Quantifying-the-energy-associated-with-everyday-things-and-events

Hi. I'm Dan Frey. I teach and do research in mechanical engineering. We're here at MIT in a student lab. And this is a place where young people come and build all different kind of vehicles, like the scooter that I just rode in on, bicycles, motorcycles, and cars. And I think what all these vehicles have in common is they're transforming energy in different ways.

Take, for example, your car. You put gasoline in there. That's chemical energy. It gets burned in the pistons, that's thermal energy. It gets turned into mechanical shaft energy, then kinetic energy of the car going down the road, potential energy of the car climbing a hill. But the key thing is that energy is being transformed. And we as mechanical engineers have to learn how to manage all that, and optimize it, and make it efficient.

Now, in order to get started on the topic of this video, which is quantifying energy, we need a unit of measure. Now, the most standard unit of measure for energy is the joule, which is defined as a Newton Meter. In order to make that more concrete, I like to think about, for example, an apple here. An apple weighs about a Newton, conveniently. And if I take this apple from a surface like this, and raise it up by one meter, it has one more joule of potential energy than it had before. So there's an example of a everyday event, lifting an apple by a meter, and the amount of energy that was involved.

Now what I'd like to ask you to do is an exercise. Get together with your instructor back there in the classroom, and with your classmates, and think of a few more examples of everyday events and tie them to a unit of energy or to a quantity of energy.

So as an example, let's say you wanted to talk about speaking on a cell phone. That would take some energy, but what I want you to do is, when you come up with your examples, make sure that you've indicated the event clearly enough that you can say how much energy there was. For example, with the phone, you'd have to say, talking on the cellphone for a minute. So try to be a little careful. Pick out everyday events, and make them vivid examples of a quantity of energy. So talk about that, and we'll come back to you after this break.

Hi. Welcome back from your intermission. So you guys were working together to come up with your own examples of some everyday event that would consume a fixed amount of energy that you can anchor to. Now, in order for us all to work together, what I'm going to do is give you a list of five everyday events that have an amount of energy associated with them. And we're all going to try to put them in order together. So let me take you through what that list is.

First, I want you to consider how much energy it takes to ride a scooter, you know, one of those two-wheeled kick scooters that I rode in on before. And to make it more specific, I'm going to say you've got to ride a kilometer, and you ride on level, smooth ground. So how much energy does that take? You know it's going to take some work pushing back with your foot, and you'll get a little bit tired. But how does that compare to other amounts of energy?

Now, the next one is-- another living thing involved. It's going to be a Canada Goose. It's that kind of black, and white, and brown sort of goose that's so common here in North America. If you need to think about some other bird, go ahead and think about that from your part of the world, but a Canada Goose is a big old bird here. It migrates from north to south every season. And I'm asking you consider, when they fly at about 1,000 meters up, how much potential energy does one of those geese have? So potential energy of a Canada Goose at 1,000 meters above the ground. That's the second common, everyday event that I want you to think about.

Now, a couple more, one is an ear of corn. So there's energy in this. If I eat it, I'd be able to do some work. And I want you to think about that. How does it relate to other things? You could think about the goose eating this corn, and what it could do. You're probably familiar with the labeling of food items. You want to think about the energy available to, say, a vertebrate who eats this corn.

One more item to put on your list is how much energy is available in a 2 liter bottle when it's pumped to 60 pounds per square inch. Now, these sort of bottles are common pretty much everywhere in the world. And they do hold pressure, because they hold carbonated beverages. And I'm telling you that we could pump it up to 60 PSI, and when we did that, there'd be a certain amount of energy available in that bottle to do useful work. I want you to think about how much energy that is.

And the last one on the list of five is going to be the energy she stored in the suspension springs of a car. We're going to go with a Honda Accord. And to be specific, it's how much energy is stored in one of those springs when it's compressed by two centimeters. So I have to give you basically the size of the spring and how much we compress it. That's a quantity of energy.

So that's our list of five for the rest of the session. But to give you something specific to work on for the next intermission, I want to take two things from that list and you're going to put those in order. And the two I want you to work on are the Canada Goose flying at 1,000 meters and the suspension of the Honda Accord being compressed by two centimeters. And your task for this intermission is to figure out which has more energy, the goose at 1,000 meters, or the suspension spring compressed by two centimeters. Good luck. Work with your classmates and your instructor, and I'll see you in about five minutes.

Welcome back from that break in the video. I know you guys have been working hard on trying to estimate these quantities of energy and put these two events in order. You've been thinking about the Canada Goose flying at 1,000 meters, and the energy in that auto suspension spring when you compress it two centimeters, trying to put those in order.

Now, let me tell you a little bit about the way that I thought about it. I considered the distances first, because those were given. You had the 1,000 meters of height for the Canada Goose,-- that's straightforward-- the two centimeters for the compression of the spring. Those are very different distances, right? That's a factor of 50,000, big difference in the distances.

Now, sometimes you can estimate energies by just multiplying a force and a distance, as long as the force and the distance are in the same direction and the force is relatively constant. With the goose, that's definitely true. And with the car spring, we're going to talk about it.

So let's compare those forces now. Are they different by a factor of 50,000? For example, a goose, how much does that weigh? Well, it's hard to know exactly. You could Google it, but the way I like to think about it is, how does a goose compare to something I know? Maybe I know what an infant baby weighs, because I'm a father. So I think a goose and an infant are about similar in size. So maybe I'll estimate that a goose weighs 10 pounds, or 5 kilograms.

So I figure a 5 kilogram goose, that's a 50 Newton goose, here on Earth, because acceleration due to gravity is about 10 meters per second squared. So I multiply those 2 and I get 50,000 joules. That's a lot of energy, I guess.

Now, how does the energy stored in the suspension spring compare to that? Well, I've got to come up with an estimate of force. How much force does it take to compress the spring of a suspension? I think that's going to be hard to estimate, so let's go do a quick experiment out in the parking lot, and see for ourselves how much force is involved.

OK. So we're out here in the parking lot to do a quick and dirty experiment. We want to estimate how much energy is stored in one of these automotive suspension springs when it's compressed by two centimeters. Now this is what the suspension looks like inside the Honda Accord. It's a MacPherson type. You've got a spring on the outside and a shock absorber on the inside. So that gives you an idea what's inside there.

Now, I'm going to set it down. And what we've got here is a meter stick attached to the wheel. And we see that the mark on the meter stick is at 31. That's where it meets the fender.

Now, when I climb up on the hood, I compress down that spring. And the whole car moves downward or this corner of the car moves down, and we get a reading of 34 centimeters. So my weight, about one kilonewton, is enough to move that spring downward by three centimeters. Or I should say, actually, that the fender moves down by three centimeters. The spring I wasn't able to observe directly. Because it's a little bit farther inboard than the fender, I think it's a little less than three centimeters. We have to make an estimate.

Now, one of the other subtleties that you have to consider here is that I'm getting onto the hood of the car, and that's causing the spring to go downward. But in assessing how much energy is in that spring, I have to consider that the weight of the car is actually helping me to compress the spring.

Now, this car weighs like 10 times what I weigh, but that's supported by 4 different wheels. So I want to say the weight of the car that's on the spring is maybe 400 pounds, plus my 200 pounds, 600 pounds applied to that spring, compressing it by 2 centimeters. So 600 pounds of force caused a compression of 2 centimeters.

Now to compute the energy, you can't just multiply those two factors, because when I started to sit on the car, it took a lot less than my weight to begin the motion. In fact, what I need to do is integrate the whole area under the force displacement curve. So at the beginning, it takes a little force. The force goes up linearly, up to 600 pounds, we estimated, and it's half the weight times the distance that we want to calculate. Not the full weight, but half, because the shape of the area under the curve is a triangle.

So we made an estimate of the amount of energy in the suspension spring of the Honda. We came up with a number like 10 joules to 50 joules. And we decided that the goose has a lot more energy than that, at 50 kilojoules, a big difference there.

Now what we want to do is organize ourselves. We're going to construct a number line. And we're going to put larger amounts of energy to the right, and smaller amounts of energy to the left. And so I'm putting the goose pretty far over to the right here, and marking that with 50 kilojoules. And I'll put a picture of a goose there. On the left side of the number line, I'm putting an image of the suspension on a Honda Accord, and marking the amount of energy there.

And now what we want to do is use this line to organize our thoughts. We are going to place another event on that number line now, put them in the right order. And the event we're concerned with here is scootering. Now, we have to be pretty specific. We're going to say that the scooter goes five meters per second on level ground, smooth ground, not going uphill or downhill, and at five meters per second. And I guess we should be specific enough to say who the rider is, because that affects the rolling resistance and the drag. So let's say it's in an eight year old girl. That's someone who might ride a scooter.

So when a little girl rides a scooter for one kilometer at five meters per second, she gets a little exercise. She expends some energy, but how much? Is it as much as the goose flying all the way up to one kilometer, or is it less than that? We're going to need to make some more refined estimates. And that's your task in the next break in the video. Please work to make an estimate of the energy. And compare it to the goose and to the automotive suspension, and put it in the right place on the on the line.

All right. Welcome back from the break in the video. You've been hard at work trying to figure out where this scooter event fits on our number line. We asked you to consider how much energy it takes for a little girl to ride a scooter like this a kilometer at five meters per second.

Now, one of the comparisons you could have made is between the scooter and the goose. That's probably the more interesting comparison than to the suspension. So let's try that. One issue is that you might try comparing the energies, again, by thinking about forces and distances. And since the two distances are exactly the same, the scooter goes a 1,000 meters horizontally and the goose has to go the same distance straight up, you might just focus on the forces for the moment.

We know how much a goose weighs. We made an estimate of that. Now, how do we think about estimating the force on a little girl scoring along at five meters per second?

Now, probably the dominant force seeking to slow down a scooter rider is aerodynamic drag. Now, aerodynamic drag is a force created as the wind, or apparent wind, goes over the body and the scooter itself. And there's a formula for this. And it is the drag force equals 1/2 rho V squared S Cd.

So let me go through those terms one by one. 1/2 is self-explanatory. The rho, that's the density of the air. That would be about one kilogram per cubic meter, in case you want to look that up. V is the velocity. We gave you that, five meters per second. S is the area that the person presents to the flow. And Cd is the coefficient of drag.

So one of the things you might try to do is figure out the drag force on the little girl scootering along at five meters per second. And the drag force is a function of the coefficient of drag, and the area, and the density of the air, and there are a lot of parameters to estimate, and a lot of uncertainty. So you can power your way through it and you can get an estimate, but at this point I really think that there is an alternative approach that you should try.

What I would tend to do, and what I'd recommend that you do now, is think of a number of physical experiments you might actually do to assess how much force it takes to propel yourself on a scooter five meters per second and continue at that speed. So I'd like you to get together with the other classmates in the room, and with your instructor, and think of different physical experiments that would give you insight into how much force is actually involved here. So think about that for about five minutes, discuss it with your classmates, and we'll come back after that.

Welcome back from the intermission. You've been working on thinking about different ways you could run an experiment to assess how much force it would take to keep a little girl on a scooter going five meters per second. Now, there are lots of experiments you could possibly conceive of, but some of the ones that I thought of that I thought were most practical involve the scooter going down some kind of a hill.

Now, I know that I said that the event was a scooter going along a horizontal surface, and therefore the energy would be put in by the little girl kicking and making the scooter move along. But for the thought experiment, I think it's useful to consider a hill, because then you get a nice consistent forward force provided by gravity.

Now here's how it works, your weight is a force that pulls down on you at all times. And if you're on a hill, some fraction of that force, your weight, is actually aligned with the surface of the hill and causing you to move forward at a constant velocity. So there's a component of the force that is moving in the same direction that you're moving, is therefore doing work.

Now what component of the force, your weight, would keep you going at five meters per second. Well, there's a couple of ways to think about this. One is, you're trying to make a comparison between the goose at 1,000. And so what you might do is ask, well, how steep a hill would give you a component of force equal to the weight of a goose?

So the way I think about is this, I think about my daughter. She's about twice as tall as a goose, twice as wide as a goose, twice as big as a goose in every direction, made of about the same stuff, skin and bones and guts and so on. So she weighs about eight times what a goose weighs.

Now, therefore, I think about the hill that would put about 1/8 of her weight as a component of a force propelling her along. It turns out that the answer is about a 10% grade. It's a hill where-- let's say you cover 100 meters. Well, on that stretch, you would have gone down by 10 meters. It's a very steep hill, it turns out. If you look at the hill, say, coming down out of the mountains of Colorado, there it may be 7% grade, and they have big warnings to the trucks to get in low gear and watch the heat of their brakes. It's pretty steep.

So I think I want to think about it a different way instead. I don't want to go down a hill with my daughter that steep. But already I've made a decision that I think probably the goose is going to take more energy than the scooter going horizontally.

But I have an experiment we actually did. What I chose is, let's pick a grade of hill that will actually keep us going five meters per second. So we went out in our neighborhood and we found a hill that I estimate is about 5% grade. And we did some measurements to check on that.

And now we have little girls scootering down that hill. We made a bunch of marks on the pavement, five meters space between each. And we measured how long it took each of those little girls to go 25 meters. We measured the time. And we could see that on that hill each of those girls was going about five meters per second.

So now we know a 5% grade hill is enough for a little girl to go 5 meters per second. And we know that on a 5% grade, about 5% of their weight is going forward. And 5% of the weight of a little girl is a lot less than the weight of a goose. It's maybe 1/3 the weight of a goose.

So at this stage, we have enough data to put that event on our number line. It goes close to the goose flying at 1,000 meters, but substantially higher than the automotive suspension. And we're going to place them on the number line right here where you see on the screen. So we have three things plotted on our number line right now. And it turns out they're all things that are kind of in the mechanical domain. We've been talking about forces and we've been talking about distances.

I want to change it up a little bit now. I'm going to ask you to consider the item in our list that is in a different domain. Let's talk about the ear of corn now.

The ear of corn has energy in a chemical form. And I want you to figure out where that lies on the number line. Is it, say, similar to the energy in the automotive suspension, or is it similar to the goose flying at 1,000 meters, or more than that?

Take some time. Work with your classmates, and take about five minutes. And we'll come back to you after that.

You may have been thinking about the ear of corn based on some things you've learned about counting calories. Maybe you or your parents look at the food labels and understand roughly how many calories are in things like an ear of corn. And I came up with an estimate of like 100. And if you do a little Googling, you'll find numbers that are in that range.

Now one thing that is potentially confusing is that you'll read about a definition of a calorie. And a calorie, in terms of thermodynamics, is the amount of energy that's required to heat up a gram of water by a degree Celsius. Now what's confusing is that these dietary calories that are labeled on our foods, those are actually 1,000 calories. Dietary calories are kilocalories.

So if you put those two pieces of information together-- you've got 100 calories, dietary calories, in an ear of corn, and the definition of what a calorie is-- you find that you could take an ear of corn, and use it to heat a kilogram of water by 100 degrees Celsius. So imagine taking a liter of water, that would weight about a kilogram, and heating it up from almost freezing cold to almost boiling hot. That's what an ear of corn could do.

Now, you want to be able to think about this and compare that amount of energy to something mechanical, like the scooter and the suspension spring in the Honda Accord. So it's important to understand that a calorie is actually four joules. There's a conversion that you have to do.

So what we find is that taking that last conversion into account, the ear of corn is 100 dietary calories, which is 100,000 calories, which is 400,000 joules. That's like a half a million joules. That's a lot of energy. It's way more than anything else that we put on our list so far.

So we're going to put the ear of corn on our number line here, way over at the right, understanding that we're crossing a lot of distance here with these numbers. Let's say that this number line is in a logarithmic scale, so each unit is not an amount of energy, but a multiplying factor of energy. So we put the corn on the list, and we've got just one more item now. The corn was in the chemical domain.

Let's do the 2 liters of compressed air at 60 PSI. Your job is to figure out how this amount of energy, which is in the fluid domain now, fits in with all these other kinds of energy that you've been considering. Take about five minutes. Talk to your instructor and your classmates there, and see if you come up with this estimate. It's probably the hardest one. But don't worry, you'll find different ways to come up with an estimate.

Welcome back from your last session of individual and team work. You've been trying to come up with an estimate now for the amount of energy in a 2 liter bottle pumped to 60 PSI. That's a hard one. There are lots of different ways you can do it, and you probably tried a lot of different ways.

And rather than go through all that in detail now, I want to let you know that, first of all, the answer is around a kilojoule. So it goes around in the middle of our list, as you'll see on the screen. And I want to tell you that in order to see some of the different ways of doing it in detail, we're making a number of resources available to you online, on the BLOSSOMS website, multiple different ways of making that estimate of the energy it takes to pump up a 2 liter bottle of air to 60 PSI.

So now we've got the complete list, five items all in order. We've covered a massive range here. The car suspension took on the order of tens of joules to compress by two centimeters. The ear of corn took like a half a million joules in order to-- that's the food energy available in that item. And the other items are covering the range in between.

Now, let me take a moment to say what are the key lessons we take away from having done this exercise of ranking different things. One is that energy is a really important concept in physics and engineering. It's something that's around us all the time, and it helps us to understand and quantify all different kinds of events. If you really want to be able to understand energy, it helps to be able to put it into a numerical form, to put quantities onto these events. And in order to do that, you have to compare them to some unit of measure. So we want to quantify energy, that requires a measurement scale, and that requires careful analysis.

Now if you want to get good at making those kinds of calculations and estimates, a decent way to start is to begin to explore, and understand, and estimate the amounts of energy in events and objects all round you. Start with the things that are familiar to you, and understand energy in those terms. And I think it'll help you to appreciate energy more.

I think that having done this exercise, you may be able to be more mindful of energy all around you, and in particular, your use of energy on a daily basis. So take these lessons with you as you go forward. And I hope you've enjoyed the session.

Hi. Welcome back. I'm Dan Frey. And welcome to the teacher guide segment. I'm just going to talk you through a few pointers on how to deal with the breaks in which you're interacting with your students in the classroom.

So in the first segment, I talked about energy. And I gave the example of a joule being the energy in an apple when you lift it by a meter. And I asked your students to come up with some additional examples, and gave them some guidance about how specific you'd have to be to tie a daily event down to a unit of energy. So I think that's one of the things you'll really want to focus on.

The students will mention events like doing a slam dunk in basketball, or, say, driving a car. And they'll put that up as an example of energy. But in many cases, these will require a few more details to be specific enough. So you might have to say, my doing a slam dunk, because that tells you how much weight there actually is. Or you could say, driving a car for a mile at 30 miles per hour. That would make it specific enough that we can tie it to an amount of energy.

Now the other thing I would like to recommend is that you encourage your students to get their examples to cover a lot of domains. It would be more interesting if their examples cover, say, mechanical energy, electrical energy, such as talking on a cellphone, chemical energy, such as energy in a liter of soda pop. So I think it's useful if they cover a lot of different areas so that they understand how ubiquitous this idea of energy really is.

So this is a segment in which your students should generate a lot of ideas and they'll be unique to each group. And I guess they'll be very different from country to country as well, based on the different experiences people have. And that's all fine.

Then in the next segment of the video, I give five specific everyday activities that have an amount of energy associated with them, and list through those, and then give you another break in which you need to rank just two of them. And the two are compressing the suspension spring in a car by two centimeters, and I picked that because I thought it would be familiar enough. People see people getting into cars and out of cars on a regular basis. And an average size adult, if you see them get into a car, you'll notice the car go down a little bit. And I estimated it would be like two centimeters. And you'll see that that's what happens when we go to the videos. So that I thought of as an everyday event.

The other one we talked about is a Canada Goose flying at 1,000 meters, and that may be something that you're familiar with in North America. If you're in another place, you might refer to a bird that's of a similar size. And if people don't feel comfortable with how large a Canada Goose is, well, what you might do is try Googling and just seeing how much they weight.

But I really do recommend that before you recourse to going and doing an internet search, that you really encourage your students to make an estimate first, because I think it's a good habit to be in to make estimates of physical quantities, rather than always relying on information from a search, because you don't know how good quality the information is that you pull up. The first thing may be off grossly. And if you've made an estimate first, you have a check on your work.

So when I think of a Canada Goose, having some sense of how big they are, and maybe they come up to my waist. And I think of that bird being next to, say, human child, maybe an infant, I think that, with its feathers off, particularly, it would look about the same size. So I know what an infant weighs, maybe a big one would weigh 10 pounds, or 5 kilograms. And so that's a good anchor for me. And you'll think of something else, something that's of a similar nature and a similar size. And that'll give you a way to estimate the weight.

OK. So we were trying to make a comparison between the amount of energy in the suspension spring of a car and in a goose flying at 1,000 meters above the ground. And there, you had to be able to make a reasonable judgment about the forces involved. And the distances were just given, so 2 centimeters for the suspension, and 1,000 meters for the goose. So you had to come up with the forces.

For the goose, you could go and Google it. But I suggested that you make an estimate. Try to imagine, say, a goose with its feathers off, and compare it to something you know, like an infant. They'd be similar, I think, 10 pounds, or 5 kilograms, for the infant, which would put you in the right ballpark for the goose.

So you just multiply the two numbers, the five kilograms times the acceleration due to gravity. That's 10 meters per second squared, roughly, times the 1,000 meters, and that gives you the energy in the goose flying at 1,000 meters. Compare that to the automotive suspension, larger force, but much smaller distance, and you get the ranking. It doesn't come out very close at all. There's a wide gap between them, maybe a factor of 100 or more between the energy in the spring and the energy in the goose.

Now, in the next segment, we add one more event, and try to put it on the line. Is it more than the goose? Is it less than the goose? Is it more than the suspension? We try to put them in order. And the specific event is scootering along for 1,000 meters at 5 meters per second.

Now, this one could be more difficult. There are a lot of ways to do it. You could try to think about the forces involved, again, because you have the distance. You could try to come up with the drag force on a rider. And you could come up with estimates. But I think it's easier to think about the scooter going down a hill. And we'll provide you some information on how to do that in the notes that will accompany this video segment. There are a lot of ways to make this estimate, and I think you'll find that the scooter takes substantially less energy than the potential energy in the goose.

Then we go to the next segment, and we have yet another event that we want to put on the time line, quantifying the energy, and this one is the ear of corn. OK. So we picked out the ear of corn because we thought it was a common enough thing, and a thing that a goose might eat, because here in North America, we like corn. And we feed it to livestock, so I can imagine the goose eating the corn.

But you may want to pick, just to give people an anchor, you may want to pick a more familiar food and a quantity that would be similar to the corn. The corn has about-- what we call 100 calories, in our food labeling system. And what's potentially confusing here is that most students will have heard of a calorie, but a dietary calorie that we talk about in packaging food is actually a kilocalorie. It's 1,000 calories, or 4,000 joules. So you want to help the students to sort out that confusing nomenclature.

Now, the last item that we put on the line to put in order is the event of pumping up 2 liter soda bottle to 60 PSI gauge. Now, I chose those values because first of all, the two liter bottle is pretty familiar across the world, I think. And also this volume is similar to what you'd find in a, say, an adult's mountain bike tire. So it's not an unusual event, although you normally wouldn't pump up a soda bottle to 60 PSI, lots of people would have the experience of pumping up a bike tire. And so that's a similar amount of pressure in a similar volume, and they have an idea of how tired you feel at the end of that.

And so, again, there are a number of ways to analyze this. You could go back and make an analogy with the spring, because it is, in a sense, something that can store energy being compressed. But you'll find some ways to make this estimate and put it on the line. And you'll find that it's quite a lot of energy, about a kilojoule in that bottle.

So that's the totality of the breaks. And there are lots of ways to handle them. It's a challenging task, I have to say. I think that your students will be stretched some. But if you just have the right approach to it, and you take an attitude that mistakes are not a problem, that you can find ways to correct them and make it fun, I think that you'll find that there's a good educational experience for your students. And I hope you have a chance to use it in your class.