So THIS is Rocket Science

by
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We have all heard the phrase “it’s not rocket science” to describe something that should not be too hard. We all know many things it is not, but what is rocket science, and is it complex? It is complex in that it involves all STEM aspects and multiple disciplines. Thus a rocket scientist needs to learn and keep in mind a broad spectrum of knowledge in their work. They have to pay attention to all the details, since they are dealing with a “controlled explosion”. It also requires linguistic and artistic skills, for it is well known that a rocket can’t fly until the paperwork describing the rocket and it’s testing, weighs as much as the rocket. (A little rocket science humor.)

But is rocket science really too complex to understand? The answer is no. The basic principles of rocket science can be explained and demonstrated with relatively simple equipment. This course will use the scientific method to cover the basics of rocket science by asking pertinent questions proposing hypotheses and providing activities to test the hypotheses. The questions will be marked by a ”Q”, possible hypotheses with a “H” and the activity by “Act”. References for the activities and answers are noted as (Reference Number - Page)*** (Careful, not all suggested hypothesis prove to be true.)

What does it take to be a rocket scientist? You need a basic curiosity and determination. As with any science, new discoveries are based on past knowledge. Therefore a lifelong pursuit of knowledge is their lot. To be successful, a person must also not be easily discouraged. In the pursuit of the unknown, many ideas and hypotheses may not work but as Edison was quoted “I have not failed, I’ve just found 10,000 ways that won’t work.” (FYI Edison was fired multiple times as a telegrapher, since his curiosity distracted him from the telegraph key.)

And most important, the work must be enjoyable. The activities in this course should be fun!!!...and educational. Hopefully this course can stimulate some new Edison or scientist of the future to start/continue on their journey for knowledge and new discoveries.

***The course is based on the 4-H rocket project curriculum “Rockets Away” by Dr. Robert Horton. Books for 2-Liter Bottle Rockets and for Solid Fuel Rockets are references 1 & 2. Additional activities are from: (3) “200 Illustrated Experiments for Children by Robert J. Brown, (4) “Naked Eggs and Flying Potatoes” by Steve Spangler, (5) “Fire Bubbles and Exploding Toothpaste” by Steve Spangler, (6) “101 Great Science Experiments” by Neil Ardley, & (7) Answer and activity sheet appendix. Of course there is much material available on the internet. Some of these are noted, but others such as http://science.howstuffworks.com/rocket.htm can be very useful.

Day 1- Basic Physics

Scientific Method: All science is based on using the scientific method of formulating a question, creating a hypothesis, and testing the hypothesis to see if it is true. If is not true, other hypotheses are formulated and tested until the truth is found.

We will use the scientific method as much as possible as we explore various concept in this course.

Q: What questions do students have and what would they to learn?
H: Answers can be found
Act: Stump the Chump: Make list of questions, see which ones will be addressed, research other questions for answers

Conservation of momentum: The principle that the total linear or angular momentum of an isolated system remains the same

Newton's Laws
First Law; Objects at rest will stay at rest, objects in motion will stay in motion unless acted upon by an unbalanced force.

Q: What does this mean, and what are some examples?
H: Momentum is conserved
Act: Testing Gravity (1-7)
Act: Let's get Lifting (1-7)
Act: The Egg Drop (4-133)

Second Law; The acceleration of an object is directly related to the force exerted on that object and oppositely related to the mass of that object.

Q: What is the mass of an object and how is it related to its weight?
H: Mass is the amount of matter in object. Its weight is the force by which it is attracted to the Earth by gravity. The force of gravity depends on the mass of the two objects and the distance between them. Thus the more mass in the object the more the force or weight.
Act: Bouncing Things (1-8)

Q: What is inertia?
H: A resistance to change in motion.
Act: Inertia (3-45)

Third Law; For every action there is always an opposite and equal reaction.

Q: What does this mean, and what are some examples?
H: There is conservation of momentum
Act: Kicking Into Action (1-9)
Act: Illustrating Newton's Third Law (3-57)
Act: "Smoke Rings" in water (3-31)
Act: Wave Transmission (3-38)

Q: How far does the earth move when a 200# basketball player jumps 4' in the air?
H: It doesn't move at all
Act: Apply Newton's Laws (7 - 1)

Q: What is kinetic and potential energy?
H: Same thing, just a different name
Act: Dripping CAndle Seesaw (5 -79)

Q: Where does the energy go from jumping up and down?
H: Into the air
Act: Hammer and Heat (3-130)

Q: Does a lawn sprinkler use Newton's Laws?
H:It demonstrates all three laws
Act: Build a Hero engine (1-10)
Act: A Simple Turbine (3-56)

Q: How will changes to the amount of water, number of holes and angle, and mass of the can effect it.
H: The amount of water will not have an effect, the angle of the holes will have no effect, the more holes the faster it will go, the can will go faster the heavier the can is.
Act: Demonstrate all three laws by changes to amount of water, number of holes and angle, and mass of can (1-10)

Q: Old Faithful is a natural rocket. How long will it take Old Faithful to change Earth's orbit enough to increase a year by one second?
H: 82 million years
Act: Apply conservation law (7 -1)

Q: Do Rockets push against the earth or the air to fly?
H: Yes
Act: Question where rockets are used; answer next question

Q: How do rockets fly in the vacuum of space?
H: They use the dark energy of the vacuum.
Act: Review of previous lessons
Act: Alternate explanation of rocket propulsion based on pressure on smaller rear surface versus the front. (7 -1)
Act: Squeeze Bottle Straw Rockets (5-25)
Act: Get a Jet Going (6-101)
Act: Coming and Going (1-9)

Act: Build either bottle rocket or Estes rocket (If weather is predicted to be good on Sunday, build bottle rocket on Thursday and Estes on Friday, so can fly Estes on Saturday. If not good on Saturday or Sunday, build Estes on Thursday, so it could be flown on Friday and build bottle rocket on Friday or Saturday to be flown when can)
Build Bottle Rocket (1 -17)
Build Estes Rocket by Manufacturer instructions and (2-17)

Act: Launch Bottle Rockets (or build Estes if Friday is only good weather day)

Q: How do you make the bottle rocket go the highest?
H: Use more water.
Act: Try changing variables in multiple launches (1-21)

Q: How close you can get to target with a bottle rocket.
H: 14 feet
Act: Try to hit target by launching at an angle and deciding on how much water to use.

Q: How high can a water air (bottle rocket)go?
H: ¼ mile
Act: http://www.wra2.org/WRA2_Standings.php
Act: http://www.popularmechanics.com/flight/a17742/water-rocket-record/
Act: http://gizmodo.com/a-water-bottle-rocket-blasted-half-a-mile-into-the-air-1735512293

As time allows start working on Rocket Design, Stability and Guidance (Exercises out of Section 2 of bottle rocket 4-H book)
Moving Questions about Rockets
Nine most commonly asked questions of NASA scientists:

Q: Do rockets really fly? (1-11)
H: No, they don't have wings
Act: Try a Little Lift (1-11)
Act: Make a Wing Fly (6-12)

Act: Bernoulli Effect on a Water Surface(3-19)
Act: Testing Turbulence (1-15)
Act: The Coanda Effect (3-6)
Act: Floating Ping-Pong Balls and Flying Toilet Paper(4-11)

Q: Which works harder – a jet engine or a rocket engine? (1-12)
H:Rocket

Q: If rocket engines burn oxygen, how do they work in space? (1-12)
H: Must take oxidizer along
Act: Internet search of oxidizers

Q: Why do rocket engines have nozzles? (1-13)
H: To increase the thrust
Act: Add a Nozzle (1-13)
Act: Extra Boost (7 - 1)

Q: Why are rockets so long? (1-13)
H: To improve stability
Act: Add a Stick (1-14)

Q: If rockets don't fly, why do they have fins? (1-14)
H: To Look pretty
Act: Investigate what pitch,yaw and roll mean for a rocket
Act: Add a Fin (1-14)

Q: Are fins needed to stabilize rockets in space? (1-14)
H: No, must use retrorockets or thrust vectoring
Act: Investigate retrorockets and thrust vectoring

Q: Why are rockets so streamlined? (1-15)
H: So they don't get stuck in the clouds
Act:Testing Turbulence (1-15)

Q: If rockets fly in space without interference from air and gravity, why must they still be balanced? (1-16)
H: So they don't tumble
Act: Find the center of gravity (3-47)
Act: Balancing Nails (5-71)

Day 2- Chemistry

Build Estes Rocket if Saturday/Sunday weather is to be good , launch Estes Rocket if only good day

Discuss History
Chinese Fire Arrows evolution to modern fireworks
Q: What were Chinese Fire Arrows
H: Arrow with flaming tips
Act: Rocket and How They Move (1-6)

Q: What does “the rocket’s red glare/the bombs bursting in air” refer to?
H: Francis Scott Key Fourth of July Fireworks display
Act: Internet Search on National Anthem

Fuses, delays, shaped charges, etc.

Q: What gives fireworks their color?
H: Heated metals
Act: Burn chemicals to show different chemicals https://www.thoughtco.com/how-to-make-colored-fire-p2-602196
https://www.thoughtco.com/colored-fire-spray-bottles-607497
https://www.thoughtco.com/where-to-find-metal-salts-3975985
https://www.thoughtco.com/how-to-make-a-colored-campfire-606197

Q: How do you make fireworks in different shapes?
H: Shape the explosive charge
Act: Internet search

Chemistry of rocket propellants, gunpowder, Kerosene, Hydrogen, nitrated fuels, etc.
Chemistry of oxidizers: Liquid Oxygen, Liquid Fluorine, FLOX, Super chilled propellants

Q: Does a rocket use the air to burn?
H:Yes
Act:Discover the Gases in the Air (6-9)

Q: What household items are propellants:
H: Alka Selzer
Act: Pop your Top (5-39)

H: Coca Cola
Act: Mentos Geyser (4-145)

H: Vinegar and Baking Soda
Act: Form A Gas (6-10)

H: Hydrogen Peroxide
Act: Exploding Toothpaste (Elephant Toothpaste) (139-149)

H: Corn Starch
Act;http://www.geek.com/news/homemade-flamethrower-runs-on-cornstarch-makes-quick-work-of-zombies-1612674/

H: Suger
Act: http://www.wikihow.com/Make-Sugar-Rockets

Explosive force and performance of rocket fuels

Specific impulse (Thrust /Weight/sec of fuel)
Q: What makes a good rocket fuel?
H: High Density
Act: Seven-Layer Density Column (4-71)
Act: Sinking Soda Surprise (4-67)

Propellants –
Q: How dangerous are rocket fuels?
H: Rocket fuels are by their nature explosives
Act: Compare Hydrogen/ Oxygen heating value to dynamite

Modern Rocketry
Q: Who invented the modern liquid fuel rocket
H: Goddard
Act: Goddard early work https://www-istp.gsfc.nasa.gov/stargaze/Sgoddard.htm

German V1"Buzz Bomb"
German V2.

Q: Why was an early German rocket called a "Buzz Bomb"
H: It was buzzed on alcohol
Act: Internet search

Q: Where did the V in the German V1 and V2 come from?
H: From the shape of the nose
Act: Internet search

Q: What major rocket coup happened at the end of World War 2?
H: The basketball team moved to Houston
Act: Race between US and Russia to capture German rocket technology; General Walter Dornberger and Werner von Braun story
Act: http://www.pbs.org/wnet/secrets/the-hunt-for-nazi-scientists/66/

Act:Show video footage of early German successes and failures.
Act:
https://www.bing.com/videos/search?q=video+of+early+rocket+failures&&view=detail&mid=FECAA46B98412846C212FECAA46B98412846C212&rvsmid=FECAA46B98412846C212FECAA46B98412846C212&fscr=0&FORM=VDFSRV
https://www.bing.com/videos/search?q=video+of+early+rocket+failures&&view=detail&mid=E4D5E456DC61E2A5170DE4D5E456DC61E2A5170D&rvsmid=FECAA46B98412846C212FECAA46B98412846C212&fsscr=0&FORM=VDFSRV

Act:Show video footage of early US successes and failures.
Act: https://www.youtube.com/watch?v=13qeX98tAS8
Act: https://www.youtube.com/watch?v=13qeX98tAS8
Act: http://listosaur.com/science-a-technology/10-spectacular-failures-of-unmanned-rocket-launches/

Evolution of modern rockets

Satellite launchers from Sputnik to SpaceX Falcon 9
Q: What are some war uses and peaceful uses of rockets over the years?
H: Put satellites in space
Act: Internet search

Q: What is an ICBM
H: Internal Cosmic Beam Machine
Act: Internet Search

Q: What is the difference between an ICBM and a satellite launching rockets
H: Completely different
Act: Internet search

Day 3- Aerodynamics and Guidance

Composition of air

Q: Does Air have Weight?
H:Very Little
Act: Weigh Some Air (6-8)

Q: How much weight of air does the roof of the 220' diameter vacuum chamber at NASA Plum Brook Station have to hold?
H: 40 tons
Act: Calculate (7-1)

Boyle's Law (Volume vs Pressure)
Q: How can you change the pressure of a gas?
H: Compress the gas
Act: Flying Potatoes (4-19)
Act: Air Expansion (3-3)
Act: Atmospheric Pressure (3-7)
Act: Floating Water(4-125)
Act: Steam, Vapor,Gas (3-127)

Charles Law (Volume vs Temperature)
Act: Soap Souffle (4-49)
Act: Egg in the Bottle Trick(4-77)
Act: Tea Bag Rocket https://www.stevespanglerscience.com/lab/experiments/tea-bag-liftoff/

Universal Gas Law (PV=nRT)

Guidance

ICBM's
Q: How do you make a ICBM hit a target thousands of miles away?
H: An internal guidance System that uses gyroscopes, GPS, or other detectors such as gravity gradients to determine the direction the rocket is going relative to where it is supposed to go. To change direction, typically thrust vectoring is then used to put the rocket back on course.
Act: https://en.wikipedia.org/wiki/Gyroscope
Act: http://www.gyroscopes.org/uses.asp
Act: https://www.youtube.com/watch?v=zbdrqpXb-fY
Act: https://www.youtube.com/watch?v=n5bKzBZ7XuM

Q: Can an ICBM hit multiple targets
H: Yes

Act: https://en.wikipedia.org/wiki/Multiple_independently_targetable_reentry_vehicle

Orbital Dynamics
Centripetal Force
Q: How do satellites stay in orbit around the Earth?
H: Gravity bends the straight line a satelite wants to travel in.
Act: Screaming Balloon (4-137)

Q: What Happens to a satellite's time to orbit if it's altitude is raised?
H: It will increase.
Act: Conservation of Energy (3 -51)

Q:Is there gravity in space?
H: No, you are weightless.
Act; To See Weightlessness (3-34)
Act:Consider what holds the moon and planets is place

Day 4 - Engineering Considerations

Act: Bottle/Estes Rocket launching – in case of bad weather on previous days
Cooling the nozzle
Q: How do you keep the rocket chamber and nozzle from burning up?
H: Make out of lightweight high temperature material.
Act:Check melting temperatures, strength , and density of materials.

H: Cool the metal some way.
Act: Burning Money (4-141)
Act: Fire Bubbles (5-121)
Act: Fireproof Balloon (5-97)

Fuel/Oxygen Tankage

Q: How do you get the liquid fuel out of the tank in space?
H: Pressurize the tank with gas; keep fuel clean
Act: Mentos Geyser (4-154)
Act: Flow from a Jug (2) (3-32)
Act:The Gurgling Jug (3-33)

H: Put in baffles to keep from swirling
Act: The Quick-Pour Soda Bottle Race (5-13)
Act: The Flow from a Jug (1) (3-31)

Q: How do you make the tank light, but strong.
H: Pressurize a thin metal can
Act: The Incredible Can Crusher (4-27)

Possible other topics and activities:

Rocket staging and recovery
Orbital dynamics to go to Moon or Mars
Improved performance (Nozzle, Aerodynamics, Materials)
Guidance systems
Manned versus autonomous control
Landing on Earth, Moon, Mars, asteroid
Advanced Propulsion Systems (Ion, solar sail, nuclear, anti-matter/matter, etc.)

Intercepting Asteroid (Mining, Destruction, Diversion)
Failure Analysis (Apollo 13)
Technical errors in Apollo 13 movie
Design Martian Colony
Telemetry, Data integrity and application to computers, internet and cell phones
Life beyond Earth
Space Station
Inflatable Habitats
Failure mechanisms of hardware in space
Design of experiments
Ground testing of space hardware

Appendix

Q: How far does the earth move when a 200# basketball player jumps 4' in the air?
Knowns; For every action there is an equal and opposite reaction. Momentum must be conserved. Gravity is always acting as a restorative force. Force equals mass times acceleration. Momentum equals mass times speed.
Answer: The force of the player's feet imparts the same momentum to the player as to the earth but in opposite directions. The earth and the player are both accelerated as long as the feet are on the ground until they each have each gained their maximum relative speed and momentum. Once the player is in the air, the force of gravity starts lowering the relative speeds of the earth and player until at the peak height the relative speed is zero. The momentum change of the player equals the momentum change of the earth. Therefore Mass of Player times movement of player = Mass of earth times movement of earth. (200#*0.45359237kg/#)*4ft. = *5,973,600,000,000,000,000,000,000 kg*x;*
((200#*0.45359237kg/#)*4ft.)/5.9736 X 10^{24} kg= 6.0746 X 10^{-23} ft.

Q: Old Faithful is a natural rocket. How long will it take Old Faithful to change Earth's orbit enough to increase a year by one second?
Answer: It won't change the orbit for multiple reasons. First if it did move the earth, as long as it isn't synchronized to the rotation of the earth, over the long term any movements would cancel themselves. Secondly, by conservation of momentum, the total momentum of the earth around the sun does not change when the geyser goes off. As with the basketball player, the earth and geyser water do momentarily move relative to each other. As the water (player) gets attracted back to the earth by gravity, and the earth attracted to the water (player), they return to their nominal former positions.

Q: How do rockets fly in the vacuum of space?
Act: Molecule ball game; Sit the students down in a circle with their legs spread out so their feet touch and make a closed circle. Put balls in the closed circle, and instruct the students that when a ball hits their legs they are to push the ball back into the circle. They are to count the times they touch a ball. Explain that the balls represent the molecules moving around in balloon (rocket) with the neck (nozzle) closed. Start the balls moving and run exercise to two minutes. Go around circle and report hits. They should be about the same, that is, the molecules push out on all sides equally. The balloon (rocket) doesn't move.
Now remove one person, or move around so there is a space left in the circle. This represents the balloon (rocket) with the neck (nozzle) open. Repeat the game for 2 minutes or until all the balls are have gone through the hole. Now go around the circle and report hits. The hits to opposite sides should be about the same and balance each other. The hits opposite the open side are not balanced by hits on the open side and this results in an unbalance force that pushes the balloon (rocket) away from the open side. This is the thrust of the rocket.

Q: Why do rocket engines have nozzles? (1-13)

Act: Extra Boost; Repeat Molecule ball game but this time add an “exit cone” to the opening by putting a person on each side at a 45 degree angle to the opening. Report “hits” again and again notice an unbalance between “open” and “closed” side that causes thrust. But now report the hits on the exit cone. Although these hits are at an angle to the desired thrust, a portion of their impact does contribute to add thrust.

Q: How much weight of air does the roof of the 220’ diameter vacuum chamber at NASA Plum Brook
Answer: (Pi*R*R)*(144 Sq. In./Sq. Ft.)* 14.7#/Sq. In.= 3.1415*110*110*144*14.7= 80,464,119# = 40,232 tons