THE STANFORD YOUNG ASTRONAUTS PROGRAM: A MODEL FOR SUSTAINABLE OUTREACH

Sarah Houts
Stanford University, USA, shouts@stanford.edu

Elizabeth Jens[1], Kimberlee Shish[2], Nicolas Lee[3], Stephen Russell[4], Peter Kimball[5]

The Stanford Young Astronauts program, run by volunteer graduate students from Stanford University, teaches space science and engineering to third- and fourth-grade students at two local elementary schools. Since 1985, it has sustainably fostered excitement and interest in learning about science and engineering. In the program, a sequence of nine hour-long lessons is taught spanning the academic year. The topic areas include a breadth of lessons such as forces, structures, and electricity, culminating in each student building and launching a model rocket. Each lesson explores a different topic but builds on previous material. As a result, important concepts are reinforced throughout the year. The Young Astronauts program has demonstrated success that was a result of certain key features, which could be adopted by other outreach programs around the world. Its focus on generating excitement about learning through hands-on activities and eye-opening demonstrations ensures that students actually learn and retain the key ideas that are taught. The longevity of the Young Astronauts program is based on its effectiveness as well as its flexible structure and affordability, which ensure that students over many years will continue to benefit from the program. This paper describes the general topics that constitute the current curriculum along with reasons for the continued success of the program. The program's sustainability is supported by the minimal requirement on volunteers, the affordability of materials used, and the broad topic areas that can be tailored yearly to leverage different expertise and current events. Program costs are outlined, with a discussion of how the lessons can be tailored to fit any budget. Specific examples highlighting successful elements of the program are discussed. Stanford student volunteers have maintained this successful program for over 25 years – this paper is presented with the hope of inspiring other student groups and elementary school educators to follow in their footsteps.

1. INTRODUCTION

Every year, graduate student volunteers from Stanford University run a monthly, in-school series of lessons and activities for local third- and fourth-grade students called the Stanford Young Astronauts (YA) program. YA has the goal of building a positive student outlook on science, technology, engineering, and mathematics (STEM). The program has been highly successful in this goal through its uninterrupted operation since 1985.

This article describes the Stanford Young Astronauts program, emphasizing how and why it is successful. The goal of the article is to enable university students and elementary school educators to incorporate successful elements of the Stanford Young Astronauts Program into their own STEM outreach programs.

Each year, YA (no affiliation with the various other groups of the same name) is run by approximately ten graduate student volunteers at Stanford University. Other than a cabinet used for materials storage, the program requires no direct support from Stanford. Most volunteers stay with YA for multiple years, but the group does change from year to year. It is composed mostly of graduate-level students in Aeronautics and Astronautics or Mechanical Engineering. Lesson plans are passed down from year to year, but are augmented or re-imagined to some degree annually.

We visit two schools in the Stanford area, once each per month during the academic year. Each visit builds upon material from the previous visits, culminating in a model rocket launch (Fig. 1) at the end of the year. For the past several years, the monthly curriculum has been as follows: Forces, the Solar System, Structures, Airplanes, Electricity, Mars, Phases of Matter, and Rockets (building and launching).

These important, high-level philosophies motivate our approach to the Stanford Young Astronauts program:

- Teaching facts about space science is not the point of YA. Rather, we use space science as an exciting context for children's exploration of fundamental truths about the physical world, and for their introduction to scientific thought as an accessible toolset.
- YA does not aim to have all children choose STEM career paths. Rather, we strive to provide a non-threatening introduction to such topics. The YA program aims to demystify the world of STEM,

[1] Stanford University, USA, bethjens@gmail.com
[2] Stanford University, USA, kimshish@stanford.edu
[2] Stanford University, USA, kimshish@stanford.edu
[3] Stanford University, USA, nnlee@stanford.edu
[4] Stanford University, USA, sprussel@stanford.edu
[5] Woods Hole Oceanographic Institution, USA, pkimball@whoi.edu

Figure 1: Student launching a model rocket.

making it familiar through student engagement. By discussing concepts and then applying them in activities, the students become confident in their own ability to pursue and understand STEM disciplines.

- In addition to making STEM intellectually accessible, YA aims to make it emotionally accessible by providing role models from a local university who share a positive outlook on STEM.

The remainder of this article details the YA curriculum, and highlights illustrative and particularly successful details of the program.

2. PROGRAM DETAILS

To give insight into the current instantiation of the YA program, further details about the volunteers, lessons and the funding structure are given here.

2.1. Volunteer Instructors

The success of the YA program is heavily dependent on the availability and enthusiasm of its volunteer instructors. The volunteers are primarily Stanford University graduate students. The recruitment process is casual and is conducted on an ongoing basis, with most student volunteers coming from within the Department of Aeronautics and Astronautics. The "Stanford helpers" are a self-selecting, annually changing diverse group united by a love of STEM. The classroom teachers describe the volunteers as "rock stars in the eyes of the children." Overwhelmingly, the students tend to adopt the Stanford helpers' positive outlook on STEM.

YA is very flexible to the availability of the volunteers, allowing them to attend sessions at either school whenever their timetable allows. Having a mix of experienced volunteers as well as new volunteers at each lesson is desirable so that new instructors can learn from their more experienced counterparts. Each year one graduate student takes on the role of managing the program. This leader is typically in attendance at most YA sessions for continuity. However, there is no strict attendance requirement enforced on any of the volunteers. Some volunteers help out at every lesson, while others may only attend one or two all year.

A fun way to start off the program for the year is with the introduction of the Stanford helpers. Each volunteer gives a one-line description of what they do, which is often some exciting aspect of space science related to what the children will learn throughout the year. This is followed by his or her current "grade," if it were to still be counted (usually in the "seventeenth" to "twenty-second" range). The students are always amazed at how long the volunteers have been in school, and it allows them to see that staying in school for many years can still be fun when pursuing a topic of interest.

2.2. Lessons

Included below is a brief description of each lesson, with a more complete lesson plan for each in the appendix. The lessons are each one hour in length, including all activities. We start each lesson with "free association," where we ask the students what they think of when they hear certain terms (e.g., "space science," "forces," "electricity"). The conversation will often vary widely with this open-ended question. Every answer, no matter how unexpected, will typically provide an opportunity to reveal some knowledge or experience of the volunteers and will often be a conduit to discuss future topics that will be covered through the year. This style of free association is a key element of the YA curriculum as a tool to engage the students and link topics.

An important component of most of the lessons is the hands-on activity or demonstration for that lesson. With each demo, we use the opportunity to invite the students to make hypotheses about what they think will happen before testing it experimentally. Hands-on

Figure 2: Styrofoam model airplane demonstration.

activities allow the students to get involved directly and are usually the elements that they remember most vividly afterwards.

Forces

The YA program commences with a lesson on forces. This lesson introduces Newton's three laws and uses them as a platform to describe how rockets are propelled. Two demos are used to show these in action. First, a person on rollerblades throws a backpack of different weights demonstrating the concept of equal and opposite reactions and the proportionality of force and acceleration. At the end of the lesson we launch a water bottle rocket with varying amounts of water, providing a memorable demonstration of the same ideas.

Solar System

This lesson covers the planets and uses a scale model to help the students grasp just how vast (and empty) our solar system is. Relating back to the forces lesson, we explain how gravity results in orbits (much like a cannonball fired very fast from a cannon at the top of a very tall mountain). As variable components of the lesson, we include an explanation of the phases of the moon and why there are seasons.

Structures

The structures lesson is designed to introduce the students to the goals of structural design, particularly as related to space structures (i.e., strong and light). We challenge them to pay more attention to structural elements that they encounter in everyday life and point to shapes that are particularly strong, such as cylinders and triangles (e.g., soda cans and bicycles). At least half of the lesson is devoted to a bridge building activity, where students in small groups build a bridge out of tape and paper to span a gap. These are then tested to determine their efficiency.

Airplanes

This lesson explains the four forces of flight (lift, drag, weight and thrust), and helps to demystify what causes lift. Using a Styrofoam model airplane (Fig. 2), we demonstrate how all the components contribute to its ability to fly by starting with just a fuselage and incrementally adding one wing, then the other, and finally the horizontal stabilizer. With each component the students hypothesize how the plane will fly. Building and testing their own paper airplanes gets the kids excited and encourages them to experiment with their designs.

Electricity

In the electricity lesson, we explain the basics of the atom and how the movement of electrons relates to electricity. During free association, we try to draw from the students their ideas about where electricity comes from, then discuss different ways that we convert other types of energy into electricity. About half of the lesson is spent in small groups (with one Stanford helper per group), where the students build their own circuits and explore how they work.

Mars

This lesson gives some motivation for why we explore the planet Mars, and explains some of the challenges. We show a video of the MER rovers landing (and also, more recently, the MSL landing), explaining the different parts of the mission, particularly the airbags and tetrahedral-shape used for the MER landings. The students then pair off to construct a Mars lander to protect an egg. While they all have tetrahedral landers with parachutes, they must make design choices about how to protect the payload, with options such as balloons, shredded paper, or chunks of foam.

Phases of Matter

In the Phases of Matter lesson, we address a very fundamental scientific concept: the students are introduced to the phases of matter and how they are related to temperature. We then perform demonstrations to reinforce these concepts by putting various items (balloon, racquetball, Silly Putty, etc.) into the liquid nitrogen and having the students hypothesize what will happen to them. The balloon provides a particularly striking demonstration of how volume decreases when gas is cooled. The Silly Putty is dropped to demonstrate increased brittleness. A final fun experiment is making liquid nitrogen ice cream for the whole class to try.

Rockets

The year concludes with the building and launching of model rockets, which takes two weeks. Each student gets to build his or her own rocket, and then launch it the following week. The Estes Gnome rocket with a 1/2A motor is an easy kit that is appropriate for this age level and can be launched within a schoolyard without being carried too far away by the wind. We talk through how all of the previous lessons can be tied into the rockets, both how they were designed and how they work.

2.3. Funding

While the budget is very flexible, the Young Astronauts program currently is structured such that the cost per year is approximately $20 for general resources plus $5 per student. This totals approximately $500 per year, with the majority of the cost being for rocket kits. addition, we estimate that the cost of resources that are reusable over multiple years totals $300. The cost breakdown by lesson is shown in Table 1. For this program to be operated under tighter funding conditions, the model rocket kits could easily be built in pairs or small groups rather than individually with little impact to the program. The kits are also reusable, permitting multiple launches of the same rocket with only a new engine. One unique advantage of the program at Stanford University is the availability of liquid nitrogen (LN2) donated by research labs. This enables the Phases of Matter lesson to include many exciting demonstrations. However, the availability of LN2 is not critical to the success of the program; demonstrations based around more readily available dry ice, or a replacement lesson focused on a different topic entirely, are both possible.

Lesson	Cost per student	Cost per lesson	One-time cost
Forces		$2.00	$90.00
Solar System			
Structures		$5.00	$31.00
Airplanes			$20.00
Electricity	$0.25		$120.00
Mars	$0.37		
Phases of Matter		$8.10	$5.00
Rockets	$4.55	$3.00	$30.00
Total	**$5.17**	**$18.10**	**$296.00**

Table 1: Breakdown of costs for the Stanford Young Astronauts program

3. PROGRAM SUCCESS

Described below are elements of the program that have contributed to its success over the years. Included are specific examples of approaches we have taken to put our philosophies in action, reinforcement of concepts with lesson-to-lesson continuity and

Figure 3: Bridge building activity.

supplementary activities beyond the lessons, and program flexibility.

3.1. "Failing is Not Negative"

One of the most important ideas we try to emphasize is that failure is not negative. In science and engineering, it is vital to treat failures as learning experiences. We cultivate the critical thinking skills necessary to look at a failed experiment, determine the cause, and speculate the best corrective course of action.

It is important to expose children at an early age to the process of hypothesizing an outcome and analyzing the result. In many of our free association periods at the beginning of each lesson, we try to provide brief glimpses of the scientific method. We often ask leading questions to the class and request that they hypothesize the outcome. For example, in the Airplanes lesson, as we incrementally build the Styrofoam airplane, we ask the students to guess how each new component will affect the flight. We then discuss the reasons for the new behavior in the context of the fundamental forces. Right or wrong, we encourage the students to compare the result to their initial conception. Effective use of the scientific method requires the ability to hypothesize an outcome and then treat a failed experiment as an opportunity for improvement.

Two specific lessons highlight failure as a learning opportunity: the bridge building activity in the Structures lesson (Fig. 3) and the Mars lander activity. In each case, we provide a concrete design goal and allow the children to create a design they feel can best meet the objective. Then, rather than emphasizing the fact that certain designs fell short of the design goal, we encourage students to evaluate the results in the context of what they would do differently if they were to repeat the exercise.

For the bridge building activity, the objective is to construct the most efficient bridge where efficiency is defined as the mass held by the bridge divided by the mass of the bridge itself. We find it useful to tell the students to think of the activity as a group exercise, such as a large structure composed of many structural components where the overall or average efficiency is important. This helps to avoid the natural tendency to treat the activity as a competition and creates a more collaborative, encouraging atmosphere during the testing of the bridges.

Once all bridges have been tested and the data tabulated, we discuss the results with the students. The important part is demonstrating that, instead of being disappointed by the results, important lessons can be learned from careful observation of the failure mechanism for each bridge. For example, bridges commonly fail due to delaminated tape joints or buckled paper members. Pointing out these specific details empowers the kids to come up with specific actions that could result in better performance. While we do not have enough time during the lesson to allow students to attempt a redesign, we encourage them to try this activity at home. It is a very easy exercise to reproduce with low cost, readily available materials.

For the Mars lander activity, the goal is for the egg to survive the descent. We provide the groups with a choice of different materials to use as cushioning, including balloons, shredded paper, and foam. This is an indirect lesson in the scientific method because the students are hypothesizing the performance of the different materials. Once the experiment is complete, we tally the results by material used as opposed to singling out individual groups. We emphasize that this activity parallels the experimental process used by professional scientists and engineers. Often the performance of different designs is unknown and, while educated guesses are made based on intuition and analysis, empirical evidence must be gathered and analyzed.

In both of these lessons, we emphasize that engineering often involves prototyping and testing designs destined to fail. The designs that fail are not bad but are in fact very valuable sources of information. The important skill is to analyze the results in the context of hypotheses and to iterate intelligently.

3.2. Demystifying Intimidating Concepts

Another common goal is teaching students to approach a seemingly intimidating concept with confidence. Often, we do this by breaking down a complex idea using more understandable abstractions or models. A good example of this is the Electricity lesson. This lesson covers what electricity is, how specific electrical components work, and a practical implementation of electronics through a simple robot.

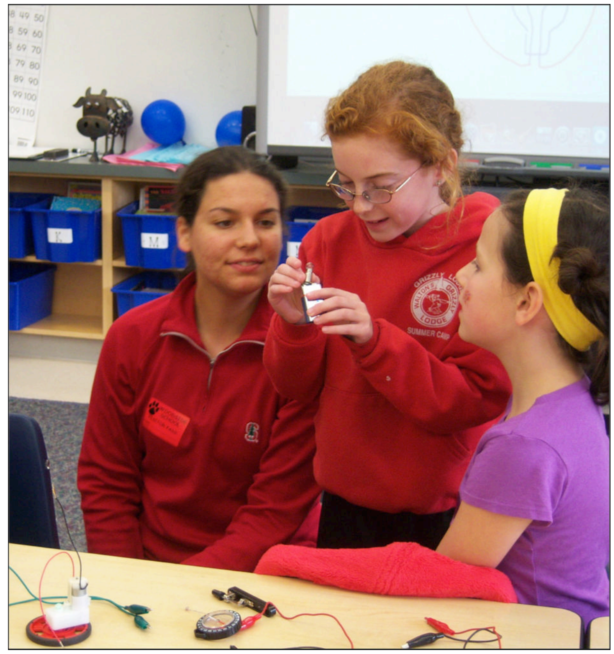

Figure 4: Circuit building activity.

Electricity is a mystifying subject because the underlying mechanism is impossible to observe: only the results are obvious. Electricity is a form of energy that can do work and is caused by the movement of electrons. A simple cartoon model of an atom illustrates what an electron is and simple mechanical analogies (e.g., cars going around a race track or water flowing down a tube) show how electrons are passed from one atom to another. Giving the movement of electrons a more physical mental representation makes the concept more tractable.

When experimenting with circuit components (Fig. 4), certain observations take some of the mystery out of electronics. One very easy point to illustrate is a basic electrical switch. We help the students to hook up simple blade switches in series with a battery and a light bulb using alligator clips and wires. As the switch is closed, the light turns on. This very simple experiment is a valuable teaching moment that should not be overlooked. As discussed in the lecture portion, metal atoms pass on their electrons more freely and the circuit must be closed so the electrons will actually flow. The switch is simply a convenient way to bring two pieces of metal into contact. The revelation for many students is that this mechanism is precisely what happens with a wall switch in their house. Because the actual electronics are hidden by the wall and the switch plate, many children have never considered how the switch works. This illustrates that the switch is not a magical component but is in fact a very simple tool to connect two metal wires.

The final demonstration involves constructing a simple light-following robot. Robotics and automatic control can be a very advanced field but, at its heart, is all about sensing information and acting based on these measurements. If asked beforehand, almost none of the students would claim they could build a light-following robot. However, we demonstrate a simple motorized cart that detects light using two photoresistors and differentially spins the left and right wheels to drive in the direction with stronger intensity light. Most importantly, this simple robot is composed of the same components that the students experiment with. This shows the children that a complicated system can be decomposed into tractable, fundamental concepts that can be understood individually.

3.3. Lesson-to-lesson Continuity

In the nine lessons taught each year, we provide continuity from month to month allowing for reinforcement of significant topics. In particular, we strengthen the connections with memorable demonstrations, and effective foreshadowing and linking. One use of a memorable demonstration is in the Forces lesson, where we introduce Newton's laws using a volunteer on roller blades throwing a backpack. The reaction force propels the volunteer backward and depends on the mass of the backpack and the force of the throw. This demonstration makes a connection to the students' own experiences and is used to provide insight into aircraft and rocket propulsion, where the exhaust is compared to the backpacks being thrown. By touching on this concept repeatedly (in the Airplanes, Mars, Phases of Matter, and Rockets lessons) we establish a common language with the students to talk about action and reaction forces without descending into scientific jargon.

Rocket launches provide a common theme woven throughout the lessons. The first lesson ends with a demonstration of a bottle rocket launch, and the year concludes with the students launching their own model rockets. This activity is referenced throughout the program as motivation for the different scientific principles being taught. In the rocket lesson, we revisit many concepts taught throughout the year including Newton's laws from the Forces lesson, thrust and drag from the Airplanes lesson, electrical circuits for the igniter from the Electricity lesson, and expansion of the exhaust gases from the Phases of Matter lesson. In this way, many lessons include links both forward to future activities and backward to material previously covered. This results in two major payoffs: first, the students become more excited about upcoming lessons when they have a hint of what it is about, and second, the material being taught is reinforced.

3.4. Beyond the Lessons

The teachers play a critical role in reinforcing the lessons by providing tie-ins to the material before and after the Stanford helpers teach each lesson. This reinforcement takes a number of different forms, from in-class and take-home writing and drawing assignments to field trips and classroom toys. The repeated exposure to ideas outside of the core lesson allows the students to think about them many times and in different ways. This improves the depth of their understanding and can help them explore ideas further on their own.

Two examples of lessons for which the teachers have follow-up lessons are the Solar System and Airplanes lessons. Around the time of the Solar System lesson (usually before, sometimes after), the students are asked to each do a report on one of the planets in our solar system. They do research, learn about the planet and write up a report on what they have learned. Each student also makes a hanging mobile with all of the planets in order. This provides an opportunity for the Stanford helpers to point out the differences in scale when we talk about our scale model of the solar system. The teachers also try to share the latest news from the space program with their classes. As another example of teacher-prescribed activity, after the Airplanes lesson the students draw airplanes with the four forces of flight (Lift, Drag, Weight, Thrust) labeled, as well as doing an experiment at home with one of the four.

Some lessons also lend themselves to individual exploration afterwards. The teachers report that for weeks after the Airplanes lesson the students make and test many different paper airplane designs during recess. Many children ask during the Electricity lesson where they can go buy similar parts to build more circuits at home. When science fair project season comes around, the teachers offer suggestions related to the YA lessons for students who are looking for ideas. These include doing an egg drop like the Mars landers with various materials, testing different paper airplane designs, and designing new paper bridges.

The classroom teachers themselves can also be role models for the students by being excited to learn about science. Often they ask questions so that they can understand the material better, and occasionally quiz the volunteers after the lessons so that they will be better prepared to answer questions the students may have later.

3.5. Program Flexibility

A contributing factor in the success of the Young Astronauts program is its flexibility in both overall structure and individual lesson content. While the overall order of the lessons taught through the Young Astronauts program has not varied for many years, they can be easily restructured without impacting the program. While many links are made between the different lessons, the primary dependency that is set up is the use of the Newton's laws in subsequent lessons after they are introduced in the Forces lesson.

Each lesson's individual demonstrations and activities can also be easily updated or changed without affecting the coherence of the program. In the past few years, significant changes have been made to the Electricity and Solar System lessons without requiring any adjustment from the other lessons to accommodate the change. The electricity lesson was modified to include new activity kits, and the solar system lesson was restructured around the concept of developing a scale model that the students can comprehend on a terrestrial scale. In addition, various lessons have leveraged the experience and knowledge of the volunteers participating at the time. This has included a discussion of Mars rover operations during the tenure of one volunteer who had actual experience at JPL working with the Mars Exploration Rovers. The concept of microgravity parabolic flights was introduced the year that another volunteer had undertaken such a flight for research. Finally, current events such as new discoveries of Saturnian moons by Cassini or the recent developments on the Curiosity rover mission are introduced to keep the lessons relevant and up to date.

4. CONCLUSION

The goal of the Stanford Young Astronauts program is to build positive student outlook on science, technology, engineering, and mathematics. The program is run by volunteer graduate students from Stanford University, and has visited third- and fourth-grade classrooms at two local elementary schools since 1985.

The program is successful primarily because the graduate students bring their own positive outlooks and enthusiasms for STEM disciplines into the classroom. The volunteers serve as role models – real people who really enjoy science and engineering. By leading discussions, demonstrations, and activities with the children, the volunteers enable the children to "do science," demystifying what "science" is, and building the children's confidence in their own abilities. The curriculum is loosely structured around space exploration, but more importantly, it provides an exciting context in which the children can learn about the physical world and the tools people can use to understand it.

The authors sincerely hope that this paper provides some of the resources and much of the inspiration necessary for other universities to begin programs like Young Astronauts within their own communities. Existing programs may also be able to gather new ideas and learn from our experiences.

APPENDIX - LESSON PLANS

The current lesson plans below provide an overview of the material covered in the program. Note that the times for each section are approximate and vary in practice. The authors are happy to correspond to discuss further details.

Forces

Introduction (15 min)

Introduce Stanford volunteers and "grade" that each is in if they kept counting. Discuss the Young Astronauts program, which is designed for the kids to be the young astronauts. Explain that they will get to learn about space and rockets, about all the things they would need to know to be an astronaut.

Start the lesson with free association by asking the students what they think of when they hear the words "space science." It should be noted that there are no wrong answers, just opportunities to link topics back to the knowledge of the volunteers and to future Young Astronaut lessons. Endeavor to generate interest in science and engineering by reinforcing why it is important and fun to learn about the topics that will be covered.

Forces (20 min)

Introduce Newton's three laws:

1) Inertia
2) $F = ma$. Explain how this formula works and what it means.
3) Equal and opposite reaction forces. Start this with forces for two free objects, rather than with static reaction forces from the ground.

Use a demonstration with a Stanford helper to highlight the above laws. Have one Stanford helper wear roller blades and throw a backpack filled with books to another volunteer. The throwing of the backpack causes the volunteer on rollerblades to move in the opposite direction.

Next, have the standing volunteer throw the backpack to the rollerblade helper, to show how that also causes them to move. The three key concepts here are:

- More force and same mass = more acceleration
- Less mass and same force = more acceleration
- Throwing mass one direction causes movement in the other direction. Link this concept to rockets to have the students start to think about how rockets are launched.

Water rocket demo (10 min)

Take the class briefly outside to witness the launching of a water rocket. Have the students hypothesize how it will perform differently for three cases: just air, full of water, and half full of water. The rocket flies farthest when half full of water. After launching the rocket, the class returns to their seats to discuss as a class how the rocket operated in terms of the forces concepts previously laid out. Briefly discuss why the rocket has fins (spinning adds stability, as with a football).

Solar System

Introduction (10 min)

Begin with names and free association. Go through pictures of planets in our solar system. Hold up a picture of each, ask the students to guess which planet it is, and share with them some fun facts about each. Feel free to include other pictures, such as the asteroid belt. Write out a mnemonic device for the order of the planets.

Orbits and gravity (10 min)

The planets travel around the sun in big elliptical paths. Ask the students why. Explain gravity as a force that acts between any two objects. To explain an orbit, a good analogy we have used is to think of a really powerful cannon sitting on top of a hill. If we fire the cannonball fast enough, what happens? What if we fire the cannonball so fast that when it falls it misses the Earth? Ask the students about which direction is gravity pulling. If fired at an appropriate speed, the cannonball will now be orbiting the Earth!

Scale model (15 min)

To get the students to grasp the immense size of the solar system, introduce the idea of a scale model, such as a train set. Everything is shrunk down by the same amount, so it helps in visualizing relative sizes and distances.

First, compare the Earth and the moon. Hold up two small balls, one that is the size of a marble for the moon, and another that is roughly three times the diameter for the Earth. Ask the children to guess how far apart they think they are, showing with their arms. They are about 4 ft apart, a full armspan for a 3rd grader. Blow up a large balloon to the relative size of Jupiter, and explain how far away it would be.

If the classroom is the sun, in size and location, explain where the nearest planets would be, choosing nearby landmarks (e.g., a park or store) that are at the appropriate relative distances. We have developed an interactive program with Google Earth, that we can bring up on a projector to show just how far the orbital radii of the planets are, illustrating the immensity of the solar system and emphasizing that there is so much empty space.

The following two sections are optional/variable.

Phases of the moon (10 min)

Explain how the Sun and orbits result in the phases of the moon. Use a ball, and either color half of it black, or use a powerful flashlight in a dark classroom to represent to illumination of the sun. Choose one direction to be that of the sun, and walk around classroom, keeping the "dark side" of the ball facing away from the sunlight. From the center of the classroom, the students can see the crescent waning and waxing.

Seasons (10 min)

A common misconception about seasons is that they are related to the changing distance from the Earth to the sun throughout the year. Begin by asking the students to hypothesize why seasons occur. Explain how the tilt of the axis of rotation results in longer and shorter days. After first explaining using drawn diagrams, use a spotlight and a globe to truly illuminate the concept.

Structures

Introduction (5 min)

This section is kept relatively short in order to keep the students engaged and to save more time for the "hands-on" part of the lesson, building bridges. Introduce structures by asking students consider what a structure is. Explain that a structure is something that holds things, both holding things up and holding things in. Pose the question: why do we use structures rather than piles of rubble? There is clearly a range of suitable answers to this question; one example is to create space underneath the object being supported. Use a whiteboard to go through an example of an everyday structure that they all know by starting with a triangle and then two triangles… then ending up with a bicycle. The bike example is typically successful in engaging the students as they can all identify with it. It is often fun to have the students guess the structure as it is being drawn.

Ask the students what the main two goals of any structure are then describe that they are to be strong and light. Ask the students for some examples of structures in space. To conclude this section, show a picture of the Space Station and highlight the truss structure.

Example structure - pop can demo (5 min)

The demonstration uses an empty pop can (have a few as backup) and a small student from within the class. Have the child stand on the pop can. With good balance, they should be able to stand on the pop can without breaking it. It is important that the pop can is fairly pristine; even a small dent can ruin this demonstration. The aim of this activity is to show students how strong something can be because of its shape. Weigh the pop can to show how light it is. Talk about different shapes in structures and which ones are particularly strong, e.g., cylinders and triangles.

Build paper bridges (40 min)

Start this activity by showing the students the width that they will need to span with their bridge (10 in), and how it's not possible with a single piece of paper, using the half sheets that we provide which are 8.5 × 5.5 in. Show the class how to roll/fold up a piece of paper to make it stronger. Show the students how a triangle has more strength than just a single piece of paper.

Separate the class into groups of three and have them start building their bridges. Have Stanford volunteers move around the room to help as needed. Let the students experiment for a few minutes, but then give directed guidance in order to speed the building process. Unfortunately this class is fairly full so there is not much time for trial and error.

Bridge testing (10 min)

Weigh each bridge and record the weight on the board. Test each bridge for strength using weights such as rolls of pennies. Invariably, a bridge will bend and slump before failing but wait until the bridge actually fails before recording the weight it could hold, this is the simplest way to be consistent. Calculate the "efficiency" for each bridge. We have found that an effective way to compute "efficiency" is as Strength (mass of weight held) / Weight (mass of bridge). Conclude the class with a brief discussion of why some bridges were more successful than others.

Airplanes

Introduction (10 min)

Begin with names and free association. To relate this lesson back to space science, pose the question: how do airplanes relate to being an astronaut? The first astronauts were test pilots, the Shuttle is a glider, and Space Ship One is an airplane.

Hold up and discuss several pictures of airplanes, noting how different wings and engines help serve different purposes. Some good examples include the Wright Flyer (first airplane), modern jets, the Concorde, fighter jets, and commercial planes.

Aerodynamics (10 min)

Explain the four forces of flight: lift, thrust (from engines), drag, weight. Draw a diagram with the forces, and explain that steady level flight has all forces equal. Explain lift as a result of the airflow around the wing. A good example that the kids can relate to is putting a hand out a car window; different tilt angles (angles of attack) create different lift and drag. As a demonstration, blow air under and then over a piece of paper. Ask the children to hypothesize on what they think will happen: will the paper be pushed up, down, or stay put? Blowing over and under both result in the paper rising up – cool!

Styrofoam airplane demo (10 min)

We have a relatively large (~3 ft in length) Styrofoam airplane model with removable wings & tail, which provides an entertaining and educational display of the performance of some of the components of the airplane. First, remove both wings and the tail, and ask the children how they think the plane will fly. Throw the plane to another Stanford helper and ask the children to comment on what they observed (plane should nose dive, and not fly far). Next have the children form hypotheses on what will happen when you add only one wing. Will lift make the plane roll one direction, or will the added weight of the wing make it roll the other? Throw the plane and again ask the students to explain what they saw. Add the second wing and toss the plane again, with the tail still absent. Ask the students what happened (the plane will fly farther, but still nose-dive at the end). Ask what direction the force from the tail should push the airplane to improve flight. The tail actually produces a downward force (which is surprising!). Add the tail, and throw the plane again to demonstrate enhanced stability.

Paper airplane demo (building 15 min, testing 15 min)

Lead students in building a paper airplane. Chose one simple design and have all the students attempt to make it. The final results will vary more widely than you might expect. Show them other paper airplane designs.

Go outside and test the planes! Have each child throw his/her plane and watch what happens. Point out how to make small adjustments to change how it flies.

Electricity

Introduction (15 min)

Start the lesson with some quick free association with the word "electricity." Ensure that during this process we mention that electricity is the movement of electrons and is a form of energy. This will lead into the question: what is energy? Explain to the class that energy is the ability to do work and ask them if they know of any other forms of energy, such as kinetic, heat, light, chemical, electrical, and potential energy. Inform the students that energy is always conserved, that it cannot be created nor destroyed; it can only change forms. Ask the students where electricity comes from and as they mention each type of power plant (Hydro, Nuclear, Coal, Gas, Wind, and Solar) outline clearly how energy changes forms within these facilities.

Balloon demo (5 min)

Draw a model of an atom on the board. Explain to students that atoms are made of protons (+) and neutrons (0), which are both in the nucleus, and electrons (−), which whirl around the nucleus. Electricity is the flowing of electrons between atoms.

Demonstrate static electricity by rubbing a balloon on a student's head. The student's hairs will be left positively charged and will repel each other. The negatively charged balloon can be stuck to the wall, pushing away electrons in the wall and being attracted to the remaining positively charged wall. Drawing a picture on the board to show the charge of the hair, balloon and wall helps to drive this concept home.

Circuits and conductivity (10 min)

Differentiate between static electricity and circuit/current/DC electricity. Show a simple circuit comprising of a battery, wires and a bulb. Ask the students what it means to close the circuit and ensure that you ascertain that air can't close the circuit but wire can. Use this idea to introduce the notion of conductivity. Reference the atomic structure again and describe that conduction is the motion of electrons from one atom to the next. Have the kids brainstorm materials that do and don't conduct easily. Introduce the idea of a battery. Explain that it has separated positives and negatives and is a storage device for potential energy. To conclude this section of the lesson discuss how electricity will be used to launch the rockets later in the Young Astronaut program.

Circuit building activity (25 min)

Explain to the students the one safety rule of the class: do not short the battery. Separate the students into groups such that there is one Stanford Volunteer per group. Pass out equipment then lead the kids through the following demos:

- Battery, light bulb, and switch: point out that the switch isn't necessary – it's just a convenient way to open and close the circuit. Build the circuit without the switch, and then even without the wire by connecting the battery directly to the bulb.
- Battery, motor, and switch: ask the students to reverse the polarity (hook it up in the opposite direction) on the circuit. What do they observe? The motor should change directions.
- Motor and light bulb (no battery): in this set-up we are running the motor as a generator. Have the students turn the motor with the circuit open and closed. Notice the difference in the force required to push the motor.
- Motor and motor: this shows students how kinetic energy can be transformed to electrical energy and then back to kinetic energy.
- Battery, light bulb and switch plus compass: the light bulb just acts as a resistor in this circuit. Use the compass to show that there is a magnetic field around the wire. Coil the wire around the compass to make the effect more pronounced.
- Battery, light bulb, and switch plus battery, photoresistor and motor: use the light bulb circuit to illuminate the photoresistor in the motor circuit. The photoresistor can conduct more easily when light shines on it so the motor will spin more quickly.
- Battery, switch, and LED: this is designed to demonstrate that the direction in which the electricity flows matters for this circuit. The LED won't close the circuit when configured in one way, but will in the other. You can also add a light bulb or motor to the circuit to clarify that the circuit is not closed, not just that the LED is not lighting up.

Wrap-up (5 min)

Conclude the lesson with a whole-class discussion of what they observed. Ask the students what they noticed about the compass. Then ask them how it interacted with the other components. Brainstorm with the class the uses of photoresistors, such as night lights, auto-brightness on iPhones, etc. To conclude the class assemble and demonstrate a pre-made light-following robot. This robot was built by Stanford volunteers using components that the students have used in the lesson.

Mars

Introduction (10 min)

Begin with names and guided free association. Pose the following question: why do we care about Mars? It is a stepping stone for further exploration, and we can learn a lot about the history of our own planet. It is the closest planet with the most similarities to Earth (Venus is hot and inhospitable). We have found water, and have searched for life. Share interesting facts about Mars (deepest valley, highest mountain, show where the rovers and landers have been on our Mars map). Ask the students what is hard about going to Mars. There is a 3–30 minute communication delay, so many operations must be autonomous (landing, MER had full schedule for each day, etc.).

Mars lander videos (20 min)

Show animated videos of Mars entry descent and landing, pointing out main features and differences between MERs, Phoenix, and MSL. Some examples of

Figure 5: Mars lander.

points to make include how the rockets fall away (separation), the spinning of final stage for stability, how hot it gets during re-entry, how fast the landers travel even after chute opens, and tetrahedron shape of the MER lander that allows it to self-right after coming to a stop.

Mars landers activity (building 20 min, testing 10 min)

Students work in pairs to construct a Mars lander (Fig. 5), built to protect an egg that will be dropped from a roof or high ladder. Give each team a parachute (octagons pre-cut from newspaper) and five pieces of string (~2 ft. each). Guide the students in taping four loops onto parachute corners, and tying the fifth string through all other loops. Give each team a pre-cut, tetrahedron to fold (8-in. equilateral triangles cut from cereal boxes work well).

Next, allow the students to make a design choice. We give them three choices on how to protect the eggs: shredded paper, a few pieces of foam, or small balloons. The kids decide where to tape the balloons and foam on to protect the egg upon landing.

Outside, from tall ladder or rooftop, release each lander with pole, and see if the egg breaks. Regroup inside to try to evaluate design choices by looking at some of the statistics from all the groups.

Phases of Matter

Introduction (10 min)

Begin with names and free association. Relate phases of matter back to rockets: how do rockets work? By throwing stuff out the back; recall the law of equal and opposite forces. How do you store a lot of "stuff" to force out the back of the rocket, but still keep the mass small? Cool it way down, so it liquefies.

Fundamentals of rocket propulsion (20 min)

Hold up a balloon and ask "what is this?". Everyone knows it's a balloon, but pose the idea that it is also a rocket! Demonstrate this idea by inflating and releasing balloon. Ask kids what they notice: it flew (propelled), but all over, and without any control. Ask the kids what features a rocket has that the balloon lacks: shape and fins. Have the kids explain how the balloon creates the propulsion force.

Explain the phases of matter, and the names of the transitions: solid, (freezing, melting) liquid, (condensation, evaporation) gas. For fun, we can include sublimation (solid to gas) and ionization (gas to plasma). Draw a thermometer and write down some key temperatures, such as room temp, body temp, water boiling, and water freezing.

Emphasize the desire for a small volume of fuel to minimize drag on the rocket.

Liquid nitrogen demos (20 min)

Pour liquid nitrogen into a glass bowl. Explain why the liquid nitrogen looks like it is steaming. Point out the ice crystals on the outside of the beaker and ask why that is happening. Insert objects into the beaker and have the children hypothesize what will happen. Blow up a balloon and put it in the liquid nitrogen. The balloon will appear to shrivel up and you can actually see a bit of liquid in the balloon. Ask the students to explain where the air has gone (this can be hard to grasp). Remove the balloon and watch it re-inflate. Silly Putty will become brittle and shatter when dropped. A racquetball will shatter and implode (air inside is liquid and acts like a vacuum).

Liquid nitrogen ice cream (10 min)

This demo is really just for fun because the kids love it. Pour cream, vanilla, and frozen strawberries into a bowl. Add liquid nitrogen and serve. Discuss the safety of "eating" the nitrogen – all the nitrogen evaporates in the process of making the ice cream.

Rocket Building

The rocket lesson is separated into two classes, each one week apart. Hence, to reflect this, the rocket lesson descriptions are separated into "Rocket Building" and "Rocket Launching."

Introduction to topic (10 min)

Inform the students that today they will be building rockets and hand out a rocket building kit to each students. The rocket kits are Level 0 educational rockets (Estes' Educator Gnome Rockets) and are typically purchased in packs of 24 online. Instruct the students to open their rocket kits carefully as there are many small parts and each part is important. After opening the kits collect all trash to keep clutter to a minimum.

Building (45 min)

Lead the class, step by step, through the building of the rocket. Point out things that relate back to all the previous lessons, such as the cylindrical fuselage (Structures), the tapered nose cone for drag and fins for stability (Forces, Airplanes), and streamer parachute for landing (Mars).

Rocket Launching

Before starting

Select an outdoor area where the rockets can be launched safely without any risk of hitting people or losing rockets in buildings or trees. It is important to consider the direction of the wind when making this decision. Have Stanford helpers go outdoors to start setting up the launch site. The launch site consists of two launch stands which are angled to launch the rockets in a safe direction, two ignition circuits and some tape or cones to mark out a launch area in which the students are not allowed to enter.

Introduction (5 mins)

Explain to the students that today they will be launching rockets outside. Draw and describe the launch site using the whiteboard. Advise the students that there is one major safety instruction for the day: they must not enter the launch area, marked by tape or cones, under any circumstances. To launch their rockets, the students will be given a control pad with a launch button on it. Explain that when they press the launch button, they will be closing a circuit and electricity will ignite the rockets.

Rocket launching (40 mins)

Have the students line up along a line set back from the launch area. Hand out the solid rocket motors and wadding and show the students how to insert them within their rocket. Ensure that each student has the nozzle facing in the correct direction. Launch the rockets two students at a time to speed up the process. The Stanford volunteers insert the rockets on the launch stands, connect the ignition circuits, and hand the students the ignition controls. Have the entire class count down to liftoff!

Wrap-up (10 mins)

Bring the students back inside and conclude the Young Astronauts program by discussing the rocket launches and asking the students if they have any last questions about any of the topics that they have discussed throughout the year. The students are typically excited from the launches and have a number of questions and comments. This time is a fabulous opportunity to recap different topics and ideas from the past nine months.