participants what you know and understand about their observations…

3. At this point, you can either take requests from the audience for specific actions with which to test the device, or you can put the device into the hands of the participants. Three sets of base units with light sensors are supplied in the SPS 2013 SOCK. **Instruct participants to NOT open the sensor base unit box.**

4. The next challenge for the participants is to figure out what kind of sensor is attached to the base unit and exactly what is causing the variation in the tone. Give sufficient time for experimentation, and then ask that participants disconnect the components. Ask for hypothesizes from the participants.

5. Some answers we have encountered include: motion sensor, light sensor, body heat sensor, air flow sensor. You will probably hear these answers, and likely others too. Ask the participants why they think their answer is correct. How could they test their idea?

6. Reconnect the components and test the ideas. One way to quickly show that the component is a light sensor is to turn off the lights. There should be a noticeable difference in tone.

Discussion Questions

- Can your brain actually "see" things?
- What makes a sensor a "good" sensor? What characteristics should a good sensor have?
- Based on your observations, can you make some assumptions about the form of the output signal that the sensor making?

Activity 4: What does a sensor sense? (Intermediate level)

Note: for young students skip this activity and go to the following qualitative activity (Activity 5)

Time estimate: 30-35 minutes

Now that participants have had some experience with sensors, they know that the sound made by the device can be affected by many different things. But how and why do the component sensors change the sound? Here we begin to investigate the principles behind the circuit that is the sensor base unit, and electronics in general.

Objectives

After successful completion of this sensor activity, participants will be able to…

- Explain the concept of electrical resistance.
- Identify resistors (including potentiometers) and explain their function.
- Use a multimeter to measure resistance.
- Show that a light sensor is a variable resistor.

Materials

- Sensor base unit ("Theremin-like" device)
- Light sensor component (Component # 3), one for each base unit
- Resistor component (Component #1), one for each base unit
- Potentiometer component (Component #2), one for each base unit
- Multimeter – the SPS 2013 SOCK is supplied with a single DMM, but if possible, securing extra meters is a great idea.

Preparation

This activity involves using a digital multimeter. If you cannot find extras, we recommend doing the measurement as a demonstration activity.

Procedure

1. Distribute sensor base units and resistor components to each group.
2. Start by having participants connect the light sensor module (Component #3) to the base unit and explore how to change the audible signal. They may already know that changing the intensity of light incident upon the sensor changes the sound. Try to get a consensus on the effect, i.e., more light means…… (higher pitch or lower pitch). Write the consensus on a white/chalkboard.
3. Next, have participants connect the standard resistor (Component #2) to the sensor terminals on the base unit. Now ask them to explore. What do they note about the sound? Can they interact with the sensor in such a way to increase or decrease the audible signal? Why or why not? Ask participants if they recognize the device (the resistor component). Discuss whether or not this is a sensor. If so, what might it sense?
4. Ask participants to disconnect their components. Bring out the multimeter and ask if the participants recognize this device. You can use this as an opportunity to query your participants' knowledge of electricity

(refer to “A Brief Introduction to Electronics”). If they don't know what voltage, current, and resistance are, hold off on the explanations for now.

5. Demonstrate how to measure resistance with the multimeter, including how to test whether the multimeter is functioning correctly. Don't actually test a component yet. Let the participants make the discoveries!

Depending on how many multimeters you have, you can either demonstrate or allow participants to conduct the following investigation:

6. Ask them to measure the resistance of Component #1 (the standard resistor) Ask participants again what they observed when they used the resistor component as a sensor. Now have the participants determine the resistance of the resistor component using the multimeter. REMEMBER: Only measure resistance on completely disconnected components! If a current is flowing through the component while you measure its resistance, you will at best get a wrong reading, and at worst damage the multimeter.

   NOTE: Make sure that the participants have connected the multimeter to terminals 2 and 3; otherwise they will neither see a change in resistance nor hear a change in sound. You can also allow participants to try connecting to other combinations of terminals to see what happens. They will see a fixed resistance value if use terminals 1 and 3.

7. Have them share their results. Is this measurement fixed, or can they change it (by touching it, covering it, etc.)? (It should be very close to 10kΩ.) This is a good time to talk about the concept of resistance if you haven’t already.
8. Ask the participants to connect the potentiometer component (Component #2) to the base unit. Have them manipulate the dial and take note of the results. What happens to the tone produced when the dial is turned clockwise? Counter clockwise?
9. Ask them to predict what will happen if they disconnect the potentiometer component and measure its resistance. Then have the students try it. What happens to the resistance readings when you turn the dial clockwise or counter-clockwise? Is there a relationship between the value of resistance shown and the characteristics of the sound produced? Go back to the place where you recorded your observations about the light sensor, and record these new observations about the potentiometer, relating the clockwise/counter-clockwise rotations of the dial with the change in resistance (increase or decrease).

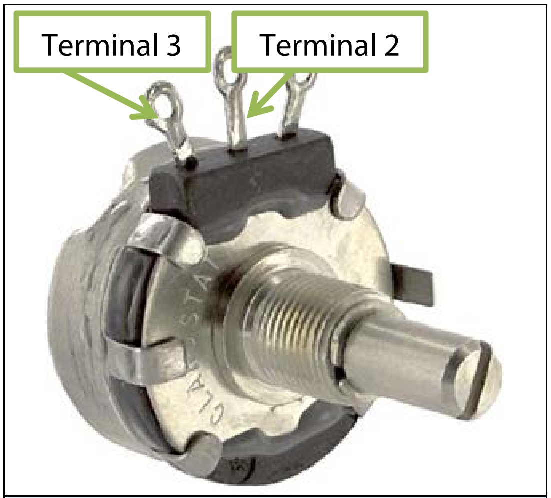


Figure 7: Potentiometer (variable resistor) with terminals 2 an 3 labeled

10. Now, ask the participants what they might expect to see if they measure the resistance of the light sensor component, based on their observations using the two different kinds of resistors. Do they predict that the resistance of the light sensor will change or stay the same? And how will they interact with the light sensor to cause an increase or decrease in the measured resistance?
11. The participants should now measure the resistance of the light sensor. Make the measurements after the sensor is disconnected. Ask them to observe the resistance as they move their hands to change the light

incident on the sensor and describe what they observe. Is the resistance value staying the same, or is it changing? What causes resistance to increase? To decrease? What can they conclude about resistance and sensors? Challenge the group to find some way to control the value that they see (possible only if the light intensity is kept constant!).

Discussion Questions

- Based on your observations – what is causing the change in the audible signal produced by the base unit?
- What is the difference between the three components examined? Which two components are the most similar? *Get to the idea that the photo diode and the potentiometer both have varying resistance values*
- What is the basic idea behind a sensor? *Get to the idea that there must be some changing quantity that can be transformed into some kind of detectable signal*

Activity 5: Qualitative Sensor Investigation (Beginner and Intermediate)

Time Estimate: 40-45 minutes

In the previous activities, participants gained some hands-on experience with sensors. They learned about resistance and how to measure it, and learned that this property is essential to the operation of the light sensor component. Here, they begin to explore other types of sensors and are asked to make broad observations. Which sensors are most sensitive? What causes their resistance to increase or decrease?

Objectives

After successful completion of the qualitative sensor investigation, participants will be able to. . .

- Make qualitative predictions about the output of the base sensor unit based on sensor input.
- Show that various sensors differ in their range of resistance and response to a variety of physical phenomena.

Materials

- Sensor Base Unit ("Theremin-like" device)
- Various sensor component modules
- Testing accessories
- Multimeter – the SPS 2013 SOCK is supplied with a single DMM, but if possible, securing extra meters is a great idea.

Procedures

Note: Beginners can do this activity and have lots of fun without doing the quantitative measurements using the DMM. For beginners, focus on the question "What does the sensor sense"?

1. Distribute the base sensor units, sensors component modules, testing accessories, and multimeters if you have not done so already. We recommend giving each group a single different sensor module (one group has pressure, another bend, etc.).
2. In previous activities, participants have worked with light sensors, resistors, and multimeters, but now they have several new components. Before attaching the new components, have the participants investigate each one. What might it be? Some may be obvious (the moisture sensor is a sponge), but others may be inscrutable (the temperature sensor).
3. Once the purpose for each sensor has been determined, have the participants begin testing them with multimeters. Does each sensor seem to have a default value? A maximum or minimum? What causes the resistance value of each sensor to reach its maximum or minimum? How large is this range? How does it compare to the range of the potentiometer?
4. After participants have some idea of their sensor's behaviors (increased light intensity decreases the resistance value of the light sensor, for example), ask them to predict what this might mean for device output. Will increased resistance mean increased pitch, or decreased pitch? The participants may already have observations from the previous activity to draw on.
5. Test the predictions for each sensor component and share the results.

Activity 6: From sensor to meter, on to calibration and prediction (Advanced level)

Estimated time: 1 hour

In this activity, participants will use all of their previous experience with sensors to create a scale that shows the correlation between sensor input and resistance. Then they will apply these inputs to the sensors, and see how well the device output matches their predictions.

Objectives

After successful completion of the sensor to meter activity, participants will be able to. . .

- Make a scale of resistance values corresponding to sensor input
- Make qualitative predictions about device output based on sensor input

Materials

- Sensor Base Unit ("Theremin-like" device)
- Light sensor component (Component # 3), one for each base unit
- Pair of linear polarizers, one pair for each group
- Protractor
- Multimeter – the SPS 2013 SOCK is supplied with a single DMM, but if possible, securing extra meters is a great idea.
- Graph paper*
- Pencils or pens*
- Rulers*

*Not included in the 2013 SPS SOCK

Procedures

1. Begin with a discussion about the usefulness of the sensor components they have explored so far. What kind of information do they provide? How sensitive are they? What would we need to do to make them more useful? How could we regulate sensor input? And how do we interpret the meaning of the sensor output?
2. Distribute sensor base units, light sensor, polarizers, and multimeters and protractors.
3. Ask the participants to experiment with rotating the two polarizers, looking through the polarizers at some light source. What happens when they start with the axes lined up, and then rotate one polarizer slowly? What can they measure with these? *Note: on the polarizers contained in the SPS 2013 SOCK, the transmission axes are noted with a line drawn on the cardboard mount. The ring may or may not have a notch.*
4. Now that the participants have a way to measure the light input into the light sensor (they can use the relative angle between the two polarizers if the polarizers are held directly over the light sensor) and output (the resistance value measured with the multimeter while the polarizers are in place), they can make a table that relates angle to resistance.
5. Hook up the light sensor component to the multimeter.

6. Hold the polarizers at 0 degrees relative to each other (with the lines marking transmission axis aligned), and then cover the tube of the light sensor component with the polarizers. Record the resistance measurement and the angle in a table.

7. Continue taking resistance measurements at increments of 15 degrees, until the polarizers are held 90 degrees relative to each other. Very little light should reach the sensor in this configuration.

8. Ask participants to compare their tables. Did they get similar results? Why or why not? What would you have to do to get more accurate or repeatable results?

9. Next, you can graph the results. Every group can do this, or you can take the data from a single group and put it on a blackboard. Using a spreadsheet program connected to a projector is also a good alternative.

10. Discuss the graphs. What kind of relationship is there between angle and resistance? Is it linear, or exponential? If you connect the light sensor to the base unit, what impact do you expect the polarizer angle will have on the frequency of the sound produced?

11. Connect the light sensor to the base unit and test these predictions.

12. (Optional) Repeat these quantitative investigations with other sensor components and testing accessories.

We suggest the following inputs and tests for each sensor:

- Pressure Sensor-Place objects of standard mass in increments on the sensor. Coins and washers work well. You can do this with the bend sensor as well if you lay it out flat (since it is just a variation of a pressure sensor). We recommend adding pennies in a stack one at a time.
- Bend Sensor-Hold the sensor horizontal (0 degrees) and bend it at 30 degree increments through 180 degrees (completely folded).
- Moisture Sensor-Wet the sponge with an oral syringe, adding 1mL of water each time. You could also try different fluids, such as comparing sponges soaked in tap water, distilled water, and various concentrations of salt water.
- Temperature Sensor-We don’t recommend using this sensor with this activity, both because the sensor is somewhat slow to register change and also because it is difficult to create a range of precisely controlled temperatures for sensor input.

Activity 7: Quantitative Frequency Predictions (Advanced - optional)

Estimated time: 1 hour

In this final activity, participants will be able to directly link sensor input and device output. They'll use existing data to predict the exact frequency of sound produced by the sensor device for a given sensor input, and learn that there is a method underneath it all.

Objectives

After successful complete of this quantitative experiment, participants will be able to. . .

- Determine the frequency that will be produced by the device for a given resistance (R2) by consulting data tables and graphs of resistance-frequency relations.
- Predict and test the frequency of the sound produced for a given resistance.

Materials

- Sensor base unit ("Theremin-like" device)
- Standard resistor component (labeled Component #1)
- Potentiometer component (labeled Component #3)
- Multimeter – the SPS 2013 SOCK is supplied with a single DMM, but if possible, securing extra meters is a great idea.
- A smart-phone app (multiple if possible) or some other means of measuring the frequency of the output device*
- Testing accessories
- Frequency – resistance data tables and graphing handouts (make copies from the ones in the Appendix)
- Graph paper*
- Pencils or pens*
- Rulers*
- For reference, the results of Activity 6*

*Not included in the SPS 2013 SOCK

Procedures

13. By now, participants should have investigated several sensors and have a good idea of how they respond to various stimuli. They should have investigated resistance values for a range of sensor inputs. Start a discussion about what they would need to make fully complete measurements, that is, what is necessary for the device to function as a detector. After you measure sensor input and sensor resistance, what needs to be measured? What makes a sensor a detector?
14. Pass out the sensor base units, components, testing accessories, multimeters, and data hand-outs. Ask the participants to follow along with you on the reference data handouts. Together, you're going to find out what frequency the resistor component should produce.
15. Guide participants through looking at the tables and looking at the graphs. Compare the values you can get from each. Which is easier to use? Why would you use tables instead of graphs, or vice versa?

16. The resistance of the resistor component is 10kΩ, so it should produce a frequency of about 4667Hz from the base unit. (Using Capacitor#1)
17. Now connect the resistor component to the base unit and use a frequency analyzer to measure the frequency of the sound produced. You may have to bring your microphone close to the speaker (there is a hole punched on the side of the box where the speaker is located) to get an accurate reading. If several units are operating at the same time, make sure they are spaced well apart so they don't interfere with each other.
18. Disconnect the resistor component and discuss the results of the frequency analysis. Is it exactly what you would predict from the reference data? Why or why not?
19. You can start using the potentiometer component next. Set a desired resistance by turning the dial, and confirm it with the multimeter. Compare this value to the reference data and determine the frequency it should produce. Disconnect the potentiometer from the multimeter, connect it to the base unit, and test the frequency produced. Does the reference data still do a good job of predicting frequency?
20. Try doing the reverse as well. Connect the potentiometer to the base unit, take a frequency measurement, and then look up what resistance value the frequency corresponds too. Disconnect the potentiometer and test your prediction with a multimeter.
21. Ask the participants to look up the resistance values from their tables on the resistance-frequency data handouts (these are in the Appendix; you may want to make a few copies for students to share). Which sensor inputs correspond to which sound frequencies?
22. Connect the appropriate sensors to the base unit and take note of the frequencies produced by various inputs. Do these values match your predictions? Why or why not?

Appendices: SPS 2013 SOCK Resources and Materials for Outreach

Appendix 1: Resources and References

The NIST Reference on Constants, Units, and Uncertainty

http://physics.nist.gov/cuu/index.html
To quote the site itself: "This site addresses three topics: fundamental physical constants, the International System of Units (SI), which is the modern metric system, and expressing the uncertainty of measurement results."

Sensors: A guide to the proper use and appreciation of sensors

http://www.ladyada.net/learn/sensors/index.html
Discusses the use of several electronic sensors, including light sensitive resistors (LSRs) and photocells.

Introduction to the 555 Timer IC (by Steve Schuler)

http://www.science20.com/square_root_not/blog/introduction_555_timer_ic-106258
This introduction to 555 Timer circuits provides the plans for an optical Theremin, which served as the starting point for our base sensor unit and its related activities.

LM555 and LM556 Timer Circuits

http://home.cogeco.ca/~rpaisley4/LM555.html#3
This site provides great detail on the operation of various 555 timer circuits, as well as various calculators.

DIY Force Sensitive Resistor (FSR)

http://www.instructables.com/id/DIY-Force-Sensitive-Resistor-FSR/?ALLSTEPS
This guide provides instructions for the creation of the force/pressure sensor components included in the SOCK.

Stickytape Sensors

http://www.instructables.com/id/Stickytape-Sensors/?ALLSTEPS
This guide provides instructions for the creation of the bend sensor components included in the SOCK.

Museum of Science and History: Feel a Minute

http://www.msichicago.org/scrapbook/scrapbook_exhibits/time/educ_pages/act_feelaminute.html
This lesson served as the basis for the Feeling Time activity.

Appendix 2: Building your own base sensor unit from scratch

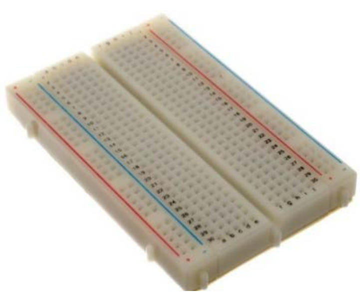
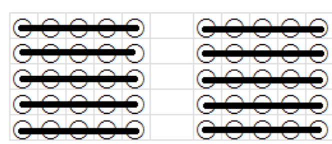
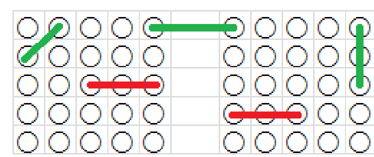
Putting together the base sensor unit ("Theremin-like" device)

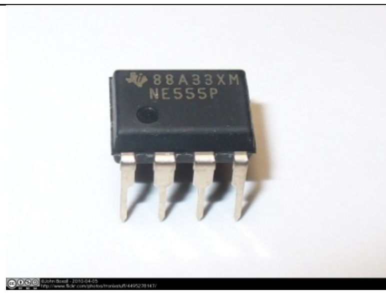
The base sensor units supplied with the SPS 2013 SOCK require very little for assembly; the parts just plug into the breadboard. If you have purchased components to build a new one, you may need the following tools:

- Wire snips and strippers (for preparing wires and trimming pins)
- Thin pliers (recommended, for inserting components and carefully bending pins)

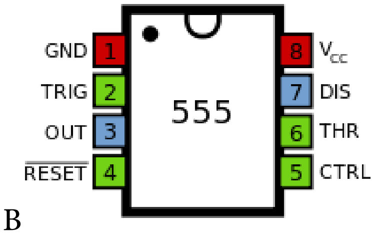
The breadboard assembly diagram below contains the suggested arrangement of components. This is not the only arrangement possible. The important thing is that each component is inserted into the appropriate horizontal row of five slots. Any slot of those five will do just as well as another. You can insert components in any order, but do not connect the battery until all other components are in place. You can preserve battery life by disconnecting the positive terminal from the bread board until needed.

You might also want to trim the metal pins of the capacitors and resistor to about half their original lengths so that they will sit closer to the surface of the breadboard. This makes them less likely to be snagged or accidently pulled out. Crimp or lightly sand the cut ends to reduce jaggedness if you do this. (The preassembled base units shipped with the SPS 2013 SOCK have already been trimmed.)

Table 7: Components and notes for assembly of the base for the modular sensor device
 A  The five ports in each row are connected. Notice the gap in the middle. B  Examples of good (green) and bad (red) connections. C
Using the solderless breadboard A. The breadboard provides the base for the building the device. The breadboards provided are *solderless;* wires and electrical components are not permanently attached to the breadboard, but can be simply pushed in or pulled out to connect or disconnect. Thin pliers can be helpful for inserting components, though these are not necessary. B. The breadboard provides points of electrical contact for the components inserted into it. As shown in (B), each row of five slots forms a line that connects all the components inserted into that slot, as if each were wired together. A gap in the middle separates these rows of five. C. If both terminals of a component are inserted into the same row of five, that component will be *shorted*; it will be effectively connected to itself. This can cause damage and should be avoided.



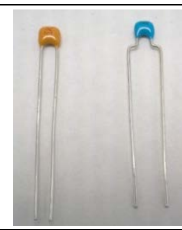
A



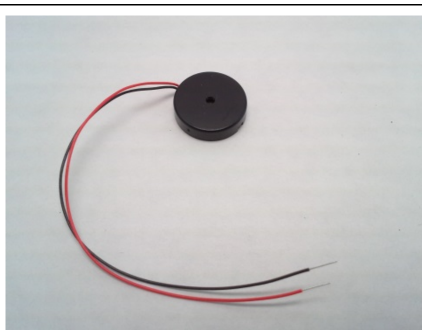
B

The 555 Timer IC: This is an integrated circuit with a variety of properties. Each of the eight legs has a different function, and only six are used for the Theremin. The top of the timer is indicated by a small notch.

10kΩ Resistor: This is a fixed value resistor, referred to as “R1”.



0.01uF (orange) and 0.1uF (blue) Capacitors: A capacitor temporarily stores energy when a circuit is operational, and also discharges that energy. The capacitance of the circuit affects the frequency of the sound produced (as does changing the resistance). Two capacitors are included. Only one is connected in the circuit. We recommend switching out the capacitors to observe different behavior in the circuit. All other things equal, a lower capacitance will produce a higher frequency sound.



Piezoelectric Speaker: The speaker is a *transducer*; it converts energy carrying a signal into another type of energy with the same signal. In this case, it turns an electrical signal into an audio signal. The decibel volume of the piezoelectric speaker depends on the frequency of the sound it produces, i.e., it does not produce a uniform intensity over all frequency ranges. This is not a simple linear relationship, and has to do instead with the speaker’s construction. Certain frequencies resonate in the speaker, producing a louder than normal volume.

9V Battery Snap: This connects to the terminals of a 9V battery and provides power to the circuit. The battery snap is direction sensitive, the black wire connects to ground (leg #1 of the 555) and the red wire connects to the voltage input (leg #8 of the 555).

Table 8: Breadboard Assembly diagram (unused rows not shown here)

				↑Unused rows ↑						
Spk	Cap		9V	1		8	9V			Res
Cap		S1	Wire	2		7	S2			Res
Spk				3		6	Wire			
				4		5				

Table 9: Key and notes for each component (color coded to the above diagram)

555 timer	Legs #4 and #5 are not used in the device. Nothing should be connected to them.
9V Snap	This is the battery snap. Red corresponds to the positive terminal, and the red wire must go in the same row as leg #8. The black is ground, and goes next to leg #1.
Wire	This is just a length of wire that connects legs #2 and #6.
Sensor 1 & 2	Insert a small piece of wire into each slot, and then attach a test clip to each wire. You now have two clips that you can connect to a modular component to complete the circuit.
Speaker	Insert the red wire into the same row as leg #3. The black wire goes to ground, the same row as leg #1.
Capacitor	Insert the two legs of the capacitor into the breadboard. There is no order. (Note: this is not the case with all capacitors, but with ours it will be fine.)
Resistor	Insert the two legs of the resistor into the breadboard.

Appendix 2: Handouts and Worksheets

Reference Data Tables for Sensor Resistance (R2) and Output Frequency

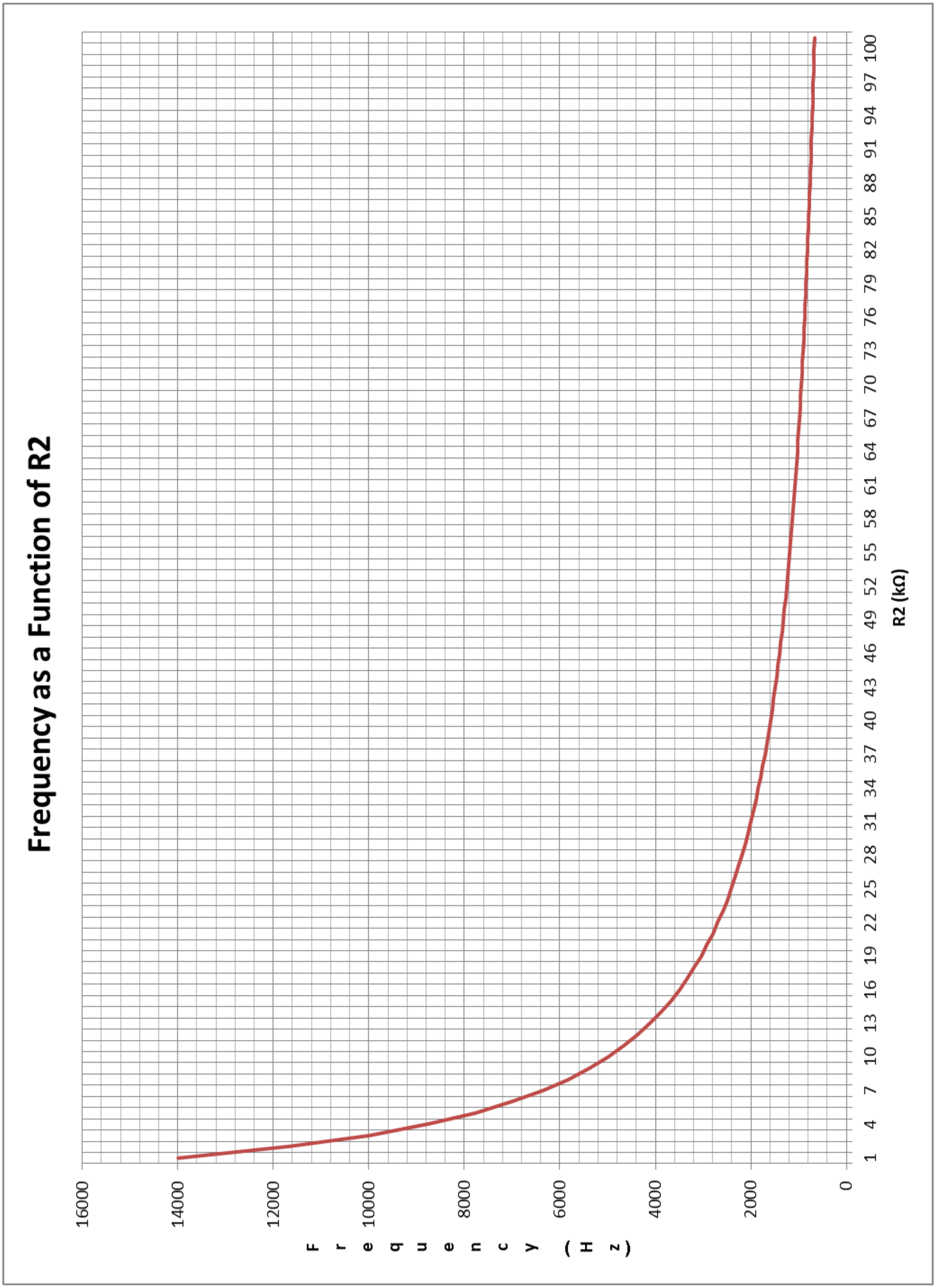
Note: Multiple tables with various ranges are presented for user convenience. These tables are intended for quick reference. Use these tables to find the frequency produce as a function of resistance, R2, or vice versa.

R2 Range 0-1 kΩ	
R2 (kΩ)	Freq(Hz)
0	14000
0.1	13725
0.2	13462
0.3	13208
0.4	12963
0.5	12727
0.6	12500
0.7	12281
0.8	12069
0.9	11864
1	11667

R2 Range 0-100 kΩ							
R2 (kΩ)	Freq (Hz)	R2 (kΩ)	Freq (Hz)	R2 (kΩ)	Freq (Hz)	R2 (kΩ)	Freq (Hz)
0	14000	31	1944	62	1045	93	714
1	11667	32	1892	63	1029	94	707
2	10000	33	1842	64	1014	95	700
3	8750	34	1795	65	1000	96	693
4	7778	35	1750	66	986	97	686
5	7000	36	1707	67	972	98	680
6	6364	37	1667	68	959	99	673
7	5833	38	1628	69	946	100	667
8	5385	39	1591	70	933	`	
9	5000	40	1556	71	921		
10	4667	41	1522	72	909		
11	4375	42	1489	73	897		
12	4118	43	1458	74	886		
13	3889	44	1429	75	875		
14	3684	45	1400	76	864		
15	3500	46	1373	77	854		
16	3333	47	1346	78	843		
17	3182	48	1321	79	833		
18	3043	49	1296	80	824		
19	2917	50	1273	81	814		
20	2800	51	1250	82	805		
21	2692	52	1228	83	795		
22	2593	53	1207	84	787		
23	2500	54	1186	85	778		
24	2414	55	1167	86	769		
25	2333	56	1148	87	761		
26	2258	57	1129	88	753		
27	2188	58	1111	89	745		
28	2121	59	1094	90	737		
29	2059	60	1077	91	729		
30	2000	61	1061	92	722		

R2 Range 0-1000 kΩ					
R2 (kΩ)	Freq (Hz)	R2 (kΩ)	Freq (Hz)	R2 (kΩ)	Freq (Hz)
0	14000	380	182	760	92
10	4667	390	177	770	90
20	2800	400	173	780	89
30	2000	410	169	790	88
40	1556	420	165	800	87
50	1273	430	161	810	86
60	1077	440	157	820	85
70	933	450	154	830	84
80	824	460	151	840	83
90	737	470	147	850	82
100	667	480	144	860	81
110	609	490	141	760	92
120	560	500	139	770	90
130	519	510	136	780	89
140	483	520	133	790	88
150	452	530	131	800	87
160	424	540	128	810	86
170	400	550	126	820	85
180	378	560	124	830	84
190	359	570	122	840	83
200	341	580	120	850	82
210	326	590	118	860	81
220	311	600	116	870	80
230	298	610	114	880	79
240	286	620	112	890	78
250	275	630	110	900	77
260	264	640	109	910	77
270	255	650	107	920	76
280	246	660	105	930	75
290	237	670	104	940	74
300	230	680	102	950	73
310	222	690	101	960	73
320	215	700	99	970	72
330	209	710	98	980	71
340	203	720	97	990	70
350	197	730	95	1000	70
360	192	740	94		
370	187	750	93		

R2 Range 0-2000 kΩ					
R2 (kΩ)	Freq (Hz)	R2 (kΩ)	Freq (Hz)	R2 (kΩ)	Freq (Hz)
0	14000	800	87	1600	44
20	2800	820	85	1620	43
40	1556	840	83	1640	43
60	1077	860	81	1660	42
80	824	880	79	1680	42
100	667	900	77	1700	41
120	560	920	76	1720	41
140	483	940	74	1740	40
160	424	960	73	1760	40
180	378	980	71	1780	39
200	341	1000	70	1800	39
220	311	1020	68	1820	38
240	286	1040	67	1840	38
260	264	1060	66	1860	38
280	246	1080	65	1880	37
300	230	1100	63	1900	37
320	215	1120	62	1920	36
340	203	1140	61	1940	36
360	192	1160	60	1960	36
380	182	1180	59	1980	35
400	173	1200	58	2000	35
420	165	1220	57		
440	157	1240	56		
460	151	1260	55		
480	144	1280	54		
500	139	1300	54		
520	133	1320	53		
540	128	1340	52		
560	124	1360	51		
580	120	1380	51		
600	116	1400	50		
620	112	1420	49		
640	109	1440	48		
660	105	1460	48		
680	102	1480	47		
700	99	1500	47		
720	97	1520	46		
740	94	1540	45		
760	92	1560	45		
780	89	1580	44		


Frequency as a Function of R2
Frequency (Hz)
R2 (kΩ)
0
2000
4000
6000
8000
10000
12000
14000
16000
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100

Extra Data Tables for Handouts (photo copy and cut in half)

Data for "Feeling time"		
Trial 1: thinking about how long – without using any counting words		
	Actual time	Notes
30 seconds		
1 minute		
Trial 2: thinking about how long – using a counting word		
30 seconds		
1 minute		

Data for "Feeling time"		
Trial 1: thinking about how long – without using any counting words		
	Actual time	Notes
30 seconds		
1 minute		
Trial 2: thinking about how long – using a counting word		
30 seconds		
1 minute		

The SPS 2013 SOCK in action

Snap shots from the SOCK Interns visit to the University of Maryland Physics Camp

Science Beyond Borders

PHYSICS FOR ALL

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