Using Geometry to Design Simple Machines
By Daniel D. Frey

Hi. I'm Dan Fry. I'm a teacher at MIT in Cambridge, Massachusetts, and today we're going to do a session about design of mechanisms. This should be a fun session that allows you to get hands on and to think hard about how machines work. This is a session that's going to rely upon your knowledge of geometry, particularly facts about circles and triangles. It turns out that this topic of geometry is related to something called kinematics that we engineers use. Kinematics is just geometry in motion. So you're going to use geometry in ways that might be a little bit different than what you're used to. But it shouldn't intimidate you because we're going to have hardware that's available so that you can gain some experience and some insight as to how it works.

Let me define a couple terms before I move on -- **design** and **mechanism**. Design is the process of creating an artifact that executes some useful function. This is one of my favorite topics because it allows me as an engineer to be creative and to make things that have never been seen before. So that's design. Now, what's a mechanism? A mechanism is a collection of items, parts, that are interconnected so that their motions are coordinated. So design of mechanisms involves choosing the shapes and locations of those parts and they way they're interconnected so that you get the function that you're interested in creating.

Mechanisms are all around us. For example in agriculture a mechanism might be used in crop processing to pick a vegetable or to take the husk off of that same vegetable. Also a mechanism might be used in a sewing machine to guide a needle and thread and make a stitch. Another very common use of mechanisms is in engines.

I have an engine here today and I want to show it to you. Over here is an engine that I have taken out of a toy. I have a bicycle pump. I'm going to use it to pump air into a one liter soda bottle here. I'm moving air from the bicycle pump into the bottle and that means that I have to do work. I have to apply a force over a distance. Energy is therefore being stored in the bottle. Now the compressed air in the bottle can operate the engine in the toy. I get a little start there and you could hear it working. Let me pop it open and show you what's inside. What we see here is the compressed air engine inside the toy. We have the bottle of compressed air. The line brings air around to the engine itself. It comes in here and the compressed air is applied to the top of the piston, this white component right there. And if I reach over and manipulate this output shaft, when I turn that you see the resulting back and forth motion of the piston. So the mechanism inside this engine is one that converts back and forth motion of a piston to rotary motion of an output shaft. Now this engine is a little small and it's hard to explain all the details here in the hardware, so I'm going to move now to a computer.

Here on the computer screen we have a model of that very same engine and it's all color coded so that we can talk about the pieces and keep track of all the moving parts. Let me start with this red piece here on the left. That's what I call a crankshaft. The red piece is mounted up in the case of the engine on a bearing here so it can rotate about this point right at the center. Let me cause that rotation now by dragging. See the rotation of the red part of the crankshaft? All right.

Now let me talk about this pin here. This is called the crank pin. This crank pin is all part of one rigid component called the crankshaft, therefore the distance between the center of this pin and this bearing here, the center of the crankshaft is fixed. So what happens when you have a collection of points which are all one fixed distance from a single fixed point? Well, that's a circle. You know that from geometry. So this configuration of parts allows the pin to move but only in a circle.

Now let's go to the other components of the mechanism. Here in blue is a connecting rod. As the name suggests it connects. It connects between this point here, the center of the crank pin, over to the piston, this green part on the right. Now again, the connecting rod is rigid. So the distance between the center of the crank pin and the center of this bearing over here that connects it to the piston is also a fixed length.

Finally we have the piston which is in green. And the piston is a cylinder and it's inside of a hole that fits closely to that cylinder so it can just slide back and forth. So what does the mechanism do? It converts the sliding back and forth motion of the piston through the connecting rod into rotary motion of the crankshaft. So this particular mechanism changes one kind of motion, back and forth motion, into another kind of motion, around and around cranking of the crankshaft.

Now I want to give you an exercise. What if I told you some facts about the geometry of this mechanism? What if it turned out that the distance between the center of the crankshaft and the center of the crank pin was three units. Let's say 3 mm. Then I also told you that the length of the connecting rod, therefore the distance from this point to this point is 5mm. And finally, what if I place the piston so that the distance from the center of this joint which connects the connecting rod and the piston to this point which is the center of the crankshaft is 4mm. So to review. From here to here 3mm. From here to here 5mm. From here to here 4mm around in the circuit. Now the challenge for you is given those facts and what you know about geometry can you figure out what location and what angle the connecting rod has to have with respect to the rest of the engine, in particular the case. Go ahead and talk to your instructor and the other students in the room with you and see if you can work out a solution to this problem I've just posed. I'll see you in a minute.

Welcome back! So what you've just seen is that geometry can be used to understand the relationship among moving parts in a mechanism. Geometry is the mathematics that allows you to see interrelationships. But it's also important to get a physical intuition. So I want you to also work with an actual prototype of a mechanism. I have something here in the room that I made out of pegboard. It's going to be very similar to the mechanism we just saw in the engine. Now you should create something similar to this, either out of pegboard if that's available to you where you are, or perhaps out of construction paper and thumbtacks, or maybe cardboard and nails. Whatever works for you.

Now this mechanism I put on the pegboard is one of a class of mechanisms called a four bar mechanism. Let me go through the four bars now. This yellow bar is stationary. It's really just a piece of construction paper that I've taped to the pegboard. Now there are two other bars that are pinned to the pegboard using folds so they can move around in circles like this. The fourth bar is a piece of pegboard that is pinned to the ends of the other two, the red one here and the green one here, pinned at the ends. Exactly how you make those joints is not important. The key thing is that they have to allow rotation. But as before they make sure that the distances between the different points are fixed and therefore that they move in circles. So for example this component here makes sure that the distance to this pin is always on a circle of 1,2,3,4 units on the pegboard. Now here's the challenge for you. What would happen if grab the end of this red link and move it around in a circle? What will be the resulting motions of the green one? And what is the relationship of this mechanism to the one that we just explored? That is the compressed air engine that was in the toy and that we also illustrated on the computer screen? Take that as an exercise. Work with the physical prototype. Talk to the other kids in the room and to the instructor and we'll come back and see you in a minute.

Great! So you're back from that interactive work session and you and the other students in the room and your instructor have been building actual physical prototypes that show how mechanisms work. And what you've seen is that one of the things you can do is make a four bar mechanism that converts rotary motion into essentially oscillating motion. What we have here is the red link. If it goes around and around, the farthest end of the green link essentially just goes back and forth. Now if we're being precise it's moving in a circle centered at this location, but the number of degrees in the arc are so short, are so few, that it's essentially a straight line motion to engineering approximation.

So now when we as engineers take a mechanism that's of a particular fixed arrangement that already exists, such as what we saw in the compressed air engine and we use our analytical skills of math and physics to figure out what it will do, we call that analysis. You've got what exists and you try to figure out how it will behave. But engineers also need to do synthesis. That is sometimes they know how we want something to behave and we have to figure out what configuration will bring that about.

So let's do a little bit of synthesis now. I'm going to move the pegboard out of the way and we're going to use a little different piece of pegboard. I've cut out a piece of pegboard into what looks to me like the bed of a dump truck. What you imagine is that this is the part that holds materials such as gravel and what we're going to do is we're going to come up with a specification for how this dump truck should operate. We're going to define some positions that indicate how it should behave when we apply some energy to it and make it operate.

So let's first depict the normal position of the bed when it's low and flat and we drive the dump truck around on a construction site. I'm trying to make it as flat as I can. I'm going to trace it out. This represents on the chalkboard one of the desired positions of the bed of a dump truck. Now what I have to show you is some motions that we want the dump truck to take. Now let's imagine that what we want it to do first is to move up and over for example to get over a barrier. So let's say that we want it to move up by eight units and over by four. So we count them out. 1,2,3,4,5,6,7,8 and over 1,2,3,4 and we make a mark. And then we move the bed over to that mark. Line it up and make it as flat as we can make it by eye. If we were working in a CAD tool we could make it exactly flat. I'm going to trace it out. So what we're imagining is we want to lift the truck up keeping it relatively flat, so for example we can go over maybe there's an obstacle there and we want to get over that. Now in the last part of the motion what we want it to do is come over further and dump out. So let's say we want it to go up six units and over fourteen units. Make a mark, lift this up, move it over to that mark. And also let's say that what we want it to do at that point is to dump out. So that's our last position. We want it to move up and over. Actually let's say that the obstacle is a little smaller than I had envisioned. It's just there. So what we have is three specified positions of the bed of a dump truck. We want to pick that bed up keeping it relatively flat, to overcome an obstacle. Then move it up and over and turn it so that the gravel or whatever else we're carrying dumps out. So what we've done is with some precision to define what we want the mechanism to do -- the motions through which we want the mechanism to guide the bed.

Now if we want to guide this motion using a four bar mechanism, consider what we need to do. We know that a four bar mechanism has two links that connect from what we'll call the ground to something that moves. So the bed is that something that moves, and we want to figure out where the links on the ground go. So we have to come up with the locations of two joints at either end of that link. Now let's assume that on this bed that the first joint goes here. That would be a convenient place to locate a joint that is at the end of one of the links of the four bar mechanism. Now if we placed the joint there, then when the bed lifts up over into this position, that point is in the same relative position. Same distance up from this corner, same distance over from this corner. It's really the same physical point but it's at a different location in space because of the motion of the bed in time.

Now in the third position, again the bearing moves to here. Again, the same relative position but with reference to the ground upon which we're driving the dump truck it has moved. But with respect to the bed itself it has not. It's the same relative location. Now what we have is three points in space that define different locations of the bearing at different points in time. And we've decided that we're going to execute this motion with a four bar mechanism meaning that the motions of this bearing are going to be guided by some kind of rigid link that's connected somewhere to our truck itself, which is we'll assume stationary. So how can we reason out the location of the stationary joint from three positions of the moving joint? That is the question that I pose to you. And what I'd like you to do now is to take another pause from the videotape, work with the students in the room and your instructor and work out how you'll do that. Take three positions of something moving and reason out the position of the fixed point. See you in a couple minutes.

OK. You've been hard at work synthesizing the mechanism and I've been working on the same problem right here. So remember you have these three points that represented locations of pin joint on the bed of your dump truck and you were trying to figure out where that stationary joint needed to be, that is where the center of a circle was that included all those three points. You've been working on that and I've been working on it too here on the board. Now there are multiple ways to do this but I'm going to sketch out one relatively easy way.

I took two of the points on the right side of the mechanism and I connected them with a line segment. Then I found the middle of that line segment. So this segment of the line above it is the same length as this segment of the line below it. Then I constructed with a square piece of paper in this case another line that's perpendicular and goes through the mid point of that segment and that extends out in this direction. Now what I know is that my joint, the center of the circle, I need is somewhere along that line. But I want it down to a single point so I know just where to put the bearing on the bed of my truck. So I take two other points from the set of three. I construct a line segment between those two and find the mid point again and run perpendicular down and I find the point where they intersect. You see I know that the center of that circle needs to be on this line and the center of that circle also needs to be on this line. The only point that obeys those two constraints simultaneously is this point at the intersection. So that is the center of my circle which contains these three points on the desired, specified position of my dump truck bed. That point I found, if I take a ruler, is just four units over to the left of the bottom left corner of my dump truck and it's five units on the pegboard or whatever you prefer up from this point at the corner of the dump truck. So four and five. So that's half our four bar mechanism.

Now I have to take the exact same process and apply it to the left half. So here I take another point on the bed of the truck, again a convenient point just the bottom left hand side. Here I've marked it and circled it. That would move up to this position in the second desired location of the bed. And finally it would end up in this position at the third location of the bed when it's dumping out. Again, those three points define one circle. A unique circle with one center and one radius. Using again the same geometric construction technique, I define the center of that circle and I would find that it's aligned with the one before and it's eight units up above it. Eight units on my pegboard or eight units in whatever scheme you're using there in construction paper and pins or whatever medium you're using. So I claim that we have now synthesized the four bar mechanism that will do three position synthesis. Let me show you that that's the case by building it out of a pegboard.

I've done the work ahead and here's the result. I've got a pegboard here and it has a link in one of the specified positions going to the left corner of my dump truck. Another link eight units below it and that's extending over to the right bottom corner of my dump truck and I've color coded it just the same way as our previous mechanism. So we've got a long green link, a moving blue link and a short red link. Now let's see it move. We start at one position which is basically flat. It then moves up into another position which is also basically flat. And you can see the correspondence between what I put on the board and that second position. Now it moves yet again over and down and you see that again it corresponds to the position that we specified. It moved over and dumped out. Also, interesting to note that it went over the obstacle that we had defined before. Started in the first position missing the obstacle. Up to the second position the bed missing the obstacle. Into the third position again avoiding the obstacle. But you'll see one problem. Although the bed that contained the gravel avoided the obstacle, look what happens to the red link. The red link goes right over it. Right over it like that. So what we have to do is to come up with a way to change the design and avoid that obstacle. So that is the next challenge for you. The task that I'm giving you is think of a few different options. What can you do to change the design of this mechanism so it still has the desired motion but won't have this interference between the obstacle and the red link? There is more than one way to do it so try to come up with a few different options. Work together with the other students in the room and your instructor. Try to be creative and we'll get back together and share our solutions in just a couple minutes.

OK. Welcome back from your brainstorming session. You were dealing with the issue of how it is that you were going to make that red link on the right side of your mechanism avoid the obstacle. Now there are lots of different ways to do this. I'm just going to show you one that I tried to work out ahead of time. Remember that before we had this red link and it was just in a straight line like this. But it turns out there's nothing particularly requisite about a straight line connection. We could have any shape of material we want as long as they connect from one point to the other. So I made this very unusual shaped piece that goes almost in the opposite direction of what we needed, but then curved back over to the connection with the bed of the dump truck. Now let's see what happens. It's going to be the same motion. Here we see that it moves the payload up. It's in a new position and it dumps it over as before. And it's always avoiding the obstacle. See that curve in the component allowed it to avoid the obstacle but still guided it in the same path that we want it.

Now there are other ways that you could have done this. You could have, for example, just decide to connect this link at an entirely different place on the bed. Lots of other options too.

The key thing is that you generate a lot of options before you decide among them. That's one of the important things that design engineers need to do. First be creative, then be critical.

Now there's one more thing that I want you to do before we leave. I want you to think about this capability that you've just exercised. The ability to take a motion, specify it with three positions and then build the mechanism that will execute those three positions. What could you do that would be useful with that skill? What things out there in the world would be useful functions that you could execute? Generate some ideas, talk to your friends and we'll come back in just a couple minutes.

Great! OK. You're really thinking like design engineers now! You've acquired a new set of skills. You now how to take a specified geometry and to synthesize the mechanism that will execute that function that you specify. You've thought about how you can use it in the real world and now I hope that this is something that you can take out into your community and apply and make life better and easier for people around you. So we've seen that geometry is useful in the real world. That you can be introduced to an engineering mindset by getting hands on with some real equipment, and I hope that this is something you can take forward and really enjoy doing. Have a good day! Good bye for now.

Welcome to the trailer for the Blossoms Module entitled Design of Mechanisms. This segment is meant for you, the instructor. This is my opportunity to communicate to you some of the tips or tricks that I think might make the session go a little bit more smoothly. One thing I want to comment on first of all is that there's a lot of material in this video and one thing that's been suggested is that some will want to do this in a single one hour session. That would mean you have roughly a one to one ratio. For every minute that students are watching the video they have a minute of hands on exercises. But some may want to stretch it out in order to give people more time to absorb the material. You could break the session into two one hour activities and that would mean you have approximately 15 minutes of video and 45 minutes of hands on. And that for some people will be a better ratio.

Now one of the things that I want to suggest is that for this topic of mechanisms I believe it will be important to have hands on experience with materials that give some of the behavior of mechanisms. One of the ways to do that, as I show in the video, is with pegboard. You see behind me here pegboard is a light material in many cases, with an array of holes in it. This is sold in hardware stores where I am, relatively inexpensively because it's just a kind of dense cardboard material. It comes in sheets a little larger than what I have behind me here and I cut it down to a size that I could use in the classroom. The other thing you'll see on the board behind me is these links that are also made out of pegboard, just narrow strips that have just one row of holes in them. I have one such right here. So I took a regular carpenter's saw and cut out strips of pegboard material and I actually put it together double width. I glued with white glue one strip to another strip to get a little more thickness and that made the links a little stiffer and also enabled me to use nails as pins so that they would stay in place a little more securely.

Now what I want to suggest is that this means of assembling mechanisms is probably the optimal one for your students because it allows them to put together mechanisms with some precision. The holes allow you to measure out distances with some accuracy. It also allows for very convenient attachment and disassembly of the mechanisms. So I'm going to move back to the board now and talk about that a little bit.

What you see here is that I've got one strip. I've colored it red just with a permanent marker and I've used a screw with some threads in order to fix it to the white background. And then near the top here I have used a nail to go through the blue link above, all the way through to the red link behind. So the nail is going through both. And that allows for relative motion such as what you see here. I'll have more on this in a handout that goes along with the video module, but I just wanted to comment on these couple of details for now.

Another option. I understand that many of you will perhaps not be able to get your hands on some pegboard or maybe you want an option that takes a little bit less preparation time so I want to offer an alternative which is probably fine for this purpose and a little simpler. I'm going to move forward to the table now and what you see is I've put together something just with construction paper. It's just paper that is colored and is a little bit heavier than the paper that we normally write on. I've cut out a strip of red colored paper here and I've used a regular thumbtack. A thumbtack has a wide top on it and then a spine coming off it, sharp. I push that into the yellow construction paper here and now you see that the red piece of construction paper is hinged now to the background. It can rotate around the spot where I've inserted it just like that. Now if I want to connect another link to it so that it's attached to the red piece, my recommendation is you put the thumbtack in the piece that can move and then turn it around so the thumbtack is behind and put it up through the back of the red piece. And now you have something that's beginning to look like a mechanism. One piece is hinged to the background. One piece is hinged to the red moving piece. And you have at this point two degrees of freedom in motion. And the paper is stiff enough so that you can move it around. You can't really transmit forces but you get the same kinds of controlled motion that you would with a mechanism. So I think this is a reasonable option for you,

I think it's important that you afford the students the opportunity to put their hands on something and to observe the behaviors of the mechanisms for themselves and to do a little experimentation on their own. So I want to recommend that you do something, either the pegboard or the construction paper, but make this a hands on experience for your students if at all possible.

So now in the rest of the trailer what I want to do is talk about some of the solutions to the questions that I pose in the video and we can go on to that now. So now we'd like to talk about the question that I posed right before the first pause in the video. At that moment we were talking about an engine that runs on compressed air and is in a toy. And I showed that to you in the video and I also showed it to you on a computer screen much of the computer screen behind me. And I set up a question in the following way. If we return to the computer screen we have a red crankshaft here and to it is connected a blue connecting rod so that the end can rotate like this. And at the other end of the blue connecting rod is this green piston. And I asked, "What if we knew that the distance between the center of the crankshaft and the left end of the connecting rod, what if we knew that that distance was 3 mm. What if the length of the connecting rod from this center to this center is 5 mm. And what if we also positioned the green piston so the distance from this point on the right end of the connecting rod to the center of the crankshaft is 4 mm."

So now I'm going to go to the board and talk about the solution to that problem. So we said that there was a connecting rod and it had a center at some location. And we indicated that there was a connecting rod that was linked to it so that it could move in a circle like this. And that from here to here there were 3 mm of displacement. We further said that the connecting rod, its two ends were configured so that there was a distance of 5 mm. And finally we also said that the piston was configured so that the distance finally horizontally here was 4 mm. And I asked if we could use geometry to then figure out what is the orientation of the connecting rod here? For example what is the angle in here from the horizontal? Now one of the things that we can do right away is to apply a theorem from geometry that you may have covered in recent weeks and months, Pythagoras theorem. And what that tells us is that if the two legs of the triangle, their lengths are such that the squares of those two distances equals the square of the last leg, if that's true, which it is, that 3 squared is 9, 4 squared is 16 and 9 + 16 is 25, which is 5 squared. Then we know that this must therefore be a right triangle. So we've established that this angle in here is 90 degrees, by applying Pythagoras' theorem.

Now if we want to establish this angle in here therefore, we see that the opposite side over the adjacent side is the ratio of 3:4. So the tangent of this angle, let's label it alpha, is equal to 3 over 4. Therefore the angle is roughly 37 degrees. If you happen to have a table or a calculator that can make this calculation. If you just want to do an estimate so that you can ascertain roughly what is the angle whose tangent is _'s, you might just try to remember some of the triangles that are important benchmarks. For example I can draw another triangle here. And what if it has 30 degrees here, 60 degrees here and a right angle there? Now one thing that you might commit to memory is that the sides of this triangle are in the ratio of 1-2 and the square root of 3. So making a comparison here between this triangle and this triangle, what you see is that the tangent of 30 degrees is one over the square root of 3. The tangent of the angle we're concerned with is 3 over 4. So making the comparison we see that this angle should be just a little bit larger than that angle, therefore a little larger than 30 degrees.

Now there's one subtlety in this problem that I want to point out. I asked if you could tell me how this connecting rod is configured given that you know these distances are 3 and 4 and 5. Now it happens to be the case that there are really two possibilities. We know that the angle in here should be about 36 degrees but here's a consideration you might want to think about. We know that this link that goes from the center of the crankshaft to one end of the connecting rod constrains it to move in a circle. We talked about that and so I have this device here that basically works like a compass except with chalk. And what I can show therefore is that somehow the geometry of this mechanism constrains it so that the end of the connecting rod has to be somewhere along this circle. The other thing we know is that if the piston is placed at that location and is 5 units long, then the connecting rod must be somewhere along this circle. Now that's consistent with the drawing we've made here, but it's also consistent with the possibility that the connecting rod is up here. So really there are two answers to my question. The connecting rod could be in a configuration like this. Or it could be up here in a configuration like this. And drawing some circles will help you to see that both of those are valid answers to the question I posed. So your students should be able to articulate some of the ideas relating to triangles and circles and geometry to the engine that we introduced in the video.

So in the second pause of the Blossom video module Design of Mechanisms, I posed the question to the students regarding this mechanism on the pegboard. I asked when the red link executes motions around and round, what will the mechanism do and in particular what will the green link do? What motions does it execute?

Now if you built the pegboard what you'll be able to do is to experiment yourself. And what you'll see first of all is that directly by experience you'll see that when the red link goes around and around, the blue link oscillates back and forth just through a small angle. And therefore the end of the link moves back and forth. Now because it tilts only by a small angle, the motions it executes are almost a straight line. They're actually motion over the arc of a circle but because the arc is _______ by maybe just 10 degrees, it's very nearly a straight line. Now that sets up a correspondence between this mechanism on the one hand and the compressed air engine on the other. So what you see is that the red link going around and around is very similar to the crankshaft on the engine. The blue link is very similar to the connecting rod. And the green link, because its end is going in almost the straight line is very similar to the green piston in the compressed air engine model we have on the computer screen here. So that's the main message to get across, that a four bar mechanism like this could behave very much like a slide or crank mechanism even though it's connected in relatively quite different ways.

A few more subtleties about the motions that you might want to note are that as the red link begins to go around and around, there's a critical point here which is of interest. You'll see that when the red link and the blue link are forming a straight line, we call that a toggle point. And at this point the green link has moved as far to the right as it ever can. Further motion clockwise in this manner begins to bring the green link back toward the left until we reach yet another toggle point. Again the blue link and the red link are in straight line, in this case though overlapping. Now the green link has moved as far to the left as it ever will and subsequent motions again clockwise will bring the green link back toward the right. The vertical position as the red link comes to the vertical position and we're right back where we started. So again, circular motions of the red link cause almost straight line motions of the top end of the green link. That means that there is something very similar to a slider crank and therefore a close correspondence between what we made on the pegboard and the compressed air engine that we showed in the video.

In the third pause of the Blossom video module on Design of Mechanisms I pose a question to the students. They have three points that characterize the motion of part of a mechanism. And I ask them how they could determine the point at which they need to locate a joint or a bearing. Now this is related to the geometry of circles. And I show a construction technique in the video itself after the pause that gives a little bit of detail. At this point I want to show just a little bit of the geometric theory behind that construction technique I show. But first, here on the board what I'm going to do is make a circle I can talk about. Let's say we knew that there was a circle and let's say that there are three points on that circle that are of interest to us. Maybe there and there and there. And I draw a line between two of the points. Now this line that goes between two points on the circle is called an arc of the circle. Now if we construct a perpendicular line to this arc that happens to bisect the line, such as this, then a theorem from geometry says that that line that is perpendicular and is a bisector of the arc, that that line must contain the center of the circle.

Now I used that construction technique in the video in order to solve for a point at which we must locate a joint. I do that by finding a second line. I then take these two points and I construct a perpendicular bisector of that arc. And I say that because we know that the center of the circle has to be along this line, and has to be along the center of this line, we know that the intersection of those two lines has to be the unique center of that circle. Now I just wanted you to know that there is this theorem. The theorem is usually referred to in the following way: That the perpendicular bisector of an arc must contain the center of a circle. Some details on that can be found at the following reference: www.mathopenref.com/const3.circle.html And this is a nice web resource that gives you more details on that theorem that I mentioned and also the construction technique that I use in the video.

So there are just two more pauses in the Blossoms video module on the Design of Mechanisms. In these two pauses I pose questions to the students that are of the nature of design questions. They have the form, "How might you do the following thing?" And therefore there's not just one answer but a huge space of possible solutions. So the ways that you'll work with the students on this is very much at your discretion. We don't want to try to anticipate how your students will respond. But I will comment on a couple of things. In the first pause I ask the students to consider ways to modify a mechanism so that you can avoid one link hitting an obstacle. And I showed us one way to do it, by changing the shape of the link. I show that in the video module itself. Now your students will find other ways to do it such as changing the position of the link on the dump truck bed. Now the thing that I can consider critical is that when your student proposes a way to do something, although there's not one right answer, there are better and worse answers. So what I think you should do is go back to the hardware. If you have pegboard in the room, have them demonstrate their proposed solution and see if in fact it does provide the desired motion and avoid the obstacle as we had hoped. Go back to the hardware and really demonstrate the solutions.

In the last pause on the video, what I ask is that the students think of things out there in their communities, out in their world that they could put to use this capability to design mechanisms to guide motion. So their reasonable answers to that question are any function out there in their community in which a body needs to move over and over along a prescribed path or in a prescribed manner. And so some of the things that come to mind are in agriculture, in manufacturing. But some things day-to-day that they might come in contact with are storage bins. Really anything is possible. You might prepare for presentation of this module by going out and observing things in the community providing some examples for your students from your area. And I think that that will make the video module and the associated session that you run more engaging for students when they see the relevance of the mechanism design topic to their lives and their community. So I want to encourage you to prepare for the session as an instructor by going out and finding examples of guided motion in the world around you. Maybe in your classroom.

So I want to thank you for your participating in this educational exercise. I hope that your students get a lot of it and I hope that this resource was valuable to you. Thanks.

END OF TRANSCRIPT