The centripetal acceleration of the bob of a conical pendulum is

Roof colours - white vs black Nobel laureate Steven Chu, former professor of physics at the University of California and nowU.S. Energy Secretary in President Obama's administration says "white paint is what's needed to fix global warming". However, Steven Chu said, even if we paint every roof white, "there was no silver bullet for tackling climate change, and said a range of measures should be introduced, including painting flat roofs white. Making roads and roofs a paler color could have the equivalent effect of taking every car in the world off the road for 11 years." That sounds like an ideal EEI. One Australian company sells just the thing: White Roof Shield is a white coating which reflects 80% of the sun's radiation. They say it "helps reduce interior cooling loads of air conditioned structures, resulting in savings of both energy and money. Even buildings without air conditioning stay cooler because roof surface temperatures are significantly reduced". Put some roofs of different amounts of whiteness in the sun for some time and measure the temperature of something underneath (maybe air, water). Maybe a heating curve is best. May need more than three trials, and what's the best way to produce this (mixing black and white paint proportionally, black masking tape etc). What about flat paint vs satin vs glossy? Home Insulation - is thicker better? Ceiling insulation is one way of improving the energy efficiency of a home. Insulation materials such as polyester, fibreglass or wool "batts", metal foil and shredded newspaper are just some of the ways it can be done. In 2010 the Australian Government subsidized the installation of batts and foil in 550000 homes at a cost of $2.45 billion. Many were installed improperly and in some case fires and death occurred. The research question that could be useful for a Senior Physics EEI is what factors affect the thermal insulation property of a material? There is a great temptation to compare the various materials to see which performs best; but you have to ask "what variables are you considering?". Such a comparison may be okay for a Junior Science project or EEI but it is very problematical for a Senior Physics EEI. Presumably you would have different building materials to test but the question is: what is the manipulated variable. If it is just "type of material" then on what basis are you comparing them? You could have variable R-values but you would need to keep all other variables constant (thickness, surface area, heat source, time). My suggestion is to investigate varying thickness of a single insulating material. That way there would be some physical quantity to analyse other than R-value (which is merely the result of an experimental determination anyway). The last thing you want is the temperature inside the house for a bunch of building materials without any physics theory behind why they have different thermal conductivity other than "they just do". That is, what is their relationship to each other? This is a physics EEI and physics principles, theories and concepts must be at the forefront of any investigation. Otherwise, I think you would find difficulty in being able to address the the criterion (Queensland Syllabus IP3): "identify relationships between patterns, trends, errors and anomalies" when there is no theoretical scientific relationship proposed in the hypothesis. This also applies to criterion EC1: "analysis and evaluation of complex scientific interrelationships". Varying the thickness avoids this. Here's a suggestion: use a light-box kit to provide the source of heat. I put the insulating material (yellow cardboard) on top and then a polystyrene cup with a thermometer stuck through it to record the air temperature inside the cup (the "home"). Worked like a charm - and so simple. As a bonus, you could even look at a second variable - that of the temperature of the heat source (try 12V, 10V, 8V....). My graph showed that the single layer of card (top line) allowed the temperature to rise quicker than for two pieces of card (bottom line) but after 25 minutes they were both the same. Hmmm - how to explain that? This is a rich source of data. What would three pieces of card show? I also tried six layers of paper towel but the temperature shot up very quickly at first (6 degrees in 1 minute). Why was that? I think hot air made its way through the paper. But 6mm expanded polystyrene foam was no better. What a great source of data to analyse. Do it well and I'd have to get an A+. Another idea is a wooden box with a 240V lightbulb as the source of heat. There is a piece of wood that fits on the front. In this photo, a sheet of 8mm polystyrene is being tested. Here's a few things you could try. But remember, you are not comparing different materials unless you can establish some physical relationship between them in terms of their insulating ability. Comparing their thickness makes for a good EEI (1 layer, 2 layers, 3 layers). Some teachers have used this idea in the context of "sustainability". Students investigated the effect of thickness of more natural construction materials such as clay (roll out thin layers of terra cotta clay from the Art Department). In this cases you would be looking at wall insulation, not ceiling insulation. Tennis Racquet - Sweet and other spots On the face of the tennis racquet, there are several points that are important to players; these are the centre of percussion, the vibration node, the best serving spot, the best returning spot and the dead spot. A couple of the spots are shown on the diagram below. The centre of percussion is one of the two "sweet spots" of the racquet. This is because at the point of impact between the centre of percussion and the ball, the hand can feel no impact. This is due to the fact that the centre of percussion is located near the centre of the face of the racquet. You can easily find out what all this means and about the other sweet spot. A good EEI would be to test the 'coefficient of restitution' (ratio of bounce height to drop height) of different parts of the face. Perhaps clamp the racquet in a vice and drop a tennis ball on different position of the face and noting bounce height as a fraction of drop height. Does drop height affect the coefficient of restitution? Is the type of ball important? Does a temperature change shift the sweet spots? Are new racquets better than old? Is aluminium better than graphite? Does string tension play any part? The possibilities are endless. The photos of professional players show that the serving spot is high and the return spot is low. Note: Brad Barker from San Sisto College has listed "Physics of Sport EEIs" that have worked at his school. Click here to download. Perfect serving spot. The various 'centres' on a tennis racquet. Experimental setup at Moreton Bay College for Year 12 Physics EEI - 2013. Year 12 student Chelsea Meadows at Mansfield State High School used Logger Pro to analyse data of a tennis ball landing on a tennis racquet. The graph shows the energy lost going across the surface of the racquet from the neck. Chelsea's photo shows that the ball rebounded at an angle and as you go across the face of the strings the rebound angle changes. My thanks to Chelsea for letting me use her excellent EEI (November 2017). Danger inside a hot car After rescuing 20% more children from locked cars last summer than the previous year the Royal Automobile Club of Queensland has urged parents not to leave children locked in cars. The RACQ says that on a typical Australian summer day, the temperature inside a parked car can be 30° - 40°C hotter than outside the car. That means that on a 30°C day, the temperature inside the car could be as high as 70°C and 75% of the temperature increase occurs within five minutes of closing the car. They also say that darker-coloured cars can reach a slightly higher temperatures than lighter-coloured cars (I would have though much higher temperatures); and that large cars can heat up just as fast as small cars. The key variables are obvious for an EEI and having a data logger would be great. But some others worth considering are the colour of interior trim; having the windows down a bit, or even fully open; dark vs light colours; big vs small; time of day (angle of sun); and window tinting. You could even model a car by using painted soft-drink cans and sealing a thermometer into the hole with Blu-tac. Maybe you could puncture holes in the side to represent an open window (or vary the number of holes as a manipulated variable). Oh, the possibilities are endless but and it looks easy but controlling the variables will be important. Descent of golf balls down an incline If you roll a golf ball down an incline you should note that as the angle increases so too does the velocity. You could measure time vs. angle; time vs. distance. Is acceleration uniform? Why do similar looking balls give different results; perhaps it is to do with their construction (see 2-piece, 3-piece and 4-piece types below. Maybe it is to do with their dimples or hardness (Novice = long, soft; Intermediate = very long & soft; Power = straight & very soft; Titleist = extremely long, and so on). Try removal of dimples! Use a light gate at bottom to measure final velocity; how does this compare with 2 x vav? That's Melody's hands in the photo below. She's from Moreton Bay College. Cars on a ramp - angle and speed. If you ride a skateboard down a hill you know that your speed increases as you go down. This happens for all sorts of things: riding a toboggan down a sandhill, skiing down a ski run, letting a shopping trolley go in a carpark, and going downhill on a bike or roller skates. Even cars get faster if they accidentally roll down a hill. You can reach dangerous speeds if you have no way of braking or slowing down. With cars and trucks it may be impossible to stop them and the consequences can be disastrous. An EEI could look at factors that affect the speed of an object as it moves freely down a slope. Knowledge of these factors may help in the design of sports grounds skateboard bowls, ski runs, toboggan slides and so on. It could even help road engineers ensure that road inclines do not create dangerous situations. What could make a good EEI is to consider the relationship between height of the incline and the final speed of the car after a certain distance, keeping mass and the surface type constant. This does make an excellent Year 10 EEI but it also is very suitable for Year 11, particularly if you choose to look at a second variable (mass). We all know that GPE is converted into KE but is it 100% efficient? By timing the car over the metre you can work out the final speed assuming constant acceleration. Varying the angle will give different times. Don't forget to include 0.0 cm height = 0.0 m/s final speed. You would think you'd get a $y \propto \sqrt{x}$ relationship but mine didn't look exactly like that. Plenty to talk about. For 6 cm, 9 cm and 12 cm ramp heights with a 72g toy car I got final speeds of 70, 124 and 131 cm/s over the 1 metre. Efficiency of energy transfer was 42%, 87% and 73% respectively. Hmmm! Cars on a ramp - stopping distance of toy cars along the floor due to friction For sliding friction on an incline, the coefficient of friction $\mu = \tan\theta$ for constant speed; but for rolling friction it may not be. You could let a car roll down a ramp on to the horizontal floor and see how long a distance it takes to stop. How does this vary with the height (which determines the starting speed) at the bottom of the ramp. It maybe tempting to use a solid ramp but the join at the bottom may not be smooth and the bump can slow the motion. To get a smooth run a curved surface could work. I just used some carpet tiles with the shiny side up. The question is: where is the friction in a toy car travelling along a surface: between the axle and the wheels, or the wheels and the road? You could also look at the effect of the mass of the car and so on. What are the practical implication for this? Does twice the mass (eg a truck compared to a car) mean twice the stopping distance? It is tempting to compare the rough carpet side with the smooth side, or to compare different carpets but the question is: just how is your "roughness" variable measured. Maybe you could measure the coefficient of friction of the material first and use that as the variable. This is certainly not as simple as it looks and may, at first glance look just like a Year 10 EEI but there is a lot in it and could be good at a Year 11 level. The distance d (or displacement s) is easy to measure but how exactly do you measure the change in height h for used in the GPE = mgh formula? I've shown it here as the vertical distance between the centres of gravity at the top and bottom of the ramp. But could that be improved? Can you assume the conversion to KE is 100% efficient to work out the speed at the bottom of the ramp? Would you need to measure the time elapsed to be able to calculate the deceleration of the car along the horizontal ($a = (v-u)/t$) or could you use $v^2 = u^2 + 2as$? Is all of the GPE converted to work done in bringing the car to a halt (GPE = mgh = W = Fs = mas)? Whew, so much to think about. On this rough side of the carpet tile and a starting height of 4 books (11.8 cm) the car travelled 83.2 cm unloaded but travelled only 63.2 cm with a 50 g mass Blu-tacked to its hood. Still with a starting height of 11. 8 cm but with two 50 g masses on the hood the car travelled just 42.3 cm. Is distance proportional to mass? Using a Smartphone Accelerometer on an inclined plane The Queensland Studies Authority has an "A" standard sample EEI on their webpage that describes the use of a smartphone in measuring acceleration down an incline. It may provide some good ideas about what you can do - and gives you an indication of what an "A" response could look like. Click here to download. 3-D accelerometer apps are available free for all phones (Moreton Bay College) Rolling friction of a ball When a ball rolls along a surface it will eventually come to rest. Because it gradually slows down we say there must be a force opposing its motion, and we call this force "friction". We can think of friction being classed as three types: static (not moving), sliding, and rolling. In class, you will have most likely dealt with static and sliding friction because they is easy to demonstrate and quantify (slide an object across a bench or down an incline). In contrast, rolling friction is harder to measure as it is usually much smaller. If a cylinder or ball is freely rolled along a horizontal surface, it will eventually come to a stop even if it does not strike any small bits of dirt or other obstacles. This slowing will arise even in the absence of air drag, as has been verified by rolling a ball inside an evacuated bell jar. A game of billiards makes use of both rolling and sliding friction. When you strike a ball with the cue stick the ball usually slides (slips) for a moment before it rolls. But what is the cause of rolling friction? You may think that the object could partially stick to the surface (by electrostatic or dispersion forces) and have to be 'peeled' away from it and thereby get slowed down, but that cannot be a complete explanation, as non-adhesive rolling objects also slow down. A simple model of rolling friction is shown in the diagram below. It suggests that the supporting surface and the surface of the rolling object are deformed by the weight of the object. The amount of deformation being dependent on the hardness of each surface. The hard billiard ball deforms the soft vinyl surface of a laboratory floor (deformation is exaggerated for clarity). This suggests a good EEI. You could roll a ball down a slope and measure its stopping distance s. The problem is what other variables will you measure and what will you control? At the top of the ramp, the ball has GPE only (= mgh). At the bottom it has translational KE and rotational KE. You should be familiar with the translational KE formula ($\frac{1}{2}mv^2$) but what of rotational KE? This you will need to decide for yourself but it involves the distribution of mass in the object, the radius and the angular velocity. You could change the height to get different starting energies. If you change to a heavier ball then will the velocity at the start of the horizontal part be the same? Perhaps you will need to measure that with a light gate. One thing you do know though is that all of the GPE at the start will be used up in rolling friction. There will be no sliding friction. So GPE = work done by rolling friction. The possibilities are endless. You could also see the EEI suggestion below for another way to do it. Rolling friction using ball bearings Rolling friction is not generally discussed in high-school physics courses or textbooks, partly because it is not well understood and partly because there are several different factors can contribute to it. A recent paper by Rod Cross from the Department of Physics, University of Sydney, Australia suggests an experiment that I think would make a good EEI. See "Coulomb's law for rolling friction" American Journal of Physics 84, 221 (2016). You are probably familiar with the work by Coulomb (1736-1806) on the force between electric charges. He later applied himself to the study of friction and found that rolling resistance was inversely proportional to the diameter of the roller. French engineer, Arsene Dupuit, later found that rolling resistance was inversely proportional to the square root of the wheel diameter, thereby sparking lively debate in the 1840s. The EEI suggested here involves rolling steel ball-bearings of different diameters across the concave surface of a watch glass, lens or mirror. The ball behaves like a pendulum speeding up as it rolls towards the centre and then slowing as it rises up the other side. Have a look at my video at (see below). A clip of the steel ball bearing rolling across a watch glass 10 cm diameter. I just sticky-taped a photocopy of a ruler on the underside of the glass. The ball was 12.5 mm diameter. I used the freeware Kinovea to analyse the motion and found a period T of 0.96 s and produced some graphs (below). Because of rolling friction the amplitude of the ball decreases with time (see Graph 1). The gradient (Graph 2) is a measure of the rate of change of amplitude (dx/dt for a amplitude in cm, or dθ/dt for an amplitude in radians). To convert from x to θ you have to divide x by the centre of curvature of the concave surface less the radius of the ball. For a radius of curvature of 16.2 cm and a ball radius of 0.5 cm, an amplitude of 6 cm would have an angular amplitude θ of 6/(16.2-0.5) = 0.38 rad. From this, the coefficient of rolling friction μ_R can be calculated: T x gradient/5.6. The factor 5.6 is merely 4(1 + k) where k is a constant (= 0.4) in the calculation of inertia of a sphere. T is the period of oscillation of the ball. You need to see Rod Cross's paper for the theory. Graph 1 shows the decreasing amplitude of the ball as it rolls back and forth. The period T is 0.98 seconds. Graph 2. The amplitude in radians plotted against time. The slope is -0.040 rad/s. The gradient was -0.040 radians/second. Using Rod Cross's formula I obtained a co-efficient of rolling friction of μ of 0.0070. The next thing to do would be to try different diameter balls - but I have exam papers to mark. Air Cannon Projectiles such as tennis balls, oranges and potatoes can be launched from a plastic pipe using compressed air. The device is called an air cannon and relies on a cylinder of air compressed with a bicycle pump being quickly released into a smaller plastic barrel via a quick-acting valve (hand operated or solenoid). There are many designs on the internet but for the purposes of a good EEI a small cannon should be made and the pressure restricted to a maximum gauge pressure of about 30 psi (200 kPa) for safety. You could examine the effect of pressure, barrel length and diameter on distance. Most of the designs on the internet look dangerous and may be classified as a Category B Muzzle Loading firearm under the Queensland Weapons Act (1990) because it could do "bodily harm" (bruising) so negotiate the design and safety considerations with your teacher (see "weapons" note above). If in doubt - don't do it. Another air cannon The photos below show the design of a typical air cannon. The rule here is simple, if you can't carry this out safely after having done a risk assessment, including arranging appropriate adult supervision, and meeting any legal requirements - don't even think about it. In fact, in Queensland, a compressed air gun like this is classified as a Category B Muzzle Loading firearm under the Queensland Weapons Act (1990) because it could do "bodily harm" (bruising) so negotiate the design and safety considerations with your teacher (see "weapons" note above). If in doubt - don't do it. It could be that it can only be used by a person with a Category A/B firearms license, either on a range or in a rural area with a property owner's permission. To anyone considering it, check before a breach of the Act is committed. It would seem very dangerous though - a small fracture in the pipe, a manufacturing flaw, or a weakened area around the solvent adhesive, etc could result in sharp fragments travelling in unpredictable directions. Under the Education Queensland guidelines it would (probably) be classified as an "Extreme" risk activity that needed parent consent and the Principal to sign off on the risk assessment. The masterpiece. To see an enlarged view, click the image. Pump up to 60 psi Pump nozzle The expensive valve The valve closed The valve open and whoosh Air powered potato cannon The other popular type of cannon based on the above design is the potato cannon. The details are easy to find on the internet. I was thinking that a good EEI would be to measure the range of a projectile when the cannon is free to move (on wheels) or placed against a tree. Soldiers know very well that if you place your cannon against the base of a tree you get better range. When a cannon is fired (restrained or free to move) the change in momentum is zero, hence, $mv_0 \cos\theta - MV_0 = 0$. If the work done by the expanding gases (W) is converted into the kinetic energy of the cannon ($\frac{1}{2}MV_0^2$) and the projectile ($\frac{1}{2}mv_0^2$), thus: $\frac{1}{2}mv_0^2 + \frac{1}{2}MV_0^2 = W$. Hence by combining the equations: $\frac{1}{2}mv_0^2 + \frac{1}{2}(mv_0 \cos\theta)^2/2M = W$. If the cannon is constrained the formula becomes: $\frac{1}{2}mv_0^2 + \frac{1}{2}MV_0^2 = W - U$ where U is the work done on the constraining tree. The rest of the equations take too long to code for this webpage so you should have a look at the linked article: Cannon recoil against tree. I'd be looking at whether the recoil adds a certain % increase in range or whether the elevation matters and so on. You should also see the "weapons" note above. Put the cannon on wheels and compare it to one staked to the ground. (Wellington Point State High School) "Windage" and air cannons To propel a projectile such as a cannon ball up a barrel it is essential that the compressed air doing the pushing can't escape around the sides of the ball. However, in the early days, because of irregularities in the size of cannon balls and the difficulty of boring out gun barrels there was usually a considerable gap between the ball and the bore - often as much as 5 mm - with a consequent loss of efficiency. This gap was known as the "windage". The windage of the guns was eventually standardised by trial-and-error: the bore diameter was to be 21/20 of the gun's round shot diameter. As manufacturing precision became greater it was reduced to 25/24. On the SBS program "Engineering Connections" Richard Hammond explained that windage was important in car engines too. There should be a minimum gap between piston and cylinder. He fired two projectiles out of an air cannon to show the effect of decreased windage (the one with smaller windage went 25% further in range). A good EEI would be to compare the effect of windage on projectile range (keeping everything else constant). The projectiles would have to have the same mass but perhaps you could make some wooden cylinders of slightly different diameters on the school's wood lathe (but how would you keep the mass the same?). Over to you. With the cannon ball placed in the barrel you can see the small gap. Close-up of the windage (about 8 mm). Nerf Gun ballistics You certainly don't need a weapons license for a Nerf Gun. They are available at big toy shops like Big W and Target for a cheapish price. The Nerf Gun fires foam projectiles up to about 11 metres. For an EEI you don't need lots of power and range, you need something that has a convenient range to measure accurately, and something in which variables can be controlled. There are many Nerf Guns on the market - from about $12 to $49. There is no point in getting a battery operated Nerf Maverick for $12.95 that shoots like a machine gun (except if you're playing Humans vs Zombies on Halloween). Better to get the Nerf-N-Strike Longshot Blaster for $49 which does a single shot from a long (90 cm) barrel a distance of about 10 m. You can vary the mass of the projectile by pushing weights into the foam, or you could alter the barrel length. Your main problem is how do you keep the pressure constant from trial to trial. Although a Nerf Gun could be considered a Muzzle Loading device under the Queensland Weapons Act it would not be considered a "firearm" as it could not do "bodily harm" (bruising). You should see the "weapons" note above. The Nerf N-Strike Maverick is cheap ($12) but the quick-firing is not much use in Physics unless Zombies are on the loose. A much better option for a Physics EEI is the Nerf N-Strike Longshot CS-6 for about $45. Also a great present for your Physics teacher. Sliding off a roof Particularly in colder climates, the problem of objects sliding off a roof is a big problem - mainly snow and ice - and many steps are taken to ensure this happens in a controlled way. A similar situation arises in amusement parks - particularly water slides - where the designers need to calculate the landing position of a person for a given incline angle, friction, and height of the launch point above the ground. For the diagram below the relationship is: $mgL \sin\theta - \mu\, mgL \cos\theta = \frac{1}{2}mv^2$. From this you can calculate launch velocity and hence horizontal range on landing. You could do a great EEI by considering these factors and seeing how they relate to your experimental data. What angle gives the greatest range - and why; and is this for all coefficients of friction? You could also consider a rolling object but rotational kinetic energy would also have to be considered. Observations to be made An EEI that is going to end in tragedy. Stanthorpe State High School perhaps. Measuring projectile velocity acoustically In the two experiments above, the range of the projectile is considered to be a measure of the velocity of the projectile. A neat EEI would be to compare methods of velocity estimation rather than just the factors that influence the range. I have seen an interesting method in The Physics Teacher (Nov 2007, Volume 45, (8), pp. 496) in which a microphone hooked up to LoggerPro or some other data recorder is used to measure the time elapsed from the initial explosion to the time taken for the sound to return from the target. You need a big metallic target like a thick sheet of aluminium placed say 10 metres away. Once the projectile strikes the target the sound is returned to the microphone at the barrel (muzzle) of the cannon. You get a waveform like the one below. The first part is saturated by the gas pressure as the projectile rushes up the barrel and the second point is when the sound returns to the microphone from the target. If you can work out the speed of sound you can subtract the time for the sound to return from the time after the ball leaves the cannon. v = s/t and you have your answer. Is this more reliable than a measure of range? How does range method and the acoustic method compare? Which is less prone to errors? Could you try 20 m rather than 10m? The possibilities are endless. Parachute descent and mass. Parachutes are not only used for sport but for dropping soldiers into war zones and delivering food and medicine to flood and drought ravaged countries. Even though they've been around for several hundred years it wasn't until after WW2 that the apex vent was invented. You could do an EEI to find out how drop time is affected by mass, canopy area, size of apex vent, number or length of strings, canopy shape and so on. That's Genevieve Ash on the right having a bit too much fun. Click here to download Moreton Bay College's Year 10 Parachute EEI task. Parachute terms Genevieve Ash doing her EEI at Moreton Bay College way back. Arrow range and draw A bow is a device that converts slow and steady human force over a distance (Work) into stored Elastic Potential Energy (in the form of tension in the Bowstave, Limbs, or Prod). This energy is converted into Kinetic Energy upon release of the Bowstring, and a great deal of that kinetic energy is transferred to the arrow. A bow is basically a spring which stores energy to be put into the arrow. However, 'draw' is not necessarily proportional to the force applied; and therein lies the complication. You could examine range vs. draw for an interesting EEI. You could consider a comparison of velocity by ballistic pendulum and by the range formula. A bow and arrow is not considered a "weapon" under the Queensland Weapons Act (even though it could be lethal - but so could a baseball bat or kitchen knife). It only becomes a "weapon" when used for a "behavioural offence" such as attacking a person. You should see the "weapons" note above. Some good advice on archery safety procedures is given in the Archery Australia Policy Number 1018 "Safety Guidelines" (2011) on their Policy and Procedures Website. Arrow elevation and range When you fire an arrow from a bow you will see that different angles of elevation give different ranges. In a vacuum it can be seen that the maximum range occurs for an elevation of 45º. However, in air, the range and elevation are not related so simply (see the two graphs below). This suggests several good EEIs. You could merely find out which elevation gives the best range when "draw" is kept constant, but you could also propose an hypothesis along the lines of "45° gives the greatest range" and that angles above or below this give a shorter range. Further, complementary angles are said to give the same range - but this could be tested (see diagram below). Lastly - is "range" the only dependent variable you want to look at. Perhaps an archer is more interested in "time of flight" as this may give better accuracy (less time for air resistance to apply). I have attached two pages from my New Century Senior Physics text that may be helpful in designing this experiment. Click here to download them. For safety information about archery, see the comments in the EEI suggestion above. Theoretical path of a projectile (in a vacuum). Complementary angles seem to give the same range - but is this true in practice? In air the path is somewhat different. This is for a cannon shell going to great heights - not an arrow. A protractor stuck to the bow and with a brass bob hanging down is one way of measuring the elevation angle. Practice firing by Year 11 Physics students at Wellington Point SHS, Queensland. Arrow accuracy and tail fletches Tail fletches are the feathers on the ends of arrows. You could do an accuracy comparison of Bulldog, Native and Pope & Young fletches; or you could try setting the fletches straight with no offset, straight with an offset, or left and right helical fletching. The combinations are enormous. You could investigate the errors with different fletches; why? What's the hypothesis? What is important - range or accuracy & why? For safety information about archery, see the comments in the EEI "Arrow Range and Draw" suggestion above. Three common methods of trimming feathers. Remember - the string on a Recurve Bow goes on the outside of the curve. Students often get this wrong. One way to measure long ranges. But how accurate is it? Slingshot range and draw You could always make your own slingshot and test out how it goes for different angles and amount of draw (pull-back). One student (Jack) at Kuranda State High School (North Queensland) made a huge slingshot using steel waterpipe and 8 mm thick speargun rubber. He worked out the spring constant in the classroom and then looked at conservation of mechanical energy in his big slingshot on the oval. He varied angle, draw and mass of projectile as his independent variables; and range was the dependent variable. The photos below came from his EEI. My thanks to his Physics teacher Ruth Moxon for getting Jack's permission to use these photos. Note: Slingshots are not "firearms" at present under the Queensland Weapons Act 1990 but there is a concern that commercial slingshots can be lethal. Of particular concern to police is the Saunders Falcon 2 Wrist Rocket Slingshot type which can be quite lethal. It may be described as a weapon in changes to the Act (you should check; and you should see the "weapons" note above). The one shown in these photos is not likely to be of any concern under the Act. The frame Measuring the spring constant Getting ready to fire The launch Measuring "g" using falling nuts Most attempts to measure the acceleration due to gravity end in disappointment as the errors in timing or from friction are a big problem. This suggestion requires the use of a set of steel nuts tied together with string at set intervals, and a microphone and CRO. Basically, you hold the nuts-on-a-string vertically and drop them on to an aluminium pie plate. The impact sounds are captured as a series of peaks on the CRO which allows you to measure the time intervals. The diagram below shows the setup. If you don't have a CRO in the lab, download a free sound analyser (Audacity or Scope for example). Click here to see my note about computer CROs further down the page. As it stands you have an experiment that could be done in the lab in a double lesson. Is this good enough for an EEI? No, you'll need to extend it so that you are using an hypothesis of some sort to guide your development of a procedure that extends the idea of measuring g with falling nuts. You could investigate ways to improve the accuracy of the method, you could look at the relationship between the measurement of g and other variables (weight of nut, spacing of nuts and so on). To get an "A" requires a carefully thought out plan of manipulating variables and detailed examination of all the uncertainties and errors you've coped with. Good luck. Get plenty of photos. Measuring "g" using a bouncing ball A neat way to measure 'g' experimentally is by using a bouncing ball (eg a superball). As it bounces the sound of each successive collision with a hard surface can be captured using a microphone and a sound recording program such as Audacity. From that you can work out the time interval between bounces. The key to the experiment is that the height of each successive bounce is a constant fraction of the previous height. This constant fraction is called 'restitution' and could be in the order of 0.7 for a superball on a hard surface. The ratio of h_2/h_1 is a constant (k) called the 'restitution'. It should also be equal to h_3/h_2. The time between the first and second bounce ($t_2 - t_1$) can be read off the CRO screen. At half-way in between the ball would be at the top of its flight. I got this idea from the work of Oliver Schwarz, Patrik Vogt, and Jochen Kuhn - Physics educators from Germany. The free-fall time of the ball from its maximum height h_2 (where it has zero velocity) until its impact is half of the time Δt between two impacts ($t_2 - t_1$). By using this and knowing that restitution (k) = h_2/h_1, and using the distance-time law for free fall, g can be obtained. I won't show you here as that is for you to work out - but it is only Year 11 kinematics. How do you make an EEI out of this? You would not be just trying to measure the value of 'g' at this location. You would need to investigate the conditions under which this result is the most reliable. You would vary the starting height (h_1) and see if that affects accuracy, and if their is some relationship between accuracy and the conditions of the experiment. You are bound to get different values for 'g' for successive bounces - but why is that? Do they vary in any sort of systematic way, or are they random. Rise of bubbles in soft-drink, champagne and beer. When you open a bottle of soft drink you get a hiss of gas escaping around the lid but you also get fizz of bubbles in the liquid itself. If the drink is warm, the formation of bubbles can be rather explosive. This is hardly new to you but the physics might be. Because gas solubility in drinks increases with pressure, the sudden reduction of pressure when a bottle of soft drink (or champagne or beer) is opened causes the gas to exsolve, forming bubbles. But if you look at the bubbles rising you may notice that they double in size by the time they get to the top. They also appear to accelerate upwards. See photo below (by Gerard Liger-Belair, taken from "Effervescence in a glass of champagne: A bubble story" in Europhysics News). Shafer and Zare (1991) took high-resolution and high-speed pictures, found that bubble growth rate is roughly constant. The pursuit of bubble physics is more than pure academic curiosity and pleasure. And it makes a good EEI. See their paper here. What causes a bubble to rise? The answer of course is that the density of a CO_2 bubble is less than the density of the surrounding liquid. The buoyancy force Fh is proportional to the volume of the liquid displaced by the spherical bubble (Archimedes' principle): $V_{bubble} \times (\rho_{beer} - \rho_{bubble}) \times g = V_{bubble} \times \rho_{beer} \times g$. (Assuming the density of the bubble of air is inconsequential compared to the density of the liquid. Note: V_{bubble} can be replaced by the volume formula $4/3\pi r^3$, and thus the buoyancy force is proportional to r^3. As a bubble rises, it encounters a frictional drag force that is a function of its radius and speed as well as of the viscosity, density and surface tension of the liquid it is in. If the ascending bubble had a fixed size, it would reach a constant velocity when the (upward) buoyancy force exactly counterbalanced the (downward) drag force. However, the bubble's radius is always increasing due to extra gas coming out of solution and into the bubble (and not due to decreasing hydrostatic pressure as is commonly thought). Thus the drag force, which increases less rapidly than r^3, can never quite catch up to the buoyancy force, which is proportional to r^3. In other words, the upward buoyancy force increases more quickly than the downward drag force, causing the bubble to accelerate upwards. This explains why in a stream of bubbles rising from a nucleation site on the beer glass, the bubbles near the bottom are smaller, slower and more closely spaced than those near the top. For example, a bubble with a radius of 0.5 mm rises in beer at 90 mm/s, but a bubble with a radius of 0.03 mm rises at only 1.0 mm/s. Although bubble radius varies linearly with time, bubble speed increases with time. This suggests a great EEI. My thanks to Brisbane Physics teacher Mike Hennessy who's students have completed many successful EEIs on this topic (and thanks, he says, to the parents who were willing to open lots of champagne for their sons and daughters to video bubble rising in slow motion). To collect data, all you really need is a thin ruler of some sort that can be placed in the bottle of drink when it is opened, or glass of drink when it is poured. Of course, a camera with high speed capabilities would be good. The iPhone6 works well for instance. The rest is up to you. Speed of sound in air as a function of temperature For his Year 11 EEI Chamara Perera from Wynnum State High School (Brisbane) made use of the coldroom at MacDonalds where he worked after school. Here's what he said: "The pictures (below) show the length of PVC pipe placed on a piece of ceramic tile (to ensure a crisp echo), with the microphone placed at the opening of the (closed) pipe. I found that the click of a pen worked really well when used to make the noise to echo, registered very clearly on the computer. The older version of the program 'Audacity' was used as the recording program, I say older program because that one measured down to more significant figures whereas the new doesn't. Measurement was then taken from the peak of the first registered noise to the peak of the second. To vary temperature, I took this very apparatus to the fridge at work which was about 5°C, the freezer at work, -21°C, outside on a cold night, about 11°C, up into my roof on a hot day about 30°C and finally just at room temperature, about 24°C. All temperatures were measured vary accurately using a temperature probe and the program Logger Pro 3.4.5". As a matter of interest Chamara obtained a resonant frequency of 240Hz at 4.2°C, 246.8 Hz at 21.1°C and 248.3 Hz at 25.8°C (I won't include all his data as you have to do this for yourself). The questions you could ask are: did you try other lengths of pipe; was the frequency of the sound important; did you try other independent variables; what was the source of any errors; is there a phase change upon reflection and is this a problem, what are the limitations of the experiment; why is this important to you and to society...and so on. Full setup Making the click The reflecting end Resonant frequency of an open pipe - when "open" is not so open. A fascinating EEI can be made out of a pipe experiment similar to the one above - but using an "open" pipe. If you slap one end of an open pipe with a piece of soft foam (rubber 'thong' or 'flip-flop', or even a piece of polystyrene foam) the air in the pipe resonates. The loudest frequency is the fundamental providing you have chosen a pipe of suitable length that resonates in the audible range. A length of 60 cm is a good start. When the compression wave travelling down the pipe meets the outside air at the end, the wave is partially reflected (and partially transmitted). It is the reflected wave that sets up the resonance condition that you will have learnt about in class ($f = v/2L$). You need to include end correction into your calculations (= 0.6133r for each end). However, here's the question: what constitutes an "open" end? If a ceramic tile (or any hard surface) was placed 1 cm away would the end still be "open"? What if it was 10 cm away - and so on? I tried this and found a delightful result. Yes, from about 0.75 cm to 6 cm there is a variation in resonant frequency but outside of that - nothing. The experiment is quite simply done but - be warned - the physics of gas behaviour at the end has not been studied much and would challenge university physics students. But this doesn't mean you can't get some great data to explore; and discuss the situation in high school physics terms. This would be a fabulous EEI. Here's the setup I used at Moreton Bay College to trial this. The hand belongs to Jade - who was slapping the end of a plastic pipe with some polystyrene foam. The microphone was connected to a computer running Soundcard Scope (but any similar program eg Audacity would work). Here's the graph of our results. I have purposely left the scale off the x-axis so that you can't just use these results. The distance from the tile to the open end of the pipe varied from about 0.75 cm up to 7 cm. The temperature, length of pipe and internal diameter must be recorded. Hydrogen explosions - the origin of the 'pop' sound. At some stage in science class you will have tested for hydrogen gas by placing a lit match to a test tube full of the gas. You would have heard the distinctive 'pop' sound as it ignited. Wouldn't it be great if setting fire to hydrogen was your EEI? Hydrogen is likely to be the most important future energy source with the potential to make significant reductions in greenhouse gas emissions. Safe use of hydrogen by the public requires that the safety issues have to be investigated. Its behaviour in accident scenarios has to be predicted, allowing safety measures to be developed where necessary. A key factor in this process is predicting the release, dispersion and combustion of hydrogen in appropriate scenarios. Investigating the events of a hydrogen 'pop' in a tube can be most instructive. A hydrogen 'pop' by students Morgan and Erin at Our Lady's College, Annerley, Brisbane. When a test tube of hydrogen gas pops, a flame front travels down the tube as the gas burns. The temperature rises quickly to 3000K. Because it is so explosive, a compression wave (with a pressure of about 7 atmospheres and speed of some 3000 m/s) travels down the tube and possibly reflects off the closed end and then travels back up the tube in the heated gaseous products. In the video you can see where I recorded the 'pop' with the audio program Audacity. From that you can analyse the waveform for frequency and see if it varies with time. Does the frequency or 'envelope shape' depend on the diameter or length of the tube (for Physics students); or even the H_2/O_2 ratio (for Chemistry students). This is so much fun. I've analysed the sound from the clip above using Soundbooth and Audacity and it looks like the images below. If you want a audio recording of the pop to try out, click here. Programs such as Audacity or Soundbooth (above) can be used to analyse the sound. The big peak comes 0.023 s after the sound starts and it has a frequency of 1000Hz. Audacity Spectrum plot of the sound from the video. Plasma Speakers - "Can't touch this" Often a student will ask if a "plasma speaker" would form the basis of a good EEI. Plasma speakers are a form of loudspeaker which varies air pressure via a high-energy electrical plasma instead of a solid (cone) diaphragm as in a normal speaker. When the plasma speakers are connected to the output of an audio amplifier, the plasma glow discharge acts as a massless radiating element, creating the compression waves in air that you hear as sound. In essence it is a circuit that produces a high frequency voltage modulated by an audio frequency (some variants simply use the 555 Timer IC for this). The modulated result is fed to a flyback transformer (via a power Mosfet) to produce a high voltage high frequency arc. The audio modulation of the arc causes it to produce (Low-Fi) sound. However, the high voltages and heat involved make this a real electrocution and fire hazard. Physics teacher Craig Airton from Tannum Sands SHS (Queensland) said: "I had a student build one of these two years ago. It was fully functional and had quite impressive sound quality, however, he burnt holes in the carpet at his house and received electric shocks (not burns). I would not approve it again due to the high risk". Plasma discharge (Indestructibles) Home-made electrodes: a couple of nails in a piece of pine. Don't rest it on mum's carpet in the lounge room. If you are keen to see what they are all about have a look at The Indestructables - Plasma Webpage. What you must ask is "could it make a good EEI?" The problem is, if you are doing a "manipulated variable" EEI then you have to decide what variable you are going to change (the independent variable) and what you are going to measure (the dependent variable). Then you have to propose a hypothesis linking the two conceptually (and maybe mathematically) and then provide a justification for your hypothesis using physics concepts, fact and principles. No easy task for a Year 12 student. The chances of a good mark maybe very slim so think carefully before you press ahead. In fact, when you do your risk assessment you will probably find the hazards of electric shock, fire, UV radiation and X-Rays are too great. Guitar Pickup - 1 The electric guitar pickup works on electromagnetic induction principles. A permanent magnet induces magnetism in a steel string and when the string moves its magnetic field induces a tiny electric current in a coil of wire. This current is amplified after it leaves the guitar and fed into loudspeakers. The electric guitar pickup was developed in the 1950s and has changed little over the following 60 years probably because it was so simple and worked so well. It makes a terrific EEI. The six separate magnets are surrounded by a single coil of wire of about 5500 turns. The magnets are positioned directly under each string. On many guitars the magnets can be seen to be different distances away for different strings, and the arrangement has to be suitable compromise for picking up vibrations of the thick "bass" strings and the thin "treble" strings. A mock-up of a single pickup coil to show the direction of an anticlockwise winding (as viewed from above). When the south pole in the string (shown in grey at the top) moves towards the coil a south pole is induced at the top of the coil in accordance with Lenz's Law. The right-hand rule can be used to predict the direction of the current and which end will become positive (A or B). What variables can be used: the size of the current depends on the number of turns ("wraps") of wire in the coil, its resistance and the cross-sectional area of the coil. The most common arrangement in a real guitar is about 5000 turns of a very fine copper wire (42 gauge, 0.064 mm diameter, insulated with an enamelled coating (not plastic-coated that you are familiar with from the lab)). Varying the number of turns also varies the resistance. The induced current also depends on the magnetic field strength of the steel wire string, the distance between string and coil and so on. Lastly, the magnetism in the string depends on the strength of the permanent magnet, its distance away, and the size of the string. You can see there are many variables to explore. What you may have trouble with is investigating how well the vibrating frequency of the string is reproduced by the coils. Because the current in the coils is alternating you will get a capacitance and inductance effect that is dependent on the frequency. The coil described about seems to have an optimum frequency of 7.4 kHz so you may need to work out how to tension your string to get this sort of value as a starting point. You may also need to work out where to place the pickup along the string and where the string should be plucked (plucked midway may give the fundamental but guitar players tend to play the strings about 1/7 of the way along to get rich overtones - but do you want that complication for a Physics EEI?). I used an electric drill to wind the coil. I just put a bolt through the spool and inserted it into the chuck of the drill. You can get 0.25mm diameter enamelled copper armature from Jaycar for $7 for 65 metres. Girls at Moreton Bay College used a digital tachometer that we bought from Jaycar (Cat. QM1448) fro $80. It worked flawlessly. Just put some reflective tape (supplied) on the chuck of the drill and point the laser in the tacho at it and away they went. Perfect. Rules of thumb they use are: the more windings you put on, the stronger the signal output, but higher frequencies will suffer; thinner wire cuts high frequencies more than thicker; tall skinny coils give a cleaner sound and shorter fat coils sound more "dirty". Guitar players often wind their own pickups (Eddie van Halen for example on the homemade Frankenstein Stratocaster-style guitar used for his classic Eruption). I made up a sonometer with a piece of pine 85 cm long with wood at either end to raise the string. Strings are about 110 cm long. The coil has a steel bolt through the middle with a rare-earth "super" magnet underneath. The lab jack is used to raise the coil to the right height. My thanks to Georgina for the photo. Her group (with Georgia and Shannon) wound various coils from 200 to 800 turns. Some hints: Guitar strings come in various diameters but you need to get "plain" ones that are not wrapped with additional wire. The wrapping they use is mostly nickel or stainless steel which complicates the design of the experiment. The first 3 strings on a guitar (high E, B, G - that is the highest pitch ones (closest to the ground) - are plain. The uppermost 3 (D, A, low E) are wound. I chose the G-string as it was the thickest (0.016 inch - commonly said to be "16 thou" referring to it's diameter of 16 thousandths of an inch. They never refer to diameters in metric (0.4064 mm) even in a metric country like Australia). The string has a "ball end" which is a little brass cylinder that you can fit a screw through. Make sure you get plain steel though, and not a iron-nickel alloy string. You could use a CRO to analyse the output but I thought I'd try a computer's sound card. I connected the two wires from the coil to a 3.5mm mini jack and plugged it into the microphone socket (pink) on the computer. I captured the waveform using Adobe Soundbooth (with the gain turned right up as I had just 300 turns on the coil). The frequency measured was 75.6 Hz. Using Audacity I also got 75.6 Hz. I found that picking the string with a stiff-bristle artist's brush kept the interference to a minimum. With effort you could get a cleaner waveform. Good luck. This promises to be a fabulous EEI. If you can't get a signal check that the microphone is selected as the input device in the audio mixer. It can be very frustrating if you don't get the input selected properly. Where to get the rare-earth magnets? If your school doesn't have a supply, you can buy them or pull them out of old hard disk drives. Secondly, manufacturers and hobbyists dip their spools in melted wax for about 20 minutes to get rid of air bubbles. Should you? This gives them more consistent results (as well as lowering their resonant frequencies a tiny bit); so 'yes', if you have time, do it but it is not critical for an EEI. What about the wire? The finest enamelled copper wire is 42 gauge which sells (as 'magnet wire') on eBay for $7 for a 2000 m spool; Jaycar (Australia) doesn't have wire this fine - but they have 33 gauge wire - 0.25 mm diameter - 60 m for $7. A coil of 600 turns on a cotton reel with takes about 60 m of the 0.25mm enamelled wire. Ideally you would use finer wire and more turns - perhaps 5000 to 8000 like they do on real guitars. Guitar Pickup 2 - The Humbucker A simple guitar pickup with one coil ("bobbin") of wrapped wire (as described above) is called a single coil pickup. Look at any original Stratocaster built between 1954 and 1979, and you will see three single coil pickups (below). The Fender Stratocaster showing the three sets of single-coil pickups. In 1977, the middle pickup was changed to "opposition" by reversing the direction of the wire wrap and changing the polarity of the magnet. When pickups 1 and 2, or 2 and 3 were used together the hum was cancelled but the strong signal from the string was retained. This was equivalent to the Gibson Humbucker. Single coil pickups are good in one way but bad in another. The good way is that they produce a "twangy" tone that many guitarists like. The single coil tone is a sound that has become closely identified with the Stratocaster. The bad news is that single coil pickups are subject to outside signal interference, resulting in "hum" or "noise" because the single coil will pick up a variety of stray fields from nearby equipment. Gibson guitars, by way of comparison, employ a dual coil pickup, which are essentially two bobbins wired in opposite directions that "cancel", or in Gibson terminology, "buck" the single coil signal interference: the classic "humbucker". Stray magnetic fields passing through the loops induce opposing currents and the result is zero current. Hence - no hum. However the magnets in the two coils are also reversed: in the first coil of the humbucker, the magnets are North pole up; in the second coil, the South pole is up. That makes the induced currents add, giving more output and a "fatter" tone. Gibson Humbucker. The two bobbins (each with six magnets) are connected "in opposition". The idea of reversing one loop of a pair to minimize interference has been around since its invention by Alexander Graham Bell in 1881. Telephone wires were twisted together ("twisted pair") for this purpose. More recently, the principle of common mode rejection in audio recording relies on this idea. A mock-up of the two coils of a Humbucker. Imagine a stray magnetic field ("Hum") threading the loops of both coils in the same direction (say increasing downward). The coils would oppose this change by generating fields in the upwards direction with and "A" would become negative. For the 2nd coil "B" would become negative. The two currents would oppose each other and cancel out. However for a string moving towards the coils the currents would add together to produce a strong signal. If you are discussing this in your EEI you'll need to refer to Lenz's Law and explain the process (I'm not going to tell you). So it has social and economic importance. So, how to make an EEI out of this? You could investigate how effectively the humbucker cancels noise from different directions (over, under, sideways, down) while still doubling the wanted signal. I'd be looking at the Common Mode Rejection Ratio (CMRR, measured in decibels) as a function of your manipulated variable - whatever you choose it to be. This EEI would require a considerable amount of research to design a worthwhile investigation. Guitar Pickup 3 - Different loads on a guitar pickup To follow on from the EEI suggestions above: one thing that guitar hobbyists argue about is the effect of different loads on the pickup? The three basic elements of passive electrical circuits interact in the guitar pickups, cables, and load, and all affect the signal that finally reaches your ears. These three elements are resistance, inductance, and capacitance. The general term impedance is used for all three or any combination of them. One this they discuss is the value of boutique cables (see below) - special low resistance, inductance or capacitance cables that are said to give a sweeter sound or other such vague claims. According to the U.S. manufacturer of Zerocap cables: The ZEROCAP cable reduces the cable capacitance to near zero (~60pf), which is effectively the capacitance of the connectors. Even the best guitar cables have 15 to 30 picofarads of capacitance per foot, amounting to a tone killing 650 picofarads for a 20 foot cable. The ZEROCAP cable lets you use long guitar cables with little high frequency loss. The ZEROCAP cable eliminates the "tone suck" when you roll back the guitar's volume pot. The output from a pickup is an alternating current and as such responds differently to the type of cable it is being fed through. You could investigate the effect of capacitive loading by comparing the output of a pickup with a normal length cable, an outrageously long cable (maybe a 50 m roll with connectors attached to each end) and a normal cable with a test box that puts different capacitors and resistors in parallel with the pickup. You could also look at the effect of frequency because capacitive impedance drops as frequency increases, and inductive impedance rises - so there is a trade-off. Here's a comment from a guitar hobbyist's blog: When you play with "hot" (low impedence) pickups for the first time, their sensitivity and output level are impressive. There's plenty of signal - sometimes enough to overdrive even what you don't want overdriven. If you want to blast an amp into distortion this is the way to go, punching out every last watt with every pluck or strum. But play soft, or turn your guitar down for a clean sound, and you may be disappointed. Where are those soaring highs, the clean brilliance, the crisp bite you got with your original pickups? Why do chords now sound so dull? Suddenly your hot pickups are only lukewarm. Could it be the cables? People say that long cables can dull your sound. But why only with these pickups? What's going on here? Keep your cables as short as possible! Half the length means only half the capacitance. If you must run long ones, use high quality, low capacitance cables. [Website URL - This is not an EEI for the faint-hearted. It is complex and has complex physics principles behind it. You would only attempt this if it all makes sense and you can see where you are heading. Be warned - without adequate theory to back up your design and discussion it may be nothing more than a hobbyist's "trial-and-error" Saturday afternoon project and unworthy of an "A". Factors affecting the frequency of an organ pipe This is another music-related investigation you could undertake - but it also applies to the exhausts of motor cars and bikes; for example, auto engineers make the exhaust pipes such that they resonate at certain desirable frequencies. For some V8s with a separate tailpipe from each bank of cylinders they run a 60mm pipe down each side and put a 50mm pipe joining them to generate beautiful beats. So organ pipe physics is used all over the place! Why not investigate end correction for different wavelengths and diameters of a simple pipe (eg PVC plumbing pipe); and for open and closed pipes. How does temperature play a part? Spacing between successive turns of a slinky suspended vertically under its own weight Here's a good one if you like playing with toys. When suspended vertically, a slinky will stretch enormously even under its own weight, its extension being tens of times greater than its undistorted length L_0 when not hung, depending on the size and material of the toy. Here are two suggestions: Suggestion 1. Suspend the slinky from any turn along its length and let the rest of the n turns below it dangle freely. Then measure the free-hanging length as a function of the number of turns in it, L(n). Physicists have calculated that $L(n) = (mg/2\kappa)\, n^2$ where κ and m are the force constant and mass of a single turn, respectively. See reference below. Suggestion 2: choose a slinky such that when suspended from the ceiling freely it stretches nearly all the way to the floor (a longer one may be cut to size). Measure the distance from the bottom end as a function of the number of turns, y(n), as you advance up from the bottom of the slinky (L_0 is the full length of the stretched spring; L = length of the spring unstretched (lying on it's side), y = distance from bottom up to turn n; N = total number of turns. Physicists have derived a formula for this: For either: What is the effect of added mass; why would anyone want to know this - what's the point? Compare a steel and plastic slinky. How do their spring constants vary? Source: Paul Gluck (2010). A project on soft springs and the slinky: Physics Education V45(2), p 180. Magnetic Field in a Slinky The availability of inexpensive Hall Effect magnetic field probes enables an interesting EEI to be done into the magnetic field strength inside a slinky. You can insert the probe beteen adjacent turns (see photo below) and measure the field as a function of the distance between turns (or turns/metre). For a second variable you could try changing the current or placing the probe at different distances from the centre. However, if you don't have a Hall Effect probe (eg from Vernier Software) and want to make your own there is a good article (for download) in Physics Education V45(5), September 2010, page 529. Hertzian Waves Many early experiments with radio used sparks as detectors and as sources of electromagnetic radiation. A good EEI would be to investigate the electromagnetic nature of radio waves. You could find out if the strength of the signal decreases of intensity with distance from the transmitter, and to investigate electromagnetic shielding. One way would be to tune a transistor radio (not digital) between stations. The radio almost certainly has an automatic gain control and so will be more sensitive when tuned between stations. However the background noise - also broadband noise - will be stronger too. Hold one end of the wire to one end of a 1.5V battery. With the other end of the wire briefly scrape the surface of the other battery terminal, making sparks that will be visible in dim light. You could use a CRO to measure the loudness of the crackle on the radio. What happens with distance, voltage of the transmitter, shielding (paper, metal, glass) between transmitter and receiver. Speed of Sound in a Metal Rod (see four approaches below). An experiment commonly used in first year physics at university is to determine the speed of sound in a metal rod. If you use metal rod clamped at the centre, standing waves can be formed in the rod by striking one end of the bar (end on) with a hammer. Since the bar is clamped at its mid-point a node forms there while antinodes form at the free ends as shown in the diagram. If the bar is vibrating in its fundamental mode, then the wavelength of the wave in the metal is equal to twice the length of the bar (L). So fair = f rod; hence $v_{rod} = f_{rod} \times \lambda = f_{rod} \times 2L$. You'll get a lot of (odd, 3rd, 5th, 7th ...) harmonics thrown in but the fundamental should be the strongest. So what variables are you going to manipulate to make a great EEI. Some continuous variables are: Perhaps see if the velocity is constant for different lengths. Does temperature affect the speed? Some discrete variables to manipulate are: What about other nodal positions: can you suspend the rod to get the 2nd harmonic and how does the speed compare when it is vibrating in the 1st harmonic? What about other metals; what characteristic of metals (Young's Modulus perhaps) provides a continuous variable that can be tested. The error analysis for any of these will be so important. The following gives you some ideas about some techniques that may work well: Speed of Sound in a Metal Rod 1 - Microphones and CRO. The frequency of the standing waves in the rod is equal to the frequency of the sound produced and this can be determined by using a microphone connected to a CRO, or if you have it, DataLogger Pro or similar. You'll get a lot of harmonics thrown in but the fundamental should be the strongest. So fair = f rod; hence $v_{rod} = f_{rod} \times \lambda = f_{rod} \times 2L$. You may be lucky enough to have access to a computer program that analyses the sound from the microphone (may have to amplify) and applies a Fast Fourier Transform technique (FFT) to convert the frequencies being received to a spectrum of amplitude vs. frequency: the largest peak amplitude being the fundamental frequency of the rod or bar. One student struck a problem with this method: she used a 20 cm rod of steel of 0.75 cm diameter and got a frequency of 2500 Hz using LoggerPro. This corresponds to a speed of sound in metal of 1000 m s^{-1} instead of 5000 m s^{-1} as expected. There's a great article in Physics Education about this (see caption below). This diagram has been taken from a great article in Physics Education 35(6) November 2000 entitled "Measurement of the speed of sound in a metal rod" by Se-yuen Mak, Yee-kong Ng and Kam-wah Wu from The Chinese University of Hong Kong, Shatin, NT, Hong Kong is attached for research purposes only (click link to download). If you have problems getting a trace on your CRO see the note below. Paige Kurmass from Thuringowa State High School, Queensland, gives the thumbs up as everything is working in her EEI. She used apparatus as shown in the diagram to the left with different lengths of steel "reo-bar" and determined the effect of temperature on the speed of sound. In her Conclusion in the EEI she commented on the problem of reflection of sound waves from the walls of the lab, and problems in heating such long lengths of rod. Speed of Sound in a Metal Rod 2 - Electromagnetic method Another good method is to use an iron or steel rod with a loose coil wrapped around one end. If the rod is slightly magnetized (as it is in the Earth's magnetic field), the increased density at the compression maximum will be accompanied by an enhanced magnetization. When this region of higher magnetic field passes through a pickup coil placed around the rod (see Fig. 1), an EMF will be induced. The signal, consisting of a series of pulses, may be fed directly into an oscilloscope. This method is described in The Physics Teacher V40, Jan 2002, p56-57 (attached for research purposes only - click to download). If you have problems getting a trace on your CRO see the note below. Speed of Sound in a Metal Rod 3 - Time of Flight method If you use a setup as in the diagram below and strike the end of the rod with a hammer, the CRO will record the initial hammer strike (Channel 2), then the sound at the far end that has travelled through the rod (steel, about 5000 m s^{-1} for a longitudinal wave and about 600 m s^{-1} for a transverse wave) on Channel 1, then lastly the sound of the hammer blow that has travelled through the air (340 m s^{-1}) again on Channel 1. If you have problems getting a trace on your CRO see the note below. Hitting the rod laterally (on the side) as in this diagram will favour transverse waves (v = 600 m s^{-1} in steel). If you want to get longitudinal waves (v = 5000 m^{-1}) then you should hit the rod on it's end. Speed of Sound in a Metal Rod 4 - Transverse Resonance. The setup used in any of the suggestions above can be used to general transverse waves. To do that you have to hit the rod on the side near one end - at right angles to the rod. It will then vibrate like a tuning fork prong. The node will still be in the middle and you'll still get the first harmonic where λ = 2L. However, the speed of sound due to translational waves is about 1/8 of the longitudinal speed. There is a formula to work out the speed: $v = \sqrt{2\pi f c K}$ where $c = \sqrt{Y/\rho}$ and Y is Young's Modulus for the metal (200 x 10^9 N m^2 for steel), and ρ is density (7800 kg m^{-3} for steel) and K = radius/2. So for a steel rod 5 mm in diameter and 20 cm long: v = 630 m s^{-1} for a transverse wave. This is about one-eighth of the value for the longitudinal wave. Note about digital CROs. If you are after cheapish computer-based CROs you can get a "Focussz" Chinese 44MHzUSB-CRO on ebay for about $40. I bought one (it works well but I have problems with adjusting the display, and the manufacturer www.focussz.com won't reply. There is also a less-useful 5 kHz one for $25 from a different company and may be okay for most EEI uses. However, there is also a free (to schools) software one called "Soundcard Scope" that uses the computer's line-in socket on the audio card. I have downloaded it and tried it out and it is quite remarkable. I struck a 440Hz tuning fork at the correct position for a pure tone and the software gave me 440.3 Hz. Not bad for a free CRO. It is written by Christian Zeitniz from Germany and is available at . If you have problems getting a trace on your (non-digital) CRO see the note below. Soundcard Scope by Christian Zeitnitz - in voltage mode Frequency analyser mode I bought a bunch of 20mm diameter aluminium rods of varying lengths(1.8m down to 30 cm)from the local metal dealer (he cut the ends perfectly square as you need for "singing rod" experiments). I held them vertically at the middle (to cancel transversewaves) and struck them square on the end with a steel hammer and they "sang" beautifully. Using the microphone, I collected the signal on the CRO. It was a bit messy as it had many overtones present but when I used the "frequency analysis" option it showed the big fundamental and all of the overtones as a histogram. You could see the various overtones die away in real time. I did this for all of the rods and the calculated speed of sound in the rods was almost all identical. I plottedf (y-axis) vs 1/(2L) and the gradient is the velocity. I got 5035.76 m/s whereas the accepted value is 5091.8 m/s. There are many great EEI possibilities in this setup. PS: I bought my 20mm aluminium rod from Brisbane Steel Supplies at Capalaba for $33.20 for a 4m length (cut to size for free). One hint passed on to me by a teacher who had problems getting a signal (it kept switching off): some computers have an echo cancellation option that is automatically switched "on" and has to be checked "off". Here's a screen capture showing the fundamental frequency of a 1.200 m singing rod and a frequency of 2104 Hz. Click here to see a larger version plus some notes. Another note about CROs This is NOT an EEI suggestion but a couple of helpful hints from Alan Whyborn of Urangan State High School. If you can't get a trace on your CRO from a microphone you could: 1. Check the range switch on the probe: most probes have a range switch on them to switch between 10x, 1x and sometimes earth (to get a zero baseline). Make sure the probe is NOT on the earth position. (The input channel controls also have an AC/DC/ground selector - make sure you don't have it switched to ground). 2. Channel selector: ensure you have selected to display the channel to which the probe is connected. 3. Triggering: this is quite likely to cause the problem (if the trigger level is set beyond the range of the input signal you won't get a trace on some trigger settings). Make sure the trigger is set to the input to which the probe is connected and adjust the trigger level until you get a trace - or try setting trigger to auto. 4. With the signal generator, if it is one of the earthed mains powered generators you MUST make sure you have the polarity on the connecting wires correct. Otherwise you will simply short out the output via earth and get zero signal reading. If it is a battery powered (hand held) generator it shouldn't be a problem - these are generally "floating" and have no earth. (worth noting here that the earthed mains powered signal generators only need ONE wire, not two, to complete the circuit, so if you have an RCA lead connected to the generator and a probe connected to the CRO you only need to connect the probe to the centre post and ignore the earth alligator clip. This MIGHT introduce a bit of 50Hz interference but compared to the generator output it should be negligible) 5. Most mics will only produce a very small voltage unless they are powered (perhaps a battery in the mic) so you will have to set the range selector on the input to a low voltage setting. 6. Make sure the vertical offset is not adjusted so high (or low) that the trace is off the screen. 7. If none of these work, maybe you have a short in the wires you are using. If the CRO is measuring DC voltages it SHOULD work fine for AC, so I would doubt it is a fault with the CRO (unless perhaps the fault is in the trigger circuitry, but that is not likely). Good luck. Alan Whyborn - Urangan State High School Speed of sound - resonance method One of the important investigations carried out by professional scientists is to improve the accuracy of physical quantities such as specific heats, resistivity and so on. The National Physical Laboratory in London was set up in the early 1900s to do just that. As part of the investigation they look for errors in methods and try to minimize them. This idea can form the basis of many EEIs - that is to extend simple experiments by extending the range over which variables are measured or to improve accuracy in existing methods. One simple but excellent experiment is carried out in high school physics labs throughout the world: the measurement of the speed of sound by resonance, in which a tuning fork is held at the end of a close (at one end) tube and the tub's length varied until resonance (loudness) is heard (see photos below). The length of the tube can be varied by immersing it in water. A good EEI would be to measure the speed of sound using the first harmonic condition (pictured below) but trying it for a range of frequencies. Is there a relationship between frequency and the speed? If there is we have a problem that bears investigating. Moreton Bay girls seek resonance Speed of sound - is "end correction" really that correct? Following on from the description above - just how correct is the end correction formula: $e = 0.4d$? The end correction is the amount of length you have to add to the value for the length of the air column to get a correct value for the speed of sound. It is like a "fudge" factor but can be justified by physics theory. My thanks to Brianna for letting me photograph her during the experiment. Where was everyone else in her group? Good question. Taking photos of themseves in slow motion I think. It would be interesting to see how accurate this factor is. For the first harmonic $\lambda = 4(L + 0.4d)$; for the next harmonic, the third harmonic (remember only odd harmonics with a closed pipe) $\lambda = 4/3 (L + 0.4d)$. If $v = f \lambda$ and v and f are constant then the velocity for the 1st and 3rd harmonics should be equal. You can solve for "end correction". What of the 5th and 7th harmonics; and does it vary with temperature, diameter of pipe and so on. This would be a great EEI that you could do at home or in the bush. There are some terrific journal articles on this: I'd start with Pat Chiarawongse's IB paper on "The Effect of Diameter on the End Correction of an Open-Ended Tube". Speed of Sound - using the stereo microphone input of a computer The little "ear bud" headphones can be used as microphones if they are plugged into the microphone socket of a computer (pink socket). They are poor microphones but are good enough for a physics experiment to measure the speed of sound. If the left and right earbuds are placed 1 metre apart then a sound coming from one side, in line with the earbuds, will take about 0.003 s to get from one to the other ($t = s/v = 1.00/330 = 0.003$ s, assuming that sound travels at 330 m/s in this example). If you use audio capture and analysis such as Audacity or Adobe Soundbooth you can measure the time fairly accurately. If the earbuds are far apart you get a more accurate time but the intensity of the sound at more distant earbud is reduced and hard to analyse. It is a tradeoff between time and intensity. I tried earbuds 10.5 cm apart and made a sharp noise by hitting a two steel bars together. I found that by hitting a glass bottle with a steel rod I got a sharper sound. Some earbud types don't seem to work. The white ones that come with an i-phone or Mac work really well. The waveform is shown below. The time seems to be 0.000305 s which gives a speed of 344 m/s. The air temperature was 20°C. This seems to be spot on as the accepted value for sound at 20°C is also 344 m/s. There's a good article on this in The Physics Teacher V50, May 2012 p308 where Patrik Vogt and Jochen Kuhn from the Department of Physics, University of Kaiserslautern, Germany, discuss further investigations. They try putting the earbuds in plastic bags and measure the speed of sound in a trough of water. A good EEI would be to try different distances and measure the times. Theoretically, a graph of t vs d should go through 0,0 and if it doesn't this may give you clues to a systematic error in the measurement device. I tried it and got a perfectly straight line going through 0,0 and the slope gave a speed of 344 m/s, so 0% error; not too bad! Then you could try different gases, or different temperatures, or water, or tape them to a steel rod, a wooden bench and so on. Screen shot of an Audacity waveform from my trial in which the earbuds were 11 cm apart. You need to remove all but the segment of the waveform that you want and then "amplify" it from the Effects menu. The red lines have been added to the image later. Vogt and Kuhn obtained a time difference of 1.49 ms with their setup, having the earbuds 50 cm apart. They calculated the speed of sound in air to be 336 m/s. accepted value is 344 m/s at 20°C. Time dependence of static friction This is going to be a tricky one and I haven't seen it done in a high school lab before. The research question posed is: how does static friction vary with contact time? That is, if you leave a block of wood sitting on a bench, is static (not dynamic) friction greater the longer you leave it. This is important in industry where detailed knowledge about static friction materials is required for the accurate calculation of the braking torque needed to hold a load at rest. This is particularly important for brakes in cranes, elevators, hoists and mining winding machines, which must meet specifications such as the definite value of the static safe braking factor. The study of static friction is also a useful supplement to the dynamic testing of brake friction materials. The time-dependence of static friction can be explained by the fact that the real contact area is a function of time. The (weight) force on the surfaces in contact gives rise to plastic deformation and causes the material to creep. Perhaps you could get some similar objects (steel, aluminium or wooden blocks and leave them on a surface for different times and measure static friction). Perhaps an incline method would be more accurate (measure height rather than angle). I've attached an interesting article by S.F. Scieszka and A. Jankowski (Poland) from the Tribotest Journal V3(2) 1996 where they show that the coefficient friction is time dependent (by up to a maximum of 7-15%): $m_s = m_o + c_1t/(c_2 + t)$, where c_1 and c_2 are constants. If you wanted to do it with low cost materials, I looked at using pine paddlepop (icypole) sticks and chopping one into bits and letting a piece slide down. Glued two bits together for a heavier object, then three. Hmmm, not happy! This could be a truly great EEI. Rolling ball down an incline I once watched my own children roll a ball down an incline and as the incline angle was increased the ball sped up. However, there came a point when it got slower even as the incline was made steeper. That made me think it would would be a great EEI as it was a bit unexpected. Obviously when the angle is 90° it won't go far - but what happens at smaller angles. A good research question is "for what angle will the horizontal speed be the fastest?" or if you are measuring the time to travel across a table (see diagram below) "for what time of travel across the tabletop be the least"? An interesting discussion by Physicist Mark Lattery from the University of Wisconsin USA appeared in Physics Education (V35(2) March 2000, 130-131. (click to download). You really need to look at changing another variable to look for interrelationships in the data (size of ball, balls of differing restitution) as this is a key criterion for an "A" in IP3. This will be so much fun. Bifilar pendulum A bifilar suspension pendulum is one in which two (bi) filaments (filar) support a rod. A schematic of this arrangement is shown in the figure below. Bifilar pendulums have been used to record the irregular rotation of the earth as well as to detect earthquakes. If a magnet is used instead of the rod, the rate of oscillating can be used to measure magnetic filed strength. If a plain metal bar is suspended symmetrically in the horizontal plane by two strings of equal length and set to swing about a vertical axis through its centre, the period of the swing (T) may depend upon some, or all of the following quantities that define the system: the length of the supporting strings L; the distance apart of the strings, s; the mass of the suspended bar, m; and the length of the suspended bar, l. There is a formula: $T = KsmLn$ in which K is a constant and m and n are unknown indices. Thus: $\log T = \log K + m \log s + n \log L$. So if you do one experiment where L is kept constant and T measured for various values of s, then a graph of log T vs log s has a slope equal to m; and similarly, for another experiment you could measure T for various values of .... keeping ..... constant and then you could graph log T against log L and this will have a slope of .....! What a fabulous EEI. Torsion pendulum A torsion pendulum consists of a weight suspended by a wire or some other fibre. The pendulum oscillates by repeatedly twisting and untwisting about the axis through the centre of the wire. Though it is not strictly a pendulum since it does not oscillate because of the force of gravity, the mathematical formulas that describe the motion of a torsion pendulum are similar to the equations that describe the simple harmonic motion of a simple pendulum. It is commonly used in those ornate clocks in glass cases (see below). For a bob of fixed moment of inertia and a wire of a given material, the period (T) depends only on the radius and length of the wire: $T = KraLb$ where K is a constant, r = radius of the wire, L = length of the wire. Hence, $\log T = \log K + a \log r + b \log L$. Hence, if you use several identical wires (of the same type and radius) but different lengths, then a graph of log T vs log L should be a straight line of slope b. Also, if just the radius is changed then a graph of log T vs ......etc. Another great EEI in the making. Cooking Meat I - Conductivity Food technology is a massive industry and physics principles can be applied to all facets. Physicist Dr Nathan Myhrvold worked alongside astrophysicist Stephen Hawking before turning his attention to cooking. He has recently released a 2438 page text on the science of cooking [Modernist Cuisine, Ingram Publishers, 2011, $625). He said most people thing that if a steak is twice as thick it should take twice as long to cook it to the same degree. However, he says that this is wrong and that heat conduction scales roughly as the square of the thickness so it should take four times as long. This would make a fascinating EEI. You would need pieces of similar meat but cut to different thicknesses. Different cuts of meat have different conductivity, with lean meat (low fat) having a higher thermal conductivity than fatty meat. The fibre direction also is important so there's a hint for a control. Government agencies define "cooked" as 70°C for 2 minutes (so does Mythbusters) so your best bet would be to see how long it takes for the temperature at the chosen positions (eg 1 cm and 2 cm) to rise to that value. It is also said that older animals have lots of connective tissue so "young" vs "old" may be interesting as another (discrete) variable. All you need is a lab hotplate and perhaps a few temperature probes and a datalogger. Cooking Meat II - Conductivity and Different Heat Sources The suggestion above describes the use of a hotplate as the heat source. A variation on that which would also make a good EEI would be to compare different heat sources. You could still use chunks of meat as above and still measure temperatures at say 1cm and 2 cm from the surface, and note how long it takes to get to say 70°C; but compare the hotplate with a microwave and convection oven. You'd need to have some sort of measure of the heat output of the various devices on the setting used - perhaps putting a known mass of water in a small beaker and heating that first (and use $Q = mc\Delta T$) and note the time taken to get a power ($P = W/t$) value. My thanks to Physics teacher and gastronome David Austin of North Bundaberg State High for his suggestion. Cooking Meat III - Specific Heat Similar to the experiment mentioned above, you could also make a good EEI out of investigating specific heats of various types of meat. The specific heat will determine how fast a piece of meat cooks. Lean meat is said to be the lowest specific heat at about 0.85 kJ/kg/K whereas fatty meat is about 0.95 kJ/kg/K. Bone is much lower at about 0.60 kJ/kg/K but this depends on how dense the bone is. You may need to develop a method based on ones you may have used for measuring the specific heat of brass, or look at the procedures used in food technology laboratories. I would look at heating a chunk to say 100°C in a laboratory oven and then dropping it in to chilled water (why chilled?). The problem you'll have is developing an hypothesis and justifying it. It is not much good for an EEI just to measure specific heats and leave it at that. You should be trying to extend knowledge about factors that affect meat specific heats and why it may be important. Talk to your teacher and look at the criteria sheet in detail before you get too carried away. I'd be thinking there is some relationship with moisture content or fat content. You could weigh a chunk of meat and dry it out for many hours in an oven, and then reweigh it to get % moisture. To measure % fat, you could extract the fat with hexane or some other non-polar solvent, and then evaporate the solvent. Plenty of methods are on the internet. Hot Air Balloons Physics teacher at Urangan State High School, Hervey Bay, Queensland - Alan Whyborn - has his students investigate hot air balloons and the conditions needed for the balloons to catch fire. He said that he once saw a colleague in Canberra make hot air balloons from shopping bags, using metho and cotton wool, simply wired across the handles of the bag. They took them outside (on a still day), lit the metho and off they flew. On a number of the bags the opening collapsed in a little and the bags caught alight. He was horrified at the sight of flaming balloons releasing drips of burning plastic as they drifted casually through the air! He says: "In August 2007 in Canada, a fire broke out in a hot air balloon. Two people were killed. Could it be that the air in such a balloon may become excessively hot and cause the material of the balloon (the "envelope") to ignite and burn?" This sounds like the basis for an EEI: factors influencing the ascent of a hot air balloon. Alan gives the following important tips: large, really thin/light garbage bags must be used, and get the lightest cane available (craft shop). Also, if the balloons are allowed to fly to the ceiling, they can tilt and the bag might catch fire, so the anchor is very important (plus it holds the balloon in place while the pebbles are added to the gondola to increase the payload). Also, still air is necessary - inside the lab with fans off is great. If done carefully with appropriate preparation and warnings, there is very little hazard. In some cases, students have had a "fuel load" big enough to create sufficient heat to shrink the bag. Ordinary cotton wool balls are perfect, but not compressed or the rate of heat release might not be sufficient to get necessary lift. Click here for: Procedures and safety notes from Urangan SHS. Constructing: a light cane loop and sticky tape holds the bag end open. Fine wire across the middle is used to attach the fuel ball and gondola. Fuelling: a cotton ball soaked in metho is attached by a hook to the centre wire. Inflating: the ball is lit and the bag fills. A slack safety cord tethers the bag to the floor. Loading: pebbles are added to the gondola to achieve neutral buoyancy. Slump of sandpile You've no doubt seen reports on TV of kids being buried on the beach when a sandhill collapses on them. The sand is stable until someone digs away at the base. When bulk granular materials (like sand) are poured onto a horizontal surface, a conical pile will form. The internal angle between the surface of the pile and the horizontal surface is known as the angle of repose and is related to the density, surface area and shapes of the particles, and the coefficient of friction of the material. Material with a low angle of repose forms flatter piles than material with a high angle of repose. The angle of repose, or more precisely the critical angle of repose is the steepest angle of descent or dip of the slope relative to the horizontal plane when material on the slope face is on the verge of sliding. Likewise, the larvae of the antlions trap small insects such as ants by digging conical pits in loose sand, such that the slope of the walls is effectively at the critical angle of repose for the sand. When the ant walks on the sand it collapses and he falls in to the hole. Now that's clever. A great EEI would be to measure the angle of repose for different grain sizes of sand, or wet vs dry sand, or if it is related to density and so on. Look up the triaxial shear test, or even the direct shear test for ideas on how to measure repose. Angle of repose is measured in degrees Antlion sand trap Insulation and cooling of hot water Bubble wrap is a good insulator but how would the rate of cooling of a PET water bottle or a soft drink can of hot water vary with the number of layers of wrap? Newton's Law of Cooling makes reference to the rate of cooling and the difference in temperature between the object and room temperature (but he also said 'in a gentle breeze' that most Physics books forget to mention). Year 12 Physics EEI at Moreton Bay College, Brisbane. Logger Pro makes life simpler. My thanks to Mackenzie for the photo (May 2015). Mackenzie has used a fan to simulate the 'light breeze' that Newton had when developing his law. See suggestion about 'cooling' and Newton's Law further down. Newton's law states that the rate of change of temperature is proportional to the difference in temperatures between the object (hot water, T) and the ambient temperature (Ta). Mathematically, this can be expressed as: $dT/dt = -k (T - T_a)$. This is a differential equation and you can separate the variables and then integrate. This technique can be found on the internet. You end up with an equation: $\ln (T - T_a) = -kt + C$. This takes the form $y = mx + c$, so a plot of $\ln(T - T_a)$ vs t (x-axis) should give a straight line. Here's an example from Mackenzie Petie: Temperature vs time graph for three layers of bubble wrap gives a typical exponential decay curve. My thanks to Mackenzie Petie for her data and graphs from her EEI. Taking the natural log of the temperature difference gives a straight line whose slope (0.0146 minute-1) is the rate constant (k). This is also for three layers of wrap. The regression coefficient 0f 0.999 indicates that the data are a good fit for the line. Can you estimate what fraction of a layer of bubblewrap the polyester (PET) bottle or metal can is equivalent to? Home Made Accelerometer Accelerometers are devices for measuring the net acceleration force acting on an object. In the computing world, IBM and Apple have recently started using accelerometers in their laptops to protect hard drives from damage. If you accidentally drop the laptop, the accelerometer detects the sudden freefall, and switches the hard drive off so the heads don't crash on the platters. In a similar fashion, high g accelerometers are the industry standard way of detecting car crashes and deploying airbags at just the right time. Apple uses an LIS302DL accelerometer in the iPhone, iPod Touch and the 4th & 5th generation iPod Nano allowing the device to know when it is tilted on its side. These are all pretty complicated but you could build a simple one from a narrow perspex or glass tank partly filed with a water and food colouring and mounted on top of a collision trolley. There is probably a relationship between the angle of the water surface and the amount of acceleration. I suspect you'll need a camera - maybe an SLR unless your compact has low shutter lag. Better still, mount your accelerometer on a spinning turntable and you'll be delighted for hours. Photonics and fibre optics The Australian Government's National Broadband Network is planned to connect 90% of all Australian homes, schools and workplaces with broadband services using fibre optic cable. Understanding the physics behind fibre optic technology is set to become even more important to those involved. As signals pass along the fibre they get weaker (attenuate) as the light gets absorbed and scattered on its way through. Attenuation is one of the most important measurements for optical transmission systems because it determines the maximum distance between repeaters. With new glass that has been developed for optical fibres, light can travel more than 10 km before 90 per cent of it is absorbed. This is a big improvement over ordinary glass which loses 90% in 20 metres. Some interesting experiments involve modelling optic fibre with glass rod (eg stirring rod) and making different bends in a number of pieces. Compare energy losses ("curvature loss" or "macrobend loss") as a function of angle. Try dipping the rod in different liquids (to simulate the cladding) and measure the attenuation again. Try different thicknesses of rod. Put scratches on the glass. I'm tld that if the radius of the bend is greater than 20 times the diameter of the fibre, then losses are neglibible. Hmmm! Bicycle Pump Thermodynamics You are probably well aware that when you compress air quickly in a bicycle pump the pump gets hot quickly. The energy imparted by your muscles is transferred into heating the gas inside the pump and increasing the molecules' internal energy. This is the same reason spacecraft get hot when they re-enter the Earth's atmosphere - adiabatic compression (not friction). Diesel engines rely on adiabatic heating during their compression stroke to elevate the temperature sufficiently to ignite the fuel. If you had access to a temperature probe and a datalogger you could mount the probe into a screw fitting and screw it into the end of a pump. Let some masses compress the gas and take a few readings. It's up to you what data to take and how to work out how much mechanical energy is imparted to the gas by the falling masses. Is it okay to assume that there is such little time for heat to escape to the surroundings that Q (lost) = 0? Will the formula $W = Fs$ be okay? Wikipedia has done a lot of the hard work for you. The Stud Finder The stud finder is a device is designed to indicate the presence of wood studs behind wallboard by detecting changes in capacitance. Generally, each detector contains a capacitor whose conductive plates are arranged so that both plates lie in the same vertical plane (see figure below). When the device is placed in contact with a wall, that plane is parallel to the wall, causing electric fields generated by the pair of plates to penetrate behind the wallboard. As the detector is moved across the wall, those fields are affected by what dielectric material is present, resulting ultimately in changes in capacitance. Those variations are detected and then indicated by changes in light and/ or sound intensities. For the stud sensor, the presence of a wood stud behind the wallboard causes the capacitance to increase in that region due to an increase in dielectric constant. For an EEI you could investigate the properties of a commercial studfinder (about $25): do different wood types have different capacitance; effect of moisture content of the stud; metal vs wood; electrical cables (on and off); effect of thickness and so on. Perhaps you could make a model one and compare. I should note that one student who did this had a lot of trouble getting useful results. Magnetic Strength and Distance In World War 2, the Navy in Australia, Britain and the United States received tens of thousands of suggestions about how to detect enemy submarines. Most involved placing big magnets in the shipping channels. These were rejected by scientists as being impractical because they knew magnetic strength falls off alarmingly with distance. However, it may not be a simple inverse square law ; it could be inverse cubed. When you have the real world of dipoles (N and S on the one object) the relationship is less clear. Here's what Wikipedia says about the relationship: Far away from a magnet, the magnetic field created by that magnet is almost always described (to a good approximation) by a dipole field. One characteristic of a dipole field is that the strength of the field falls off inversely with the cube of the distance from the magnet's centre. Closer to the magnet, the magnetic field becomes more complicated and more dependent on the detailed shape and magnetization of the magnet. At close range, many different fields are possible. For example, for a long, skinny bar magnet with its north pole at one end and south pole at the other, the magnetic field near either end falls off inversely with the square of the distance from that pole. So, for an EEI you could investigate force vs distance for a pair of magnets. The diagram below may give you some ideas. But is the "dipole" a problem. If you had really long magnets then the second pole on each magnet may not be as important. That is, is length of the magnet a variable? Force between two current-carrying wires. If you've ever watched someone try to "jump start" a car with a flat battery you may notice something funny happen to the wires. "Jumper leads" are two heavy duty copper wires that are connected between the good battery on one car to the flat battery on the second car. Positive is connected to positive, and negative to negative. When current is drawn through them by the flat battery trying to start, the leads move towards each other (if they are close enough). Ampere devised a formula relating the length of the wires and the currents being carried. You could test this in an EEI but the formula may hold for an ideal case of very long (infinitely long?) wires. How does it hold as the wires are varied in length. That is, are there any "end effects"? And should the force be zero when they are at right angles (the textbook say "yes"). Here's a suggestion: use an electronic balance, hold a stiff wire (rod) in a clamp and blu-tac the other rod to the balance pan (see below). Solder (clip) lightweight flexible wires to the ends and connect to power supply (full-wave rectified?) and appropriate meters. Bob's your uncle. Newton's Cradle and non-elastic collisions Newton's cradle, named after Sir Isaac Newton, is a device that demonstrates conservation of momentum and energy. It has no real-world application other than as a toy. A typical Newton's cradle has a series of identically sized metal balls suspended in a metal frame so that they are just touching each other at rest. Each ball is attached to the frame by two wires of equal length angled away from each other. This restricts the pendulums' movements to the same plane. There are plenty of videos and demos on the internet if you have not seen one live. They work well for steel balls; but what about brass, what about lead. Is there a relationship between starting height and final height when less elastic metals are used. It's no good just finding out there is a difference without having some hypothesis to test. Is it a density thing, or interatomic force thing? There must be some quantitative difference between the metals that gives rise to observed differences in the balls' behaviour. This will be hard. Heating up gases You would have seen how gases expand when they are heated. Your teacher may have heated a flask with a balloon on the top to show it expanding; you may have seen a balloon shrink when dipped in liquid nitrogen at -198°C; and it is the principle behind how hot air balloons work. In class you would have called the law describing the relationship between temperature and volume Charles's Law or perhaps Amonton's Law ($V \propto T$, when T is in kelvin and P and n are kept constant). There could be a great EEI in revisiting this relationship. There is no point in just verifying it as this has been done a million times. What you want to do is to extend the investigation of this law to look at the impact of changing variables and to consider allowing for errors. The diagram below shows a setup that may be useful. It really just show the connection of two things: a flask with a sidearm (maybe a Büchner flask) and a graduated glass syringe. The exact positioning is something you should determine. Glass syringes are precision-made with low friction between the plunger and the barrel (unlike plastic ones that have high friction). Your chem lab should have some and if not they are reasonably cheap (about $50 for a 100 mL one). You need to introduce a gas (eg CO_2) into the flask and surround the flask with water in a beaker on a hotplate. As it slowly heats (I mean slowly, maybe 20ºC to 80°C over 40 minutes) the gas expands and the syringe is pushed out. With the syringe on it's side there is no need to worry about the weight of the plunger. You could compare gases - oxygen, nitrogen, hydrogen for example. But how to get samples of these gases? You may have cylinders but you could produce H_2 and CO_2 by reaction (or let some dry ice sublimate); let some liquid nitrogen evaporate (or remove oxygen from air). And why not propane (BBQ gas) or butane (cigarette lighter fluid)? Remember that balloon gas is not just helium - it has 3% air mixed in with it. The main point is that the law holds for ideal gases but at atmospheric pressure and room temperature they won't be that ideal. And is the deviation from ideality dependent on the molar mass of the gas, or whether it is polar or non-polar, and where on earth do you get a polar gas from (HCl is too dangerous)? What range of temperatures will you use (consider liquid nitrogen, dry ice). What value will they give you for absolute zero when the V/T graph is extrapolated? How do you draw the line of best fit (is least-squares the best, does it give you the most accurate value for absolute zero?). And what is the volume of the gas in the apparatus? And what is the best way to measure temperature (of the gas as in the diagram, or of the water surrounding it)? Perhaps the temperature of the gas in the flask is the water temperature and the temperature of the gas in the syringe that of the surrounding air (work out a weighted average). And how do you control atmospheric pressure (do you have a barometer, or perhaps get the data from the meteorological bureau website). What a fabulous EEI. I must put this on the Chemistry EEI webpage as well. The Heat Engine You are probably quite familiar with things physicists and engineers call "Heat Engines": the petrol and diesel engines for cars and trucks are heat engines as they convert heat energy to mechanical work by exploiting the temperature gradient between a hot "source" and a cold "sink". The diagram below left shows this process schematically. Heat is transferred from the source (T_{hot}) through the "working body" of the engine, to the sink (T_{cold}) , and in this process some of the heat is converted into work (W) by exploiting the properties of a working substance (usually a gas or liquid). Even a "Dunking Bird" is a heat engine (centre). This suggests a good EEI based on an experiment often done in thermodynamics labs in 1st year university physics or engineering. The diagram to the right shows the setup. It consists of a flask connected to a glass syringe (see description in the "Heating up Gases" suggestion above. The heat engine works when the flask is shifted by hand from the cold water to the hot water and back again. The pressure of the system is monitored with the pressure sensor (to computer) and the volume of the system can be measured with the rotary motion sensor on the piston. You start with the flask in ice water and no mass on the piston. Then place a mass on the piston and the plunger falls. Then transfer the flask to the hot water and the piston rises. When it stops rising you remove the mass and then move the flask back to the cold water. That is one cycle. Some data I have from the American Journal of Physics (V 74 (2) Feb 2006, p 99) has T_{hot} = 90°C, T_{cold} = 25°C, mass added to piston = 100 g, height lifted = 2.7 cm). With the right formula you get a value for W_{in} (heat) = 29 mJ, and W_{out} (GPE) of 26 mJ giving a mechanical efficiency of 90%. Ask yourself - what is the source of energy loss? For an EEI you would need to research these formulas and the underlying theory and propose some variables to manipulate such as DT, mass, type of gas and so on. Whatever you choose you should have some way of justifying your hypothesis. Hard, but may be fun. Datalogging Power Generation The fundamental principles of electricity generation were discovered during the early 1830s by the British scientist Michael Faraday. His basic method is still used today: electricity is generated by the movement of a loop of wire near a magnet (or vice versa). You could do an EEI on the factors influencing the generation of an electric current. A good way would be to use a Pasco (or similar) datalogger and record the voltage induced in a coil (air solenoid) by a spinning magnet nearby (see photo). The experiment could be repeated with the spinning magnet closer to the coil, or the number of turns on the coil can be increased or decreased. These variations will cause the area for a half-cycle to change, but again this can be shown to be independent of speed. If the number of turns on the coil is changed by a known ratio, the area for a half-cycle should change by the same ratio. You could also set up three coils at 120° to each other. Photos courtesy of Mark Dixon, Clifton College, Bristol, UK. The Physics of the Bungee Jump National Geographic magazine first reported this sort of jump by Pentacost Island natives in 1955. It was later popularised by A. J. Hackett in NZ. The conversion from GPE to EPE is an interesting one but the relationship is far from simple. You could model a bungee using rubber bands and brass weights, or do something more dramatic. You may even find out why they say bungee jumping is glue sniffing for Yuppies. One of the problems is that as the jumper falls the mass of rope hanging below is getting less so acceleration is actually greater than g. That sounds wrong but it appears to be true. Have a look at: Understanding the Physics of Bungee Jumping from Physics Education V45(1) 63-72 (January 2010) and you'll see what I mean. What type of waterwheel is the most efficient? A water wheel is a machine for converting the energy of flowing or falling water into more useful forms of power, a process otherwise known as hydropower. In the Middle Ages, waterwheels were used as tools to power factories throughout different counties. The alternatives were the windmill and human and animal power. Overshot (and particularly backshot) wheels are said to be the most efficient types; with claims that a breastshot steel wheel can be up to 60% efficient (but who'd believe Wikipedia?). Why not make this the subject of an EEI and see if efficiency depends on fall height, rate of flow, paddle area and so on? Great fun if you're good at constructing things. But be warned - it's no good just making a couple and testing them; you need to vary some of the parameters and hypothesise how this may affect efficiency. Flight of a Golf Ball This was first investigated by Prof. Peter Tait of Edinburgh University in 1900. His son was Scottish National Golf Champion who could hit a ball further than the mechanics formulas of the time predicted because they didn't know about spin. It still makes a great EEI as there are so many things to investigate. Try: angle vs. number of dimples; try sanding off one-quarter of them and putting gloss paint to make it smooth again; then try half (see below), and three-quarters. Design a device for giving it a constant velocity, eg falling pendulum, or something spring-loaded. Vary angle, try at different speeds. How to get top spin? Gravity car An old favourite for physics and engineering competitions is the 'gravity car'. It involves the transfer of gravitational potential energy from a falling weight to an attached small model car which acquires kinetic energy. There are many designs but a simple one is shown below. The brass weights are attached to a string passing over a pulley attached to the car. The string is wound around the axle. As the weights fall and lose GPE, the string turns the wheels and the car begins to move. Your EEI could investigate the optimum falling mass and cart mass combination for maximum acceleration or velocity. Remember - as you increase the falling mass (and thus DGPE) you are increasing the mass of the whole system. This will have implications for acceleration. A great EEI and lots of scope for demonstrating advanced thinking. Components Alex Schumann-Gillett from Moreton Bay College used a Meccano "Buggy" car for her investigation. Alex is now doing her science PhD at ANU (2016). You can see the hanging brass mass that provides the driving force for Alex's car. Inside the gravity car built by Codi Baker-Lahey - Year 12, St Andrew's Anglican College, Sunshine Coast, Queensland. Codi's car moving along the benchtop. Codi plotted total distance travelled vs hanging mass. And here she worked out the kinetic energy of the car as a function of hanging mass. Descent of a ball bearing in oil or honey It is vitally important that motor oil doesn't get too thin in summer nor too thick (too viscous) in winter otherwise the car engine might seize. A Falling Ball Viscometer uses the rate of descent of a ball bearing to measure the viscosity of a liquid. Try investigating drop time vs. temperature, type of oil (20W50 etc), size, mass or density of ball, width of column. This can be very messy; oil is such a pain to clean up you're probably used to having someone else clean up for you. So don't be surprised if your teacher seems reluctant and suggests you use honey. I wouldn't allow oil. The first thing you should read is about Stokes' Law and the variables within. A sophisticated setup using a Buchner flask to maintain a water jacket of constant temperature. Setup using honey - Villanova College, Brisbane. You can see the ball dropping through the honey. At 90°C it drops very fast (and how would you measure that?). Viscosity of vegetable oil vs temperature - Moreton Bay College Year 12 EEI May 2015. Oil is such a pain because it is hard to clean up (well - for the lab staff to clean up). Harman is pouring hot oil into a big dish, and down the sink, and over the bench. Air resistance and the descent of a balloon - #1 - Constant Velocity Inflated party balloons fall slowly to the ground because of their large cross-section for their weight (low density). Students often think a good EEI would be to investigate the effect of air resistance on falling objects (eg tennis, ping pong and cricket balls) but mostly the objects fall too fast and the measurement error is too great. A great EEI would be to suspend a motion sensor (ie a sonic ranger) from the ceiling and let an inflated balloon fall from underneath it. You could increase the mass (add paperclips etc) and redo the measurements keeping diameter constant. Then you could keep the mass constant and change the .... (you work it out!). The main things to look for are large lightweight objects such as party balloons (recommended if you don't have a sonic ranger), plastic soccer balls, inflatable beach balls, styrofoam balls (eg the round foam fishing floats in the photo below). Small weights can be taped on the bottom or pushed into the foam; and you may need quite a large fall height. The simplest experiment would be to look at the effect of these variables on terminal velocity. If you want to look at the accelerating phase as well then you should read the caution below. For terminal velocity you just need to work out when the balloon has stopped accelerating. Usually it is after about 1.5 m of freefall but you would need to establish that. Most students put two horizontal rods (eg rulers) about 1 metre apart vertically and time the balloon's descent between these two markers. If you put another marker 1 m under the bottom one and timed the balloon through the second distance, the time should be the same if it is at constant velocity. The downward force (weight) is balanced by two upward forces: buoyancy and air resistance. I'd be looking up Reynolds Number (no apostrophe) and Stokes' Law (with apostrophe). Remember that air resistance varies with velocity (squared). And that why this is a tricky (but great) investigation for an EEI. Air resistance and the descent of a balloon - #2 - Accelerating The simplest experiment is with constant velocity (above). A more complex EEI is to investigate the motion of a balloon while it is still accelerating (between 'let go' and terminal velocity). You need to be cautioned again that this is hard to do and difficult to analyse. When a large, light, spherical ball is dropped from a height (in air), it appears to descend slowly. It is obvious that the surrounding air has a profound effect on the motion of the ball, reducing its acceleration. One reason for the reduced acceleration is the buoyant force. This force acts opposite to the force of gravity and reduces the net force on the ball. There is also another effect of approximately equal importance. As the ball accelerates, it must also accelerate the air around it. Thus a ball moving through air has a larger effective inertia than one moving through vacuum. This increase in inertia also reduces the acceleration from the force of gravity acting on the ball. The increase in inertia of an object moving through a fluid is usually called the "added mass". Even though this idea was discovered by d'Alembert in 1752, it is not well understood and is not dealt with in most introductory university physics texts. But the idea of added mass is used elsewhere in physics to account for oscillations of a massive spring or the motion of electrons in a crystal (where their effective mass is different from their mass in vacuum), and added mass is used to explain how neutrinos travelling through the Sun change their 'flavor' content, which is crucial for explaining the observed flux of solar neutrinos. You can sum all of this up by using the familiar relationship: Net force = buoyancy force - drag force. However, net force is no longer ma (where m = mass of the sphere) as the mass is increased by the "added mass" (m'). So the net force is now (m + m')a where m' = mass of air in the balloon multiplied by a constant CM (which is approximately 1/2). There is a good article about it in American Journal of Physics, Vol. 79, No. 12, December 2011, p 1202. Stability of a bicycle Have you noticed how you can ride a bike with your hands off the handlebars and you don't fall over? But if you give it a push just how long does it take to fall over? Variables - linear speed, mass, angular speed of wheel, rotational inertia of wheel $I = mr^2$; add lumps of clay or lead to rim). Sliding friction - variation with speed? You've no doubt measured the coefficient of friction by pulling a wooden block across various surfaces at constant speed and measuring the force with a spring balance. Probably you've found that friction is independent of surface area and normal reaction force (laws of da Vinci, Amonton and Coulomb). That's fine but you might recall how difficult it is to get constant speed. The problem is that friction does change with speed (particularly for dry, unlubricated metals) although it may be not noticeable. For steel, copper and lead, the frictional force seems to decrease with speed; with Teflon it increases with speed; and in many cases complicated relationships exist: for example, for steel sliding on polymers such as polypropylene and butadiene acrylonitrile, a peak in the graph of friction versus speed is observed. See Cross, R. (2005). Increase in Friction Force With Sliding Speed. Physics Department, 812-816. A good EEI would be to have the setup shown below and then use trial and error (adding or subtracting masses from the hanging bucket) to get the block to slide at constant speed. Using a datalogger would do this fine. Then load up the sliding mass and add more masses to the bucket to get constant speed each time. The hanging mass provides the force to pull the block along the horizontal surface. James Reich's setup at Villanova College, Coorparoo, Brisbane. The surface is painted Masonite (hardboard sheeting). James used a DataMate and plenty of trial and error. James Reich did this at Villanova College, Brisbane and found that the coefficient of kinetic friction does indeed increase as speed is increased. For example, for a constant velocity of 0.01 m/s the COKF was 0.693576 and for a velocity of 0.05 m/s the COKF was 0.694207. James Reich's tray of weights on the hardwood surface. Another good EEI would be to extend this idea and measure the displacement or speed as a function of time as you add different weights and try different surfaces. Think about grouping the surfaces into elastically hard and elastically soft (rubber, textiles). Some computer interface packages have a "smart" pulley that gathers data. The diagrams below may give you some ideas. Perhaps a better way of measuring friction would be to measure the acceleration of the system and using Newton's 2nd law (where F_{nett} is the calculated force accelerating the blocks and m is the total mass of the system (both objects). The nett force will be less than the applied force (the weight of the block) and the difference will be due to friction. A good paper for background reading is "How to teach friction: Experiments and models" by Besson, Borghi, Ambrosis and Mascheretti from the A.Volta Department of Physics, University of Pavia, Italy in the American Journal of Physics, December 2007, V 75, No. 12, pp 1106. Pulling a nail out Use a claw hammer to pull a nail out of wood. See suggestion below. Need to compute mechanical advantage of lever. How does force (calculate $F_1r_1 = F_2r_2$) vary with depth of nail, diameter of nail, grain orientation (end, side, top), density of wood. How does a pre-drilled hole (varying diameter) help or hinder? Scientific American had an article in about 2007. They said the force to pull a 50mm nail out of end-grain of seasoned hardwood was about 260N, but the force became lower as it came out. How would you measure the force as a function of distance embedded. Now that's difficult!! Cooling rates of water in a freezer Some people say that warm water freezes before cool water but that seems to violate common sense and physics principles. This is known as the Mpemba effect, named after Tanzanian student Erasto Mpemba, who made this assertion in a paper published in 1969. Although there is anecdotal support for the effect, there is no agreement on exactly what the effect is and under what circumstances it occurs. At first sight, the behaviour seems contrary to thermodynamics. Many standard physical theory effects contribute to the phenomenon, although no single explanation is conclusive. He pointed out that investigations of the phenomenon need to control a large number of initial parameters (including type and initial temperature of the water, dissolved gas and other impurities, and size, shape and material of the container, and temperature of the refrigerator) and need to settle on a particular method of establishing the time of freezing, all of which might affect the presence or absence of the Mpemba effect. The required vast multidimensional array of experiments might explain why the effect is not yet understood. There is a world-wide competition regarding these experiments. I'm told a Yr 12 student at Villanova College, Brisbane, submitted his Physics EEI and was placed 11th in the world. If I were you I'd Google Mpemba Effect and take it from there. You could investigate some factors: Rate vs. container size, thickness or type of material, covered/uncovered, initial temperature, stirred/unstirred, temperature gradients from top to bottom of the container. Good one for thermometer probes and a computer interface, eg TI-CBL2, Casio, Datamate etc. Elephants vs mice: surface area, volume and staying cool. You may wonder how large mammals such as camels can survive in the hot climate of outback Australia - and maintain a constant body temperature while standing in the hot sun. The same is true of other big mammals - like elephants - in the tropics. The trick is that their surface area is small relative to their mass so that they can continue to absorb heat for the entire day without their temperatures rising to do any damage. Little mammals have a big surface area to body weight and are not as adept. Here's a good little project that would make an interesting EEI. The aim is to study the surface area to volume ratio of an object. The area of a cube is $6L^2$ whereas the volume is L^3. The ratio A/V is thus proportional to L^2/L^3 or $L^{2/3}$. We can rearrange this such that $A \propto V^{2/3}$. If we can measure surface area as an object shrinks in volume we could verify this relationship. If we plotted $\log_{10}A$ vs $\log_{10}V$ we should get a slope of 2/3. That's the theory anyway. Suspend the ice block on the hook under an electronic balance but wait until it starts to drip before you collect data. You can count the drips for a minute every 10 minutes or so. Here's a log/log graph of my results. I started with 120g of ice. The slope is not 2/3 like I expected but just 0.456. Not sure why but that's what an EEI is like. If we use a block of ice as the object we can measure its volume as it melts by measuring its mass and using the relationship $m = \rho V$. The measurement of its surface area is more complex. A block of ice that is melting is getting its heat from the surrounding air. The heat that flows in is proportional to the surface area, and for every Joule that flows in a set amount of ice must melt (think latent heat of fusion of ice = 334 J/g). Thus the number of drops of melted ice that fall off the ice block per second is a measure of the surface area at that short moment in time. So we just need to keep a record of the mass and the rate of water droplets per second for various stages of melting and we have our data. If you want to collect data more simply just measure the mass as time passes and estimate the rate (drops/minute) frome the change in mass Δm. Too easy. One thing you must do it to wait until the block reaches 0°C and starts to melt. When it comes out of the freezer it might be at -10°C so you have to let it warm up to 0°C before it will start melting. Should only take 5-10 minutes. In summary, the data are: (i) volume (proportional to mass), and (ii) surface area (proportional to rate of melting in drops per second). The premise is that as an object shrinks in volume its mass will shrink too but at a faster rate. See the suggestion below for some alternative ideas. Iceberg Melting Rates The melting and breaking up of polar ice has become an even more important issue since the impacts of climate change have been recognised. Research on the factors affecting the melting of icebergs has been going on for some time though; for example Dr W. F. Ross from the University of Melbourne was publishing his work in the Annals of Glaciaology back in 1978. In the EEI suggestion above I considered the importance for large mammals of the relationship between volume and mass (using a melting iceblock). But this technique could be applied to an investigation of the factors affecting how fast an iceblock melts as it applies to climate change science. It is well-known that the most important factor affecting iceberg melting is the temperature of the surrounding fluid (as you would have guessed). The fluid can be either the air around the exposed part of the iceberg or the warm water underneath (called 'basal' melting - which seems to be the cause of the ice-shelf loss in Antarctica). But other factors are the volume and shape of the icebergs. As stated in the suggestion above, the bigger the surface area (and in practice this also means volume) the faster the melting rate. When an iceberg melts it often cracks in two and, depending on the size and shape, has a 'rollover'. In the photo below you can see some different sized icebergs and these will have melted at different rates. Can you predict which of these icebergs will melt faster? It is hard to tell their size but they are actually the size of office blocks. This photo was taken by Ted Scambos of the National Snow and Ice Data Centre during the 2006 IceTrek Expedition to Antarctica. Pieces smaller than 5 m are called "Bergy Bits" and pieces less than 2 m are known as "Growlers" (if they are also