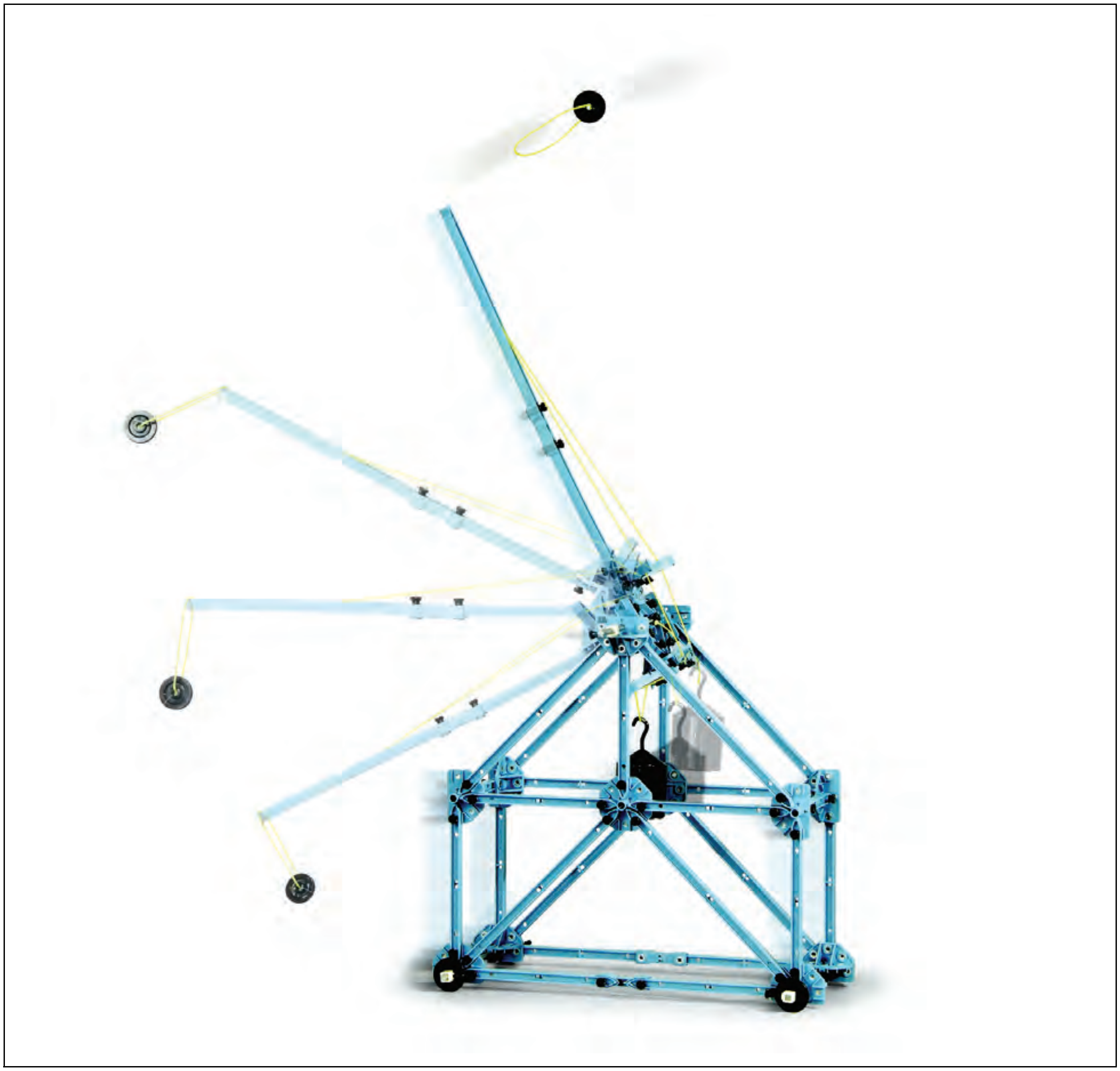
Instruction Manual
012-11734A

High School Physics Structures Set

ME-7000



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High School Physics Structures Set

ME-7000

Included Equipment	Qty	Included Equipment	Qty
1. #5 I-Beam (24 cm long)	16	15. “O” Ring	12
2. #4 I-Beam (17 cm long)	16	16. Spacer	12
3. #3 I-Beam (11.5 cm long)	36	17. Collet	24
4. #2 I-Beam (8 cm long)	36	18. Pulley	12
5. #1 I-Beam (5.5 cm long)	16	19. Wheel and Tire	4
6. Flat Round Connector	6	20. Straight Connector	24
7. Full Round Connector	6	21. Road Bed Clip	24
8. Half Round Connector	6	22. Angle Connector	24
9. Road Bed (3 m)	1	23. Sliding Connector	12
10. Photogate Flag	1	24. Cord Tensioning Clip	32
11. Mini-Car Mass (about 200 g)	1	25. Yellow Cord	76 m
12. Mini-Car, Red	1	26. Axle, medium (21.5 cm)	2
13. PAStrack Connector	6	27. Axle, long (26.5 cm)	2
14. Screws (6-32)	150	28. Axle, short (10.5 cm)	2

Not Shown: Mini-car Collision Bumper (2), Mini-car Starter Bracket (1), Road Bed Coupler (2), Mini-Car, Yellow (1)

Other Equipment for Experiments	Other Equipment for Experiments
Mass and Hanger Set (ME-8979)	Rod, 45 cm, Stainless Steel (ME-8736)
Large Slotted Mass Set (ME-7566)	Rod, 120 cm, Stainless Steel (ME-8741)
Aluminum Table Clamp (ME-8995)	Force Platform (PS-2141)
Double Rod Clamp, 3-pack (ME-9873)	Force Platform Structures Bracket (ME-6988)
Accessory Photogate (ME-9204B)	Rotary Motion Sensor (PS-2120)
PASCO Data Acquisition Interface*	PASCO Data Acquisition Software*

*See the PASCO catalog or web site at www.pasco.com

Introduction

For years children have experienced the wonder of creating structures utilizing popular toys such as LEGO® and K'nex®. But these systems provide only a vague qualitative understanding of how structures function. Classic popsicle stick bridge competitions are time consuming, expensive, sometimes dangerous and yield minimal gains in student understanding of how structures work.

The PASCO Structures System has been designed from its inception to provide valid modeling of pin ended truss structures. The system is fully compatible with load sensing elements that allow students to build, measure and revise their designs. Further, the elements of the structures system allow for the use of pure tension elements as well as alternate beam forms and student designed and built composite beams. When used in combination with PASCO force sensors, amplifiers, data logging interfaces and software, this system provides an accurate method of modeling and measuring the behavior of structures under both static and dynamic loading. This system is currently used in university level engineering programs.

This High School Physics Structures Set has been selected to maximize the number of different structures that can be built in support of physics learning. The essence of project based learning – building, testing, measuring and revising – is embodied in the PASCO Structures System. With the High School Physics Structures Set students can build structures that are used to learn about the core subject matter of physics. Literally in minutes students can build, measure, and revise their designs based on data rather than guesses. This manual introduces examples of structures that may be built. These do not represent every possible configuration and you should encourage students to explore other possible uses and designs.

The High School Physics Structures Set is one part of the PASCO Structures System. Although the High School Physics Structures Set can be used as a stand-alone set, it can also be combined with other parts of the PASCO Structures System. For example, the Load Cell and Dual Load Cell Amplifier Set (PS-2206) can be added to measure compression and tension forces in the structure members. Other sets of plastic parts are available.

PS-2206 Load Cell and Dual Load Cell Amplifier

The PASCO Structures System includes:

Truss Set (ME-6990) - A small set of I-beam members, connectors, and thumbscrews for building trusses

Bridge Set (ME-6991) - A larger set with a mini-car, road bed, cord tensioning clips, and braided cord for building bridges and roller coasters

Advanced Set (ME-6992A) - The largest set with flexible I-beam members, flat beam members, pulleys, axles, drive wheels, and additional connectors that allow beams to be joined at angles other than 45 and 90 degrees.

This set can also be used to build suspension bridges, cranes, cars, catapults, and models of parts of the human body.

Load Cell Amplifier (PS-2198) - The Load Cell Amplifier can support up to six Load Cells and requires a PASPORT interface to connect to the USB port of a computer.

Load Cell and Amplifier Set (PS-2199) - This Set has a Load Cell Amplifier (PS-2198) and four 100 N Load Cells (PS-2200).

100 N Load Cell (PS-2200) - The 100 N Load Cells has strain gauges mounted on a beam but no electronics so it requires a Load Cell Amplifier (PS-2198) or Dual Load Cell Amplifier (PS-2205).

5 N Load Cell (PS-2201) - The 5 N Load Cell has a range of +5 N to -5 N.

PASPORT Displacement Sensor (PS-2204) - The sensor includes a digital indicator to measure displacements to within 0.01 millimeters over a range of 10 mm.

Dual Load Cell Amplifier (PS-2205) - This amplifier supports one or two Load Cells.

About the Components

Assembling Beams

Attach beams to a connector using the included thumbscrews (6-32, slotted) as illustrated.

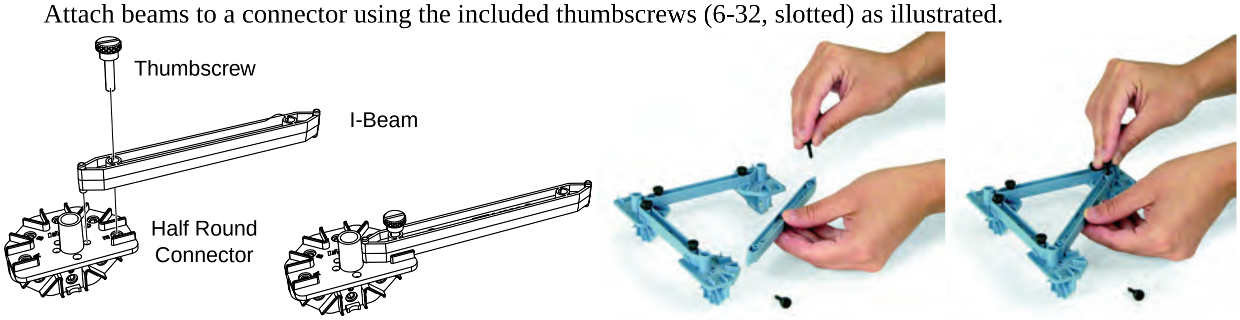


Figure 1: Attaching beams to connectors

For example, each half round connector has eight slots, labeled A through H, for accepting beams. There are five sizes of I-Beams, labeled 1 through 5. Beam #1 is the shortest beam.

Attaching Cords

When attaching cords for lateral bracing or for suspension or cable-stayed bridges, Cord Tensioning Clips are used to assist in adjusting the tension in the cords.

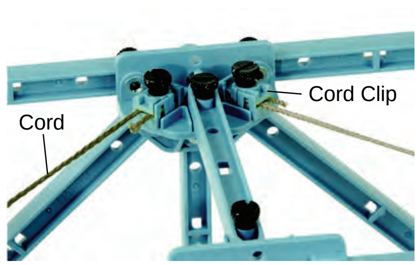


Figure 2: Lateral bracing

The Cord Clip has a top part and a bottom part but it does not come apart. It is best to thread the cord through the clip before the clip is installed on the bridge or other structure. Prepare to thread the cord by holding the top half of the clip as shown in Figure 3 so the two halves of the clip will separate, leaving an opening through which the cord is threaded. The cord is inserted into the end opposite the pointed end of the clip. The cord should be looped back through the clip as shown in Figure 4. Then the Cord Clip can be used in the bridge or other structure, using the attachment screw to tighten the clip shut. To adjust the cord tension, loosen the screw and pull on the cord to the desired tension and then re-tighten the screw.


Figure 3: Hold half of the cord clip so the two halves separate


Figure 4: Loop the cord back through the cord clip


Figure 5: The cord goes around the screw hole


Figure 6: The cord clip is ready to be attached to the structure using a screw

Attaching the Road Bed.

To attach the blue road bed to the cross-members of a bridge or other structure, first connect the road bed clips to the underside of the road bed by twisting the clip into the slot so the edges of the slot capture the clip (see Figure 7). Slide the clip in the slot a short distance to align it with the cross member of the bridge.

Figure 7: Attach road bed clip to road bed

Using the Road Bed Coupler

Each end of the coupler is inserted into the slot on the bottom of the Road Bed to join two Road Beds together (see Figure 8).

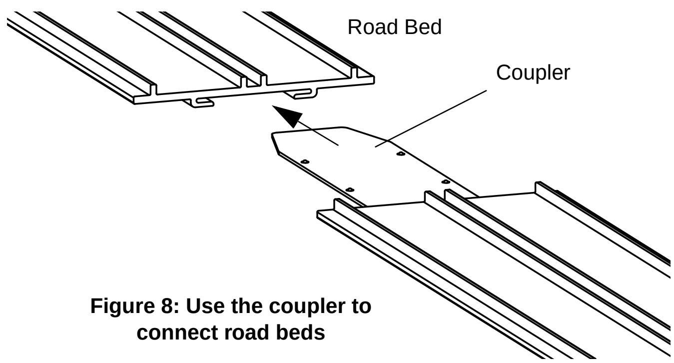


Figure 8: Use the coupler to connect road beds

Attaching the Starter Bracket

The main purpose of the starter bracket is to align the Mini-car wheels with the ridges in the road bed when the car is placed on the road bed. In general, install the starter bracket at the end of the road bed.

To attach the starter bracket to the road bed, squeeze the spring metal clip and insert the clip into the slot on the bottom of the road bed, then release the clip (See Figure 9).

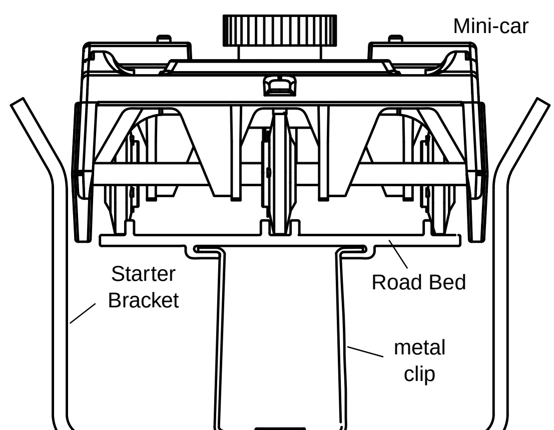
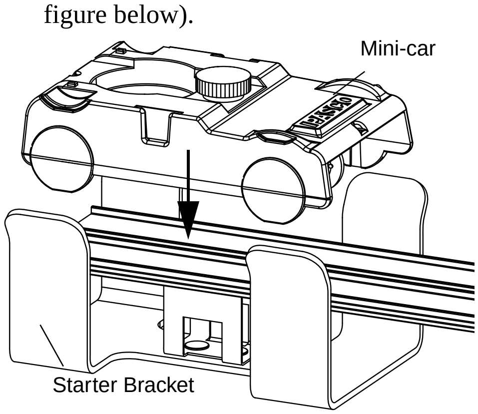


Figure 9: Attaching the starter bracket to the track (end view)

Place the mini-car between the sides of the starter bracket to align the wheels with the ridges on the road bed (see the figure below).



Using the Mini-Car

The ridges in the road bed guide the Mini-car wheels. The supplied mass (approximately 200 g) can be set in the recess in the Mini-car to give the car more mass. If smaller masses are desired, use the Mass and Hanger Set (PASCO Model ME-8979).

The photogate flag fits into the slot on the side of the Mini-car. As the car passes through a photogate, the infra-red beam is blocked twice by the flag. To find the speed of the car, measure the distance between the leading edges of the flag (approximately 1 cm) and measure the time between the events when the infrared beam is blocked.

The Accessory Photogate with Stand (PASCO Model ME-9204B) is useful as a free-standing photogate.

Using the Mini-Car Collision Bumper

The collision bumper can be attached to the mini-car with a thumb screw through the hole in the center of the mini-car (See Figure 10).

Orient the bumper so the circular indentation in it is up and it is aligned with the mini- car's circular mass tray.

To make an elastic bumper, small rubber bands are supplied with the bumper. Stretch a rubber band across the bottom of the two prongs on the bumper. For high speed collisions, it is necessary to double over the rubber band to make the rubber band stiffer.

For completely inelastic collisions, remove the rubber band and put a small amount of clay in the "V" slot on the bumper. (See Figure 11).

The bumpers are also used to couple two or three mini-cars together for a roller coaster train. To accomplish this, put rubber bands on the bumpers to make elastic bumpers. Then place the pointed front bumper of the trailing mini-car over the rubber band of the mini-car in front of it, letting it fit loosely into the "V" slot of the leading car (see Figure 12).

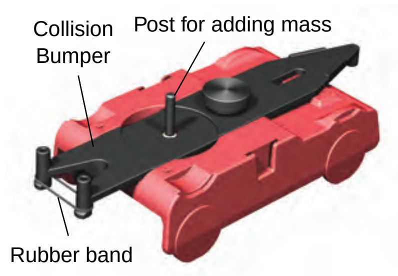


Figure 10: Mini-car with Bumper

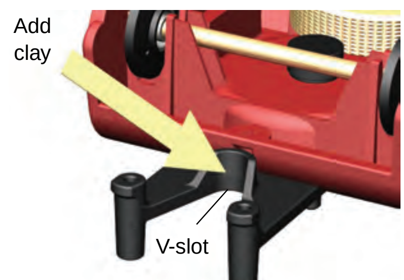


Figure 11: V-slot on the Bumper

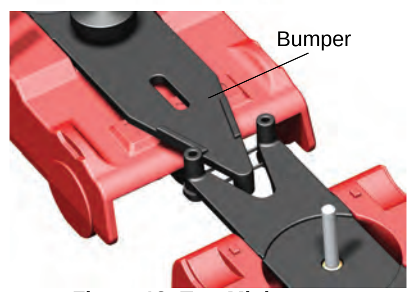
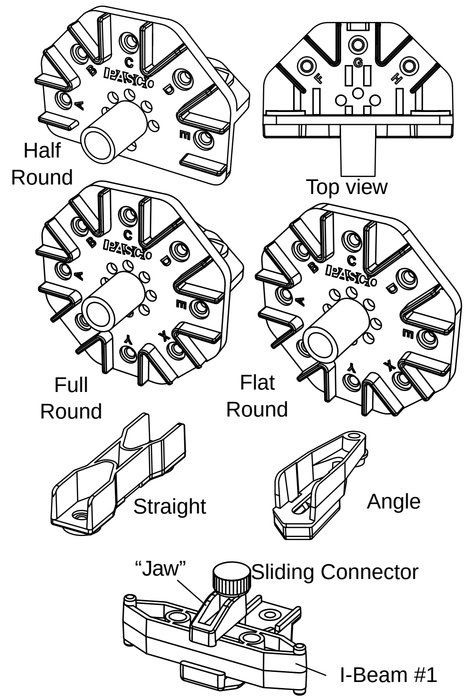


Figure 12: Two Mini-cars connected together

Connectors



Half Round Connector: The half round connector has eight slots, labeled A through H, for accepting beams.

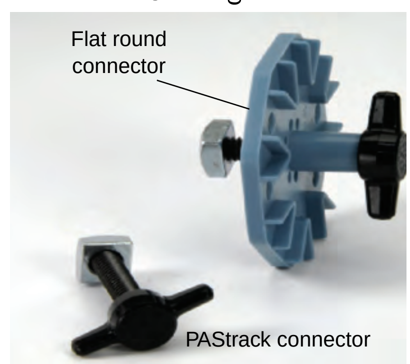
Full Round Connector: The full round connector has eleven slots, labeled A through H and X, Y, and Z, for attaching beams

Flat Round Connector: The flat round connector has eight slots, labeled A through E, and X, Y, and Z, for attaching beams. The PAStrack Connector with square nut can be used with the flat connector to fasten a bridge or other structure to the PASCO PAStrack.

Straight Connector: The straight connector can connect two beams to make a longer beam.

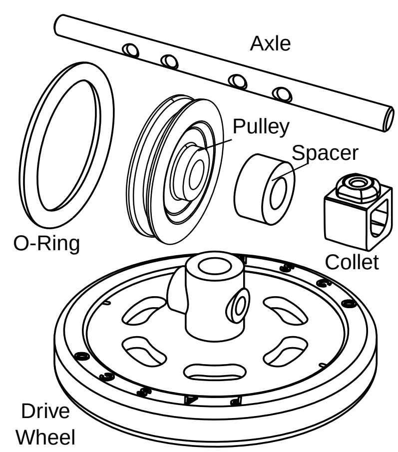
Angle Connector: The angle connector allows a beam to be connected to a half round connector, full round connector, or flat connector at an angle different than zero, 45, or 90 degrees. The angle connector also allows for a small adjustment of the length of the beam.

Sliding Connector: The sliding connector has upper and lower "jaws" that fit over a beam. The sliding connector allows one beam to be connected to another beam at any position along the length of the second beam. To use the sliding connector, loosen the thumbscrew and rotate the top "jaw" to the side. Place the beam onto the lower part of the connector, rotate the top "jaw" into place, and tighten the thumbscrew.



PAStrack Connector: The PAStrack connector with square nut can be used with the flat round connector to fasten a bridge or other structure to the PASCO PAStrack (see the PASCO catalog or web site at www.pasco.com.)

Axles, Pulleys, Spacers, and Collets



Axles: There are two each of three different lengths: 10.4 cm (4.1 in), 21.3 cm (8.4 in), and 26.6 cm (10.5 in). Each axle is 0.635 cm (0.250 in) in diameter.

Pulleys: There are twelve pulleys, each 3.175 cm (1.250 in) in diameter and 0.558 cm (0.220 in) wide. To make a wheel, put one of the "O" rings into the pulley's groove.

Spacers: There are twelve spacers, each 0.635 cm (0.250 in) inside diameter, 1.25 cm (0.50 in) outside diameter, and 0.635 cm (0.250 in) wide.

Collets: There are twenty-four collets that can be used with screws (6-32) to hold pulleys and spacers in place on an axle.

Drive Wheel with Tire: There are four drive wheels with tires. The drive wheel can be attached to an axle using a thumbscrew. To attach the wheel firmly to the axle, line up a hole on the axle with the thumbscrew hole on the wheel. If the rubber tire is removed, the wheel can be used as a large pulley.

Adding Load Cells

To measure the compression and tension forces in individual members, add load cells (PASCO Model PS-2199) to any PASCO Structure. Replace a beam with two shorter beams and a load cell.

#5 beam = load cell + two #3 beams

#4 beam = load cell + two #2 beams

#3 beam = load cell + two #1 beams

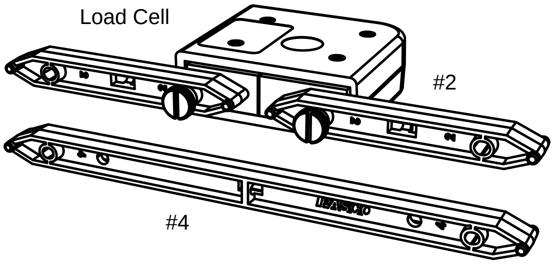


Figure 13: A load cell combined with two #2 beams is the same length as a #4 beam

Use thumbscrews to attach two beams to a load cell as shown in Figure 13.

When using load cells, assemble your structure with the screws loose. This will simplify the analysis by ensuring that the members experience only tension and compression without moments.

See the instructions that came with the load cells for details about how to connect the load cells to an interface or datalogger and collect data.

Example: Bridge with Load Cells

The bridge shown (Figure 14) uses six load cells to measure the tension or compression in various members. A hanging mass is used to apply load. The mass is adjusted so that the compression in one of the legs is 1.0 N. Compression is registered as a positive value and tension as a negative value.

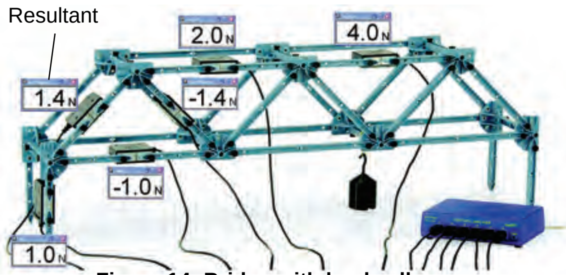


Figure 14: Bridge with load cells

If the screws are loose, the theoretical analysis of the bridge can be carried out by assuming that the net force at each node is zero. Thus, the vertical component of compression in the left-most diagonal member must be 1 N (to oppose the force applied by the leg). The horizontal component must also be 1 N since the member is at a 45° angle. The predicted resultant force is:

$$\sqrt{(1.0\ \text{N})^2 + (1.0\ \text{N})^2} = 1.4\ \text{N}$$

The actual measured force confirms the theory.

Dynamic Load

With the load cells inserted as shown in Figure 15, push the Mini-car with its extra mass across the bridge. Zero the load cells before the measurement. Examine which members are under tension or compression.

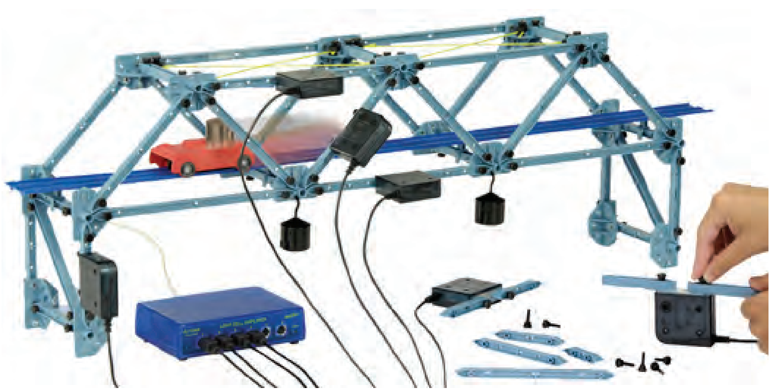


Figure 15: Recording the forces measured by the load cells as the mini-car crosses the bridge.

Calibration of Load Cells

Load cells are factory calibrated; however, you can recalibrate them in software or on the datalogger. See the documentation for your software or datalogger for instructions.

When calibrating a load cell, it is necessary to apply a known load. Assemble the fixture shown in Figure 16 to support the load cell. Hold or clamp the fixture at the edge of a table and hang a mass from it as shown.

Note that the hanging mass applies tension to the load cell; therefore the known force that you enter into the software or datalogger should be a negative value. For example, if the mass is 1.0 kg, the applied force is -9.8 N.

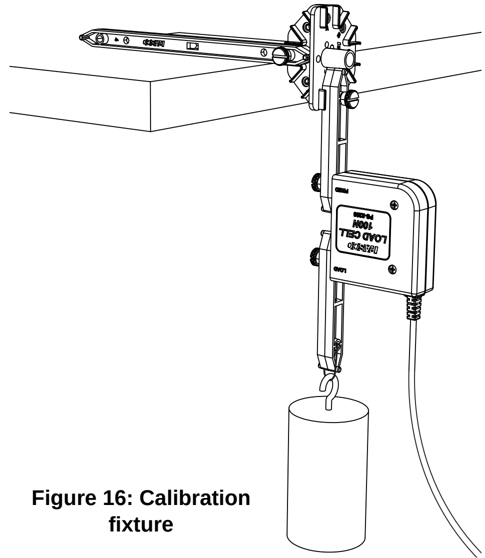
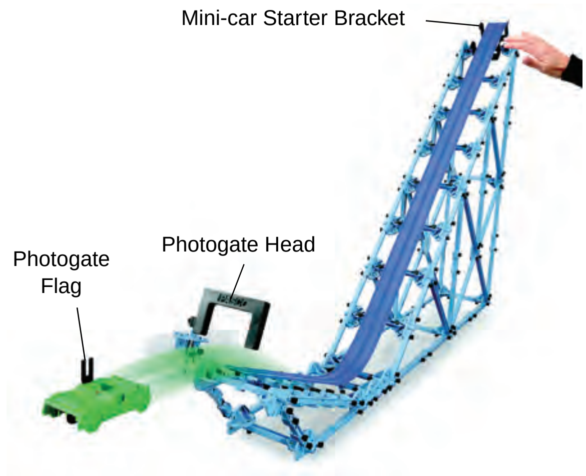


Figure 16: Calibration fixture

Two Dimensional Motion

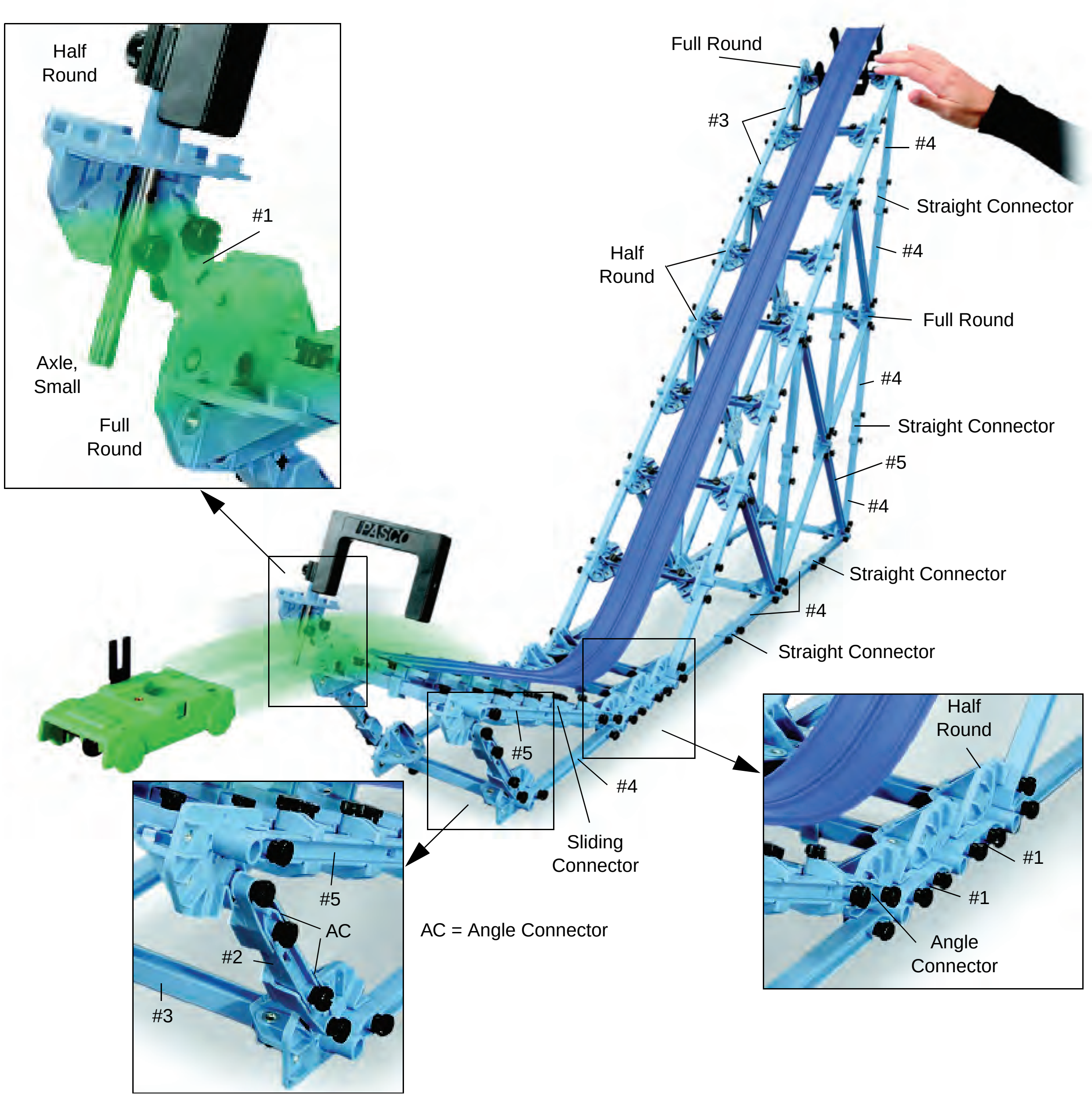
Ski Jump

By creating an angled track as shown below a ski jump may be created that allows students to perform two dimensional motion experiments. By releasing the mini-car from various distances up the slope different initial velocities may be achieved. These velocities are most easily measured using a photogate (ME-9498A) at the end of the track as shown. The launch angle is easily changed by elevating or lowering the hill side of the ski jump.



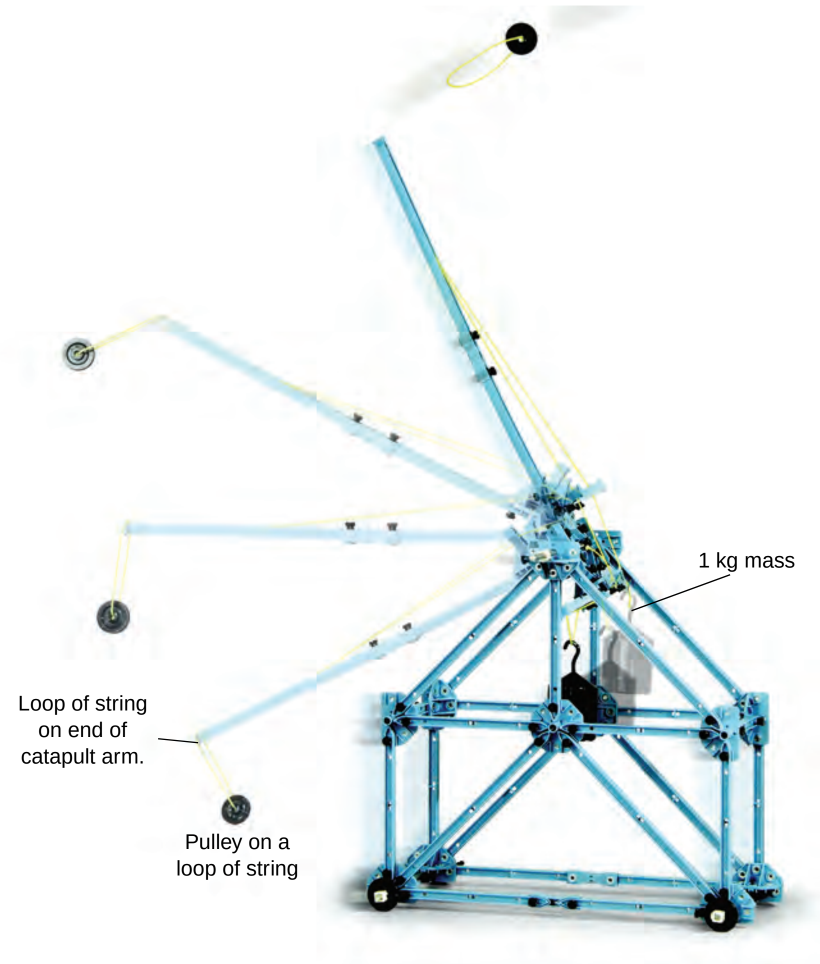
Details of the Ski Jump

Other equipment: Photogate Head (ME-9498A)



Catapults

Students can design, build and test catapults using the structures system. The catapult shown is representative of how a trebuchet might be configured. Once built the students can explore the effect of launch angle, energy storage (spring or mass) and projectile weight and how they alter the distance of the throw.



Hang a 1 kg mass from the loop of cord shown in the Rear View Detail below.

Thread a piece of cord about 20 cm in length through a pulley and tie the cord so it makes a loop. Hang the loop at the end of the catapult arm.

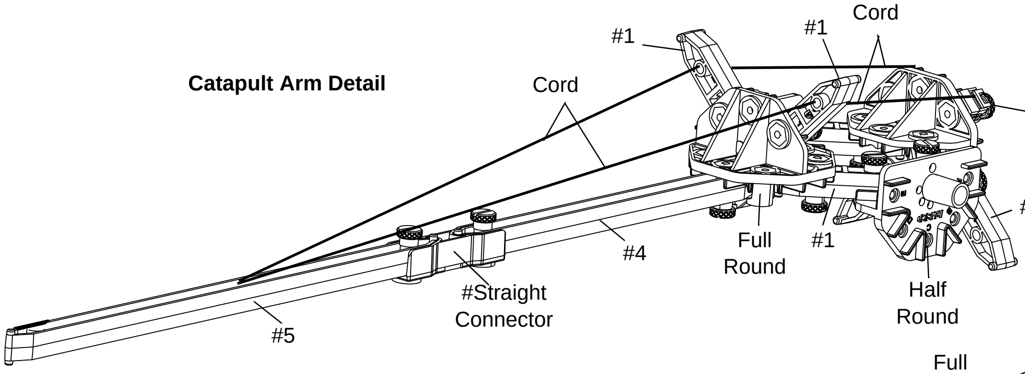
Pull the catapult arm down so that the pulley/projectile is near the table top and the catapult arm is touching the front of the base.

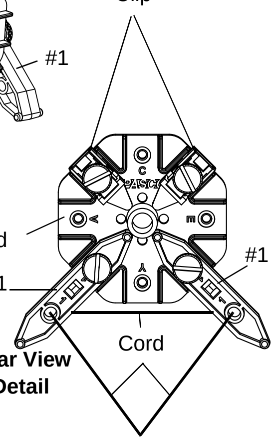
Release the catapult arm to send the pulley/projectile on its way.

Catapult Details

Extra Equipment	Model
Hooked Mass Set	SE-8759

Catapult Arm Detail

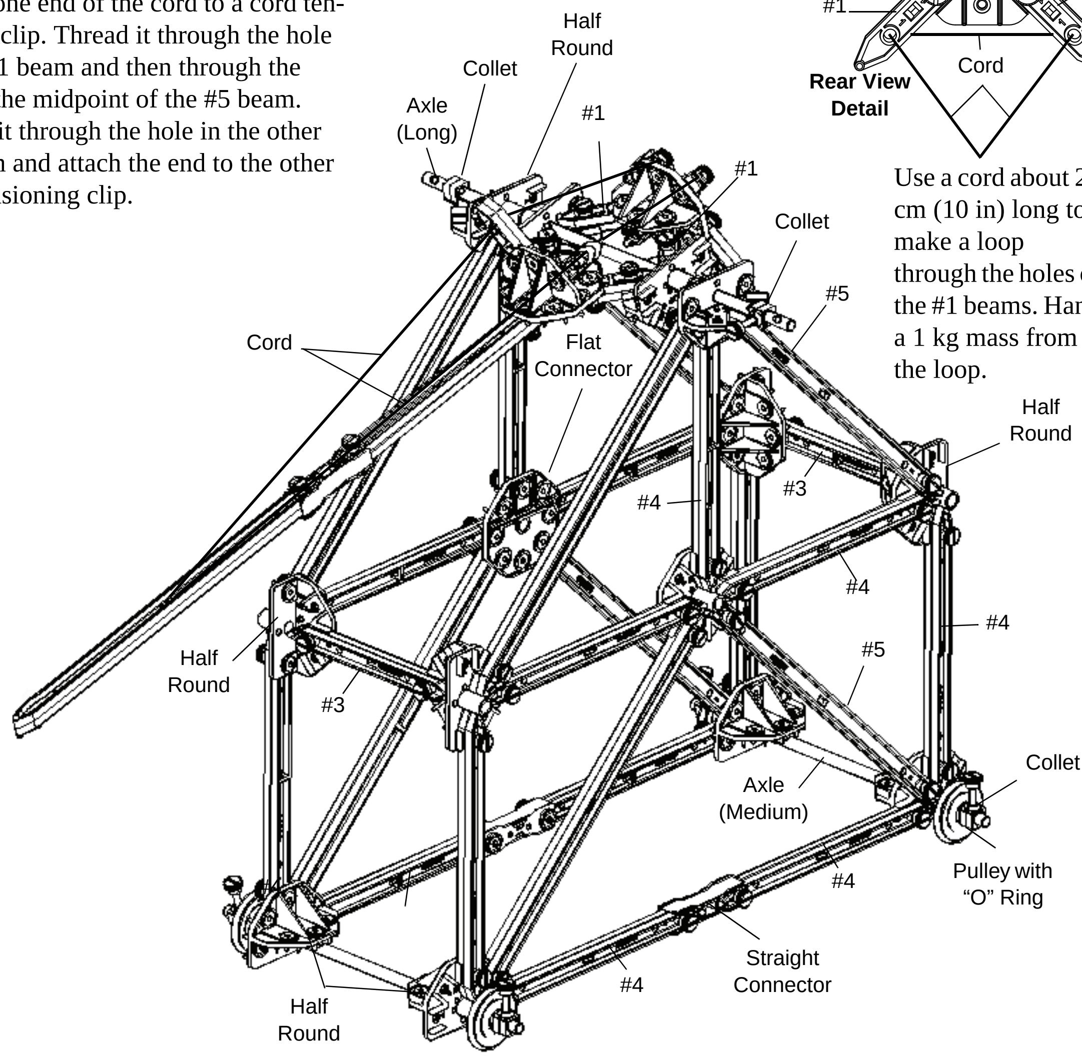




Rear View Detail

Use a cord to support the Catapult Arm. Attach one end of the cord to a cord tensioning clip. Thread it through the hole of the #1 beam and then through the hole at the midpoint of the #5 beam. Thread it through the hole in the other #1 beam and attach the end to the other cord tensioning clip.

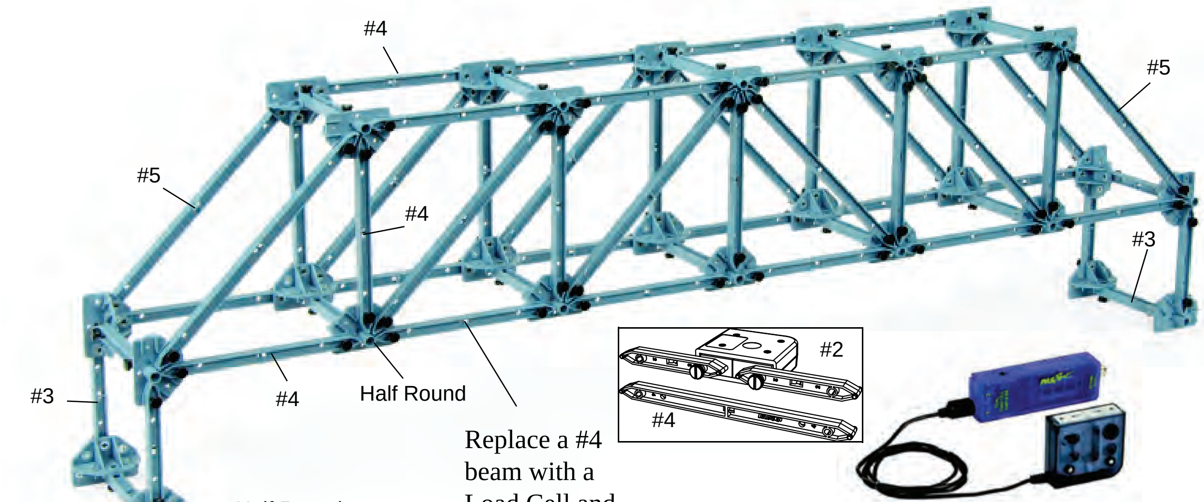
Use a cord about 24 cm (10 in) long to make a loop through the holes of the #1 beams. Hang a 1 kg mass from the loop.



Catapult Base Detail

Newton’s Laws: Bridges

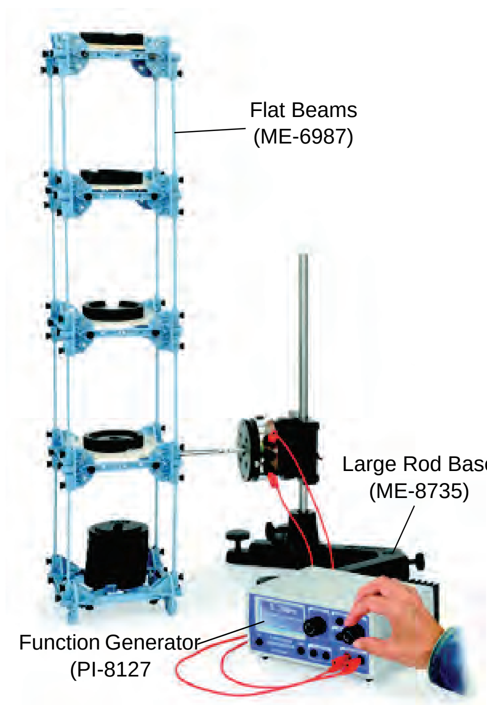
Many different types of truss and suspension bridge may be built using the components in this set. A representative bridge is shown with a load cell installed (PS-2206 Load Cell and Dual Load Cell Amplifier Set). By loading the bridge structure students can explore the nature of the forces in various parts of the bridge moving the load cell from one location to another. Student design competitions can now center on building bridges of specified span that achieve predetermined force levels.



PS-2206 Load Cell and Dual Load Cell Amplifier Set

Bridges may also be dynamically loaded utilizing a low frequency driver such as the Mechanical Wave Driver (SF-9324). Students in upper level courses can explore the factors that determine resonant frequencies of bridges and other structures.

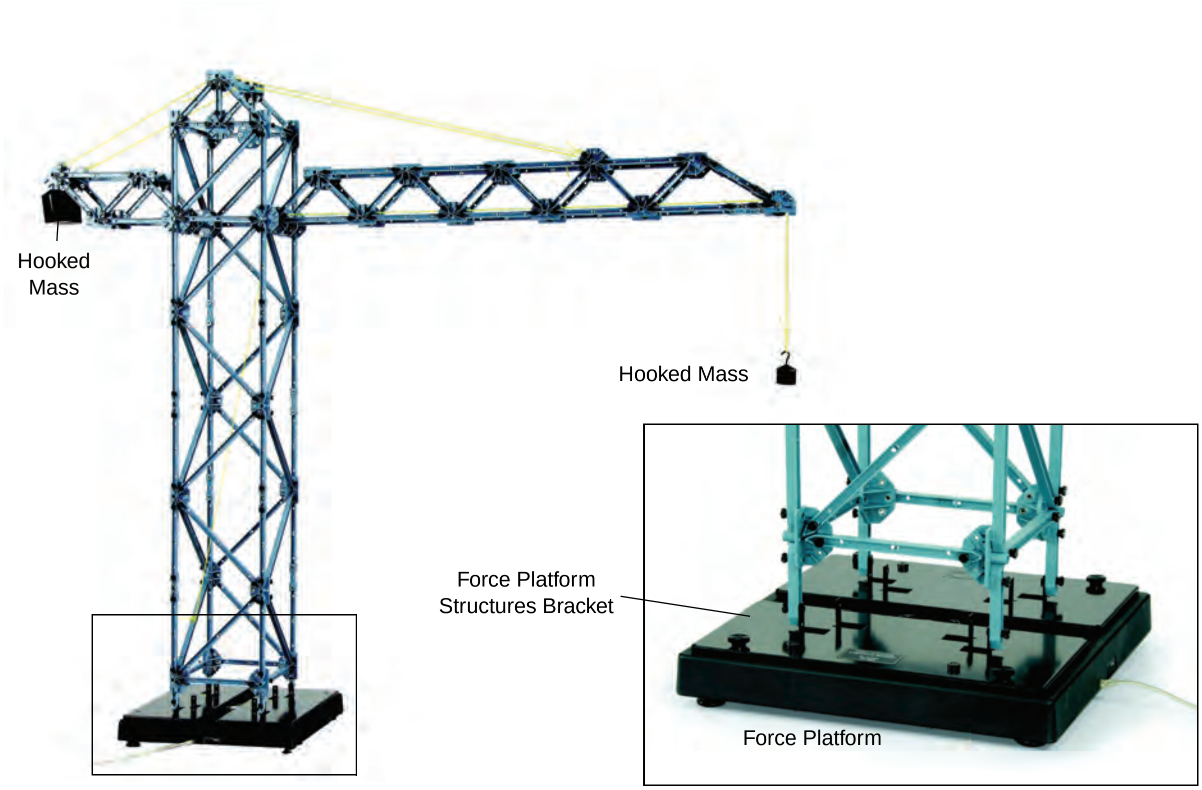
SF-9324 Mechanical Wave Driver



Use a Mechanical Wave Driver to shake a tower loaded with slotted masses.

Newton's Laws: Cranes

Cranes provide an ideal real world example of the meaning of lever arms, center of mass, pulleys, and cable forces. As shown below a very realistic crane may be built that allows students to measure the forces that exist anywhere in the structure and even the reaction forces at ground level utilizing the Force Platform Structures Bracket (ME-6988) and a Force Platform (PS-2141) as shown. Over turning forces can be measured when a load is shifted outside the safe center-of-mass range.



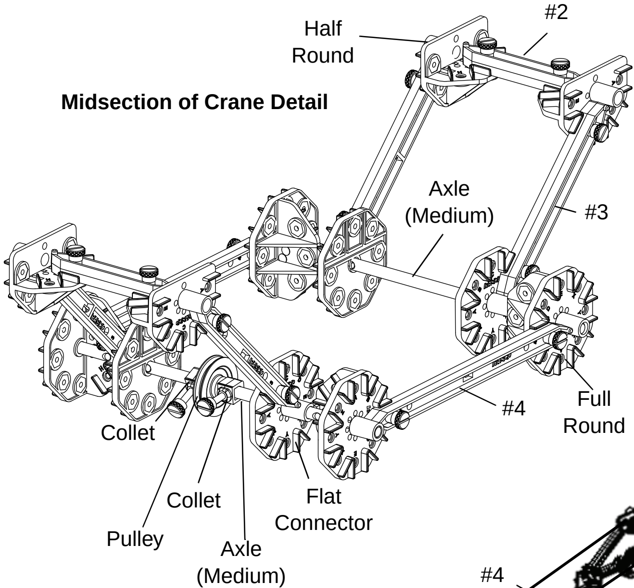
Extra Equipment	Model
Hooked Mass Set	SE-8759
Force Platform	PS-2141 or CI-6461
Force Platform Structures Bracket	ME-6988

Force Platform

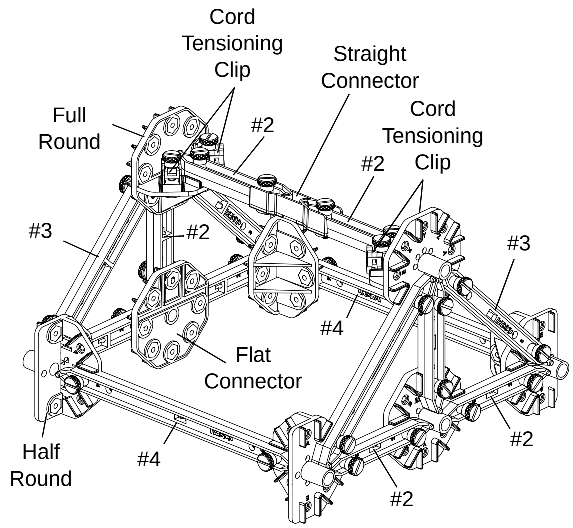
The Tower Crane is shown with #1 I-beam members at the bottom of the base. They are needed only when the structure is used with a Force Platform and the ME-6988 Force Platform Structures Bracket.

The Force Platform has four individual Load Cells inside that combine to measure the total vertical force on the platform. The ME-6988 Force Platform Structures Bracket is needed to attach the I-beam members at the base of the Tower Crane to the Force Platform.

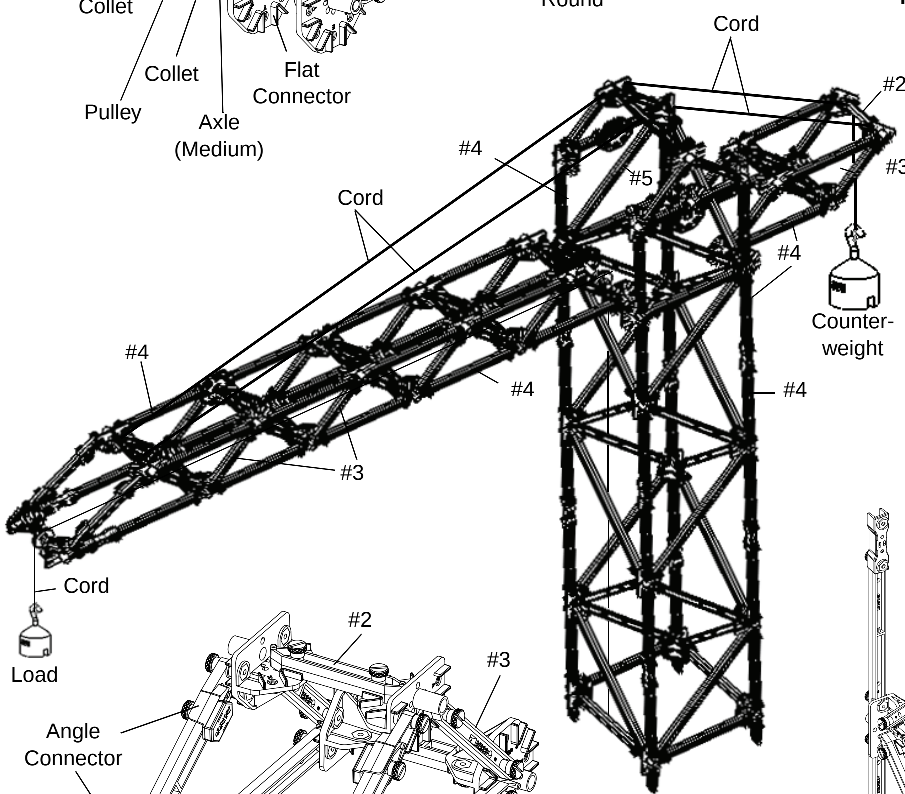
Tower Crane Details



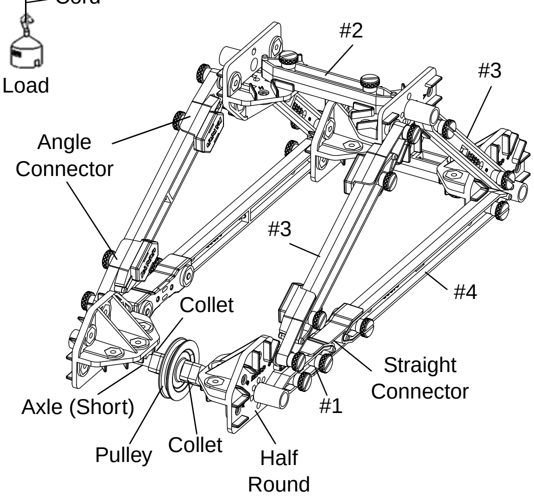
Midsection of Crane Detail



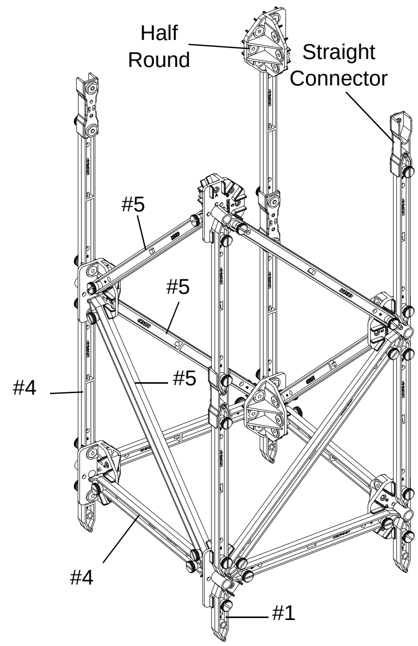
Top of Tower Detail



Tie cords from the cord tensioning clips on the top of the tower to both ends of the crane.



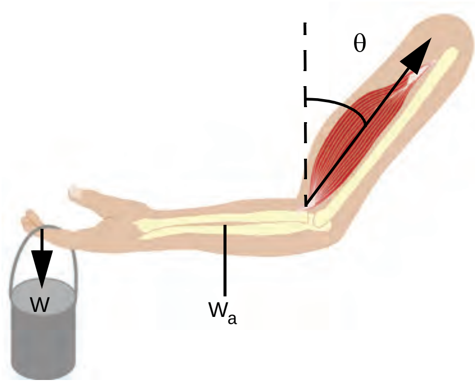
Front End of Crane Detail

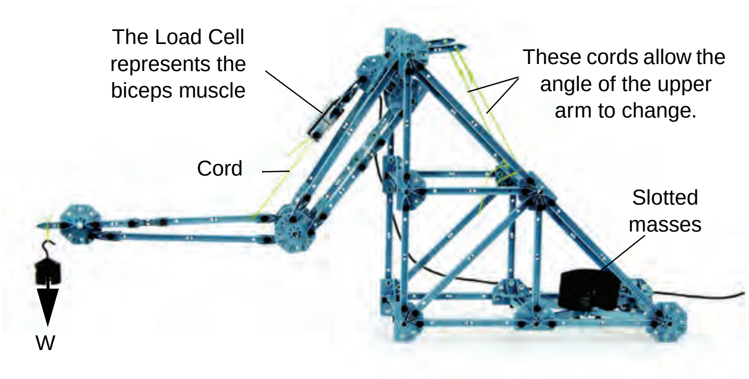


Base of Tower Detail

Newton’s Laws: Modeling the Human Body

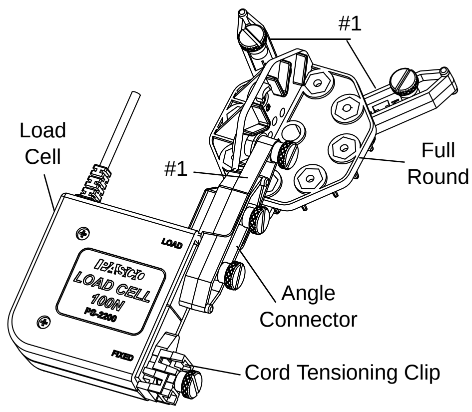
Force on bones, tendons and muscles can be measured using models of human and animal joints and subjecting these models to loads. A model of the classic human arm holding a cup of coffee is shown below. In this model load cells are measuring the force that a biceps must exert to hold a pail of water.



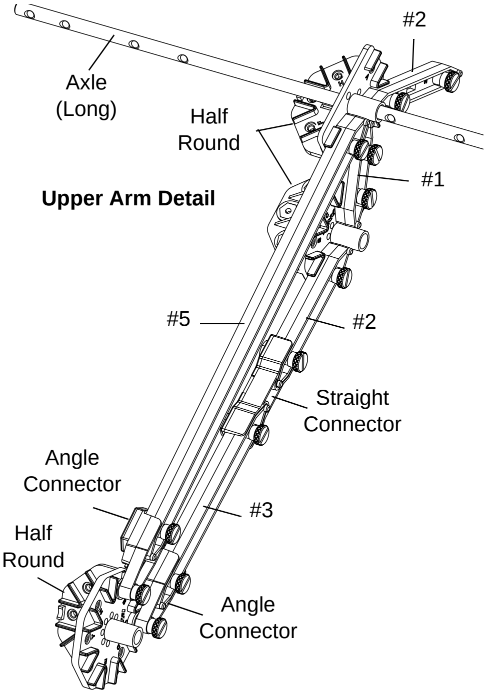


Extra Equipment	Model
Hooked Mass Set	SE-8759
Large Slotted Mass Set	ME-7566
Load Cell	PS-2200
Load Cell Amplifier	PS-2198

Human Arm Details

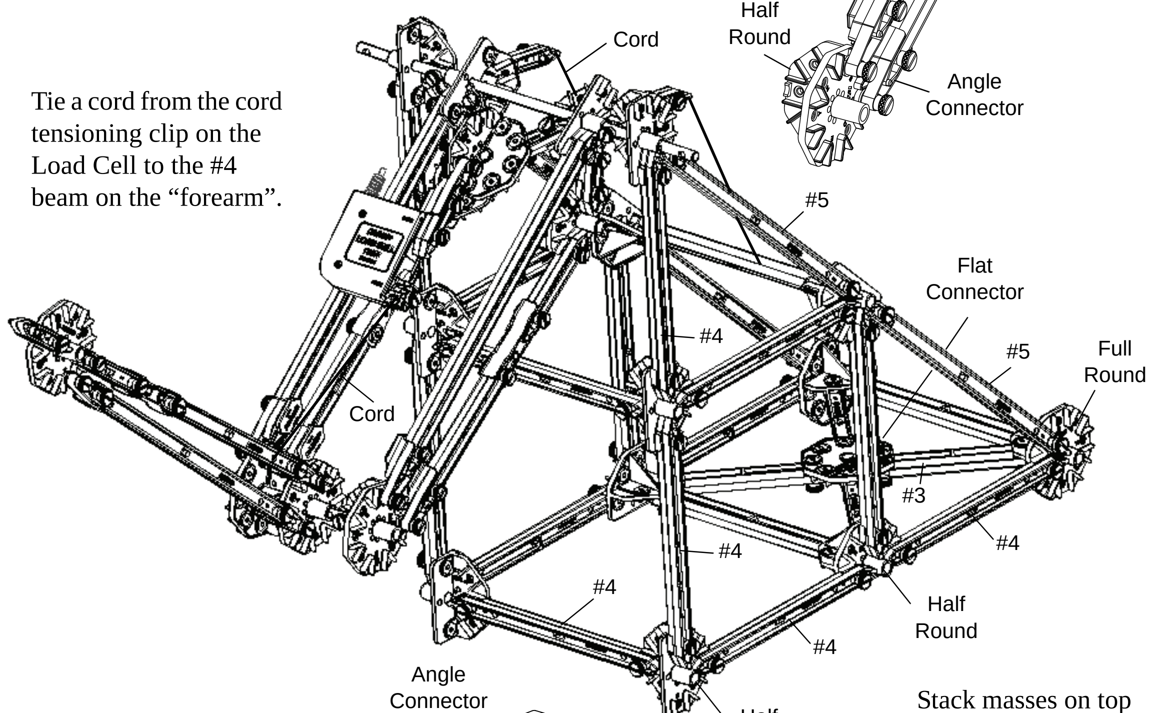


Load Cell Detail

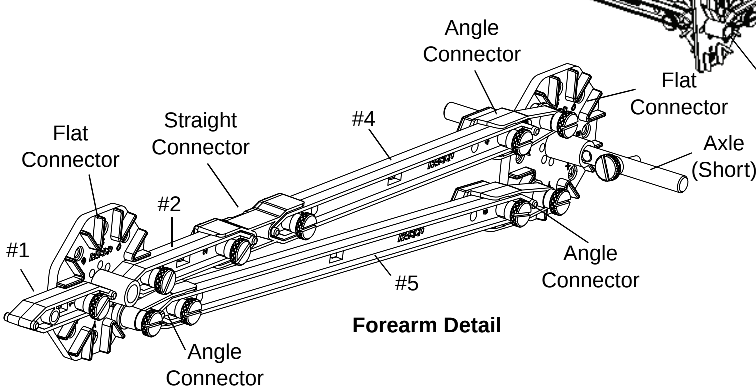


Upper Arm Detail

Tie a cord from the cord tensioning clip on the Load Cell to the #4 beam on the “forearm”.



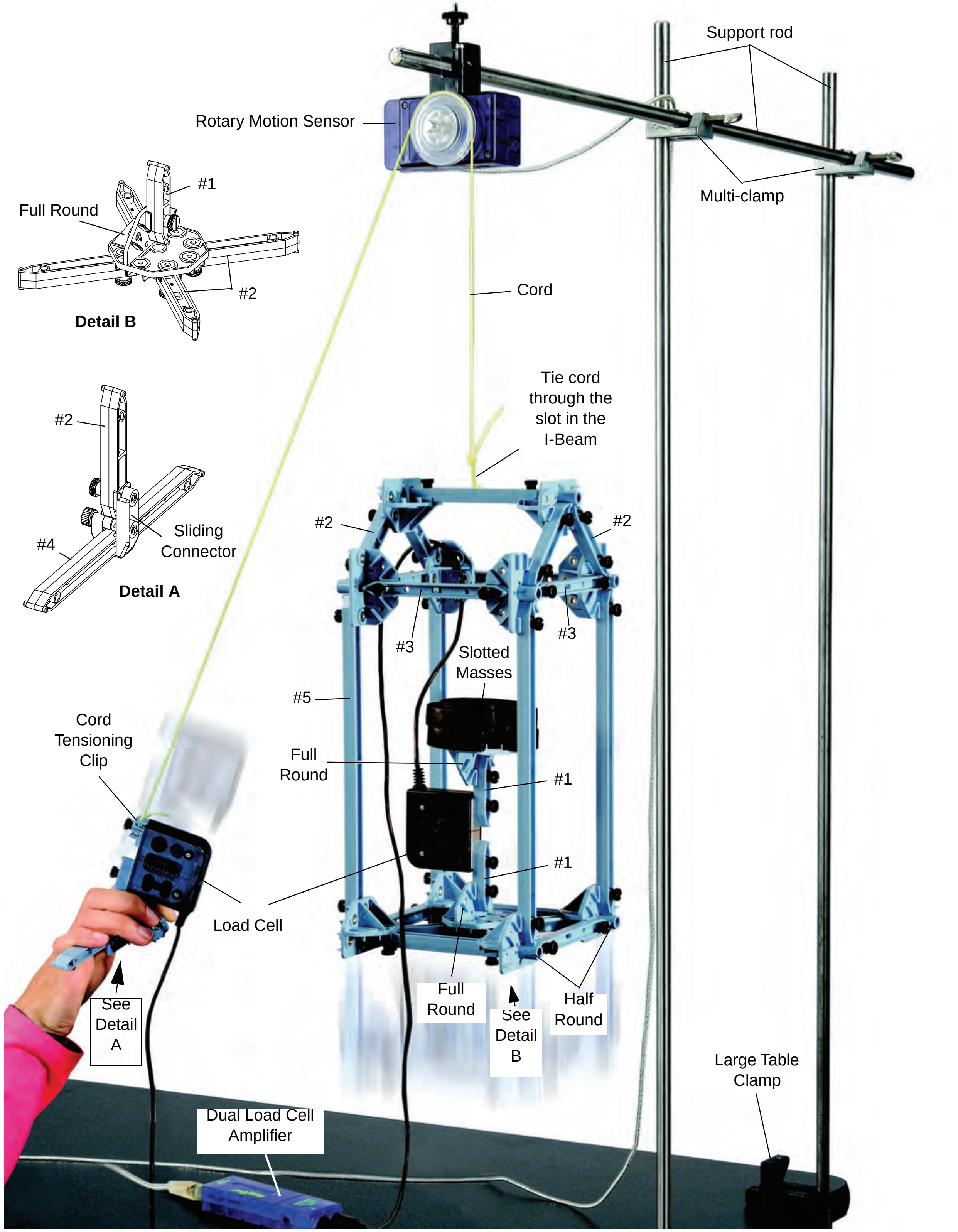
Stack masses on top of the flat connector.



Forearm Detail

Newton's Laws: Elevator

Rather than trying to explain the perennially difficult elevator problem, have students build and test an elevator as it moves up and down. The addition of a 5 N Load Cell (PS-2205) with an inertial mass allows the measurement of relatively low accelerations. By setting up a Motion Sensor (PS-2103A) or a Rotary Motion Sensor (PS-2120) as pictured the force in the elevator cable, the acceleration of the elevator and the acceleration experienced by the occupant can all be measured. Students can measure the effect of free-fall by releasing (for a short distance!) the elevator to see what happens to the acceleration the occupant experiences.

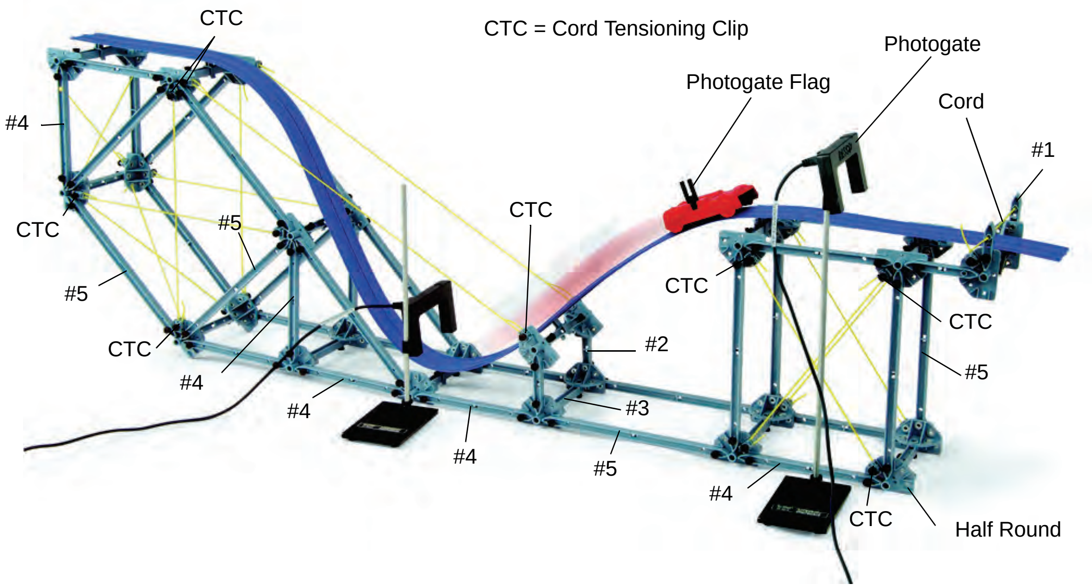


Elevator Details

Extra Equipment	Model	Extra Equipment	Model
Multi-clamp (2)	SE-9443	45 cm Rod	ME-8736
Large Slotted Mass Set	ME-7566	120 cm Rod (2)	ME-8741
Load Cell (2)	PS-2200	Large Table Clamp (2)	ME-9472
Dual Load Cell Amplifier	PS-2205	Rotary Motion Sensor	PS-2120

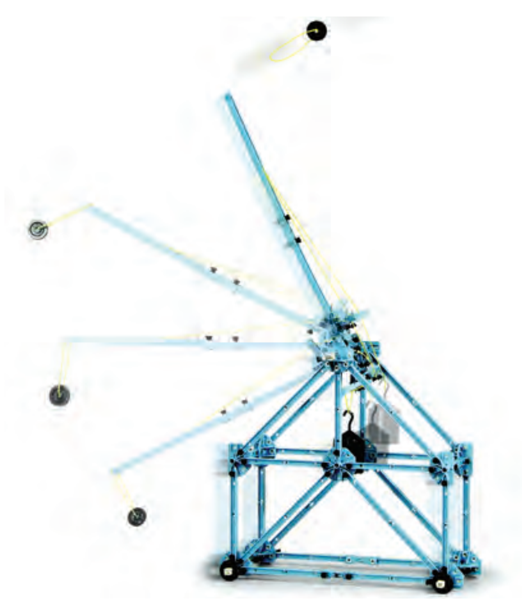
Conservation of Energy: Roller Coaster without Loop

A simple roller coaster without a loop may be built to explore the transition between gravitational potential energy and kinetic energy. Design a valley at the bottom of which the Mini-car is going the fastest possible without having the Mini-car leave the track at any point on the track. As shown, photogates are used to measure the velocity of the cart at the lowest point and at a mid-level recovery point to show the conservation of energy.



Catapult

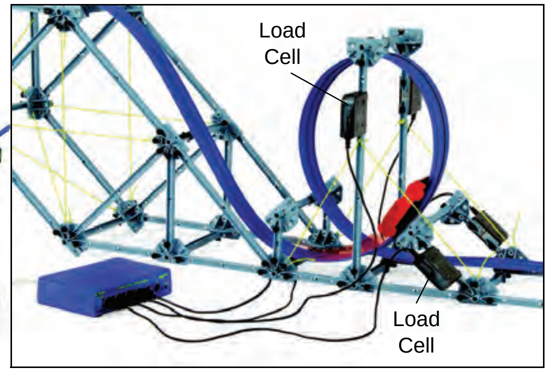
The trebuchet previously shown and pictured here may be used to explore conservation of energy and discuss the sources of loss in a mechanical system.



Rotational Motion: Roller Coaster with Loop

Students can design and build roller coasters that incorporate a loop. The Mini-cars are withheld until after the students have built their roller coaster and checked their design calculation on initial gravitational potential energy and velocity at the top of the loop. Then they can check by testing.

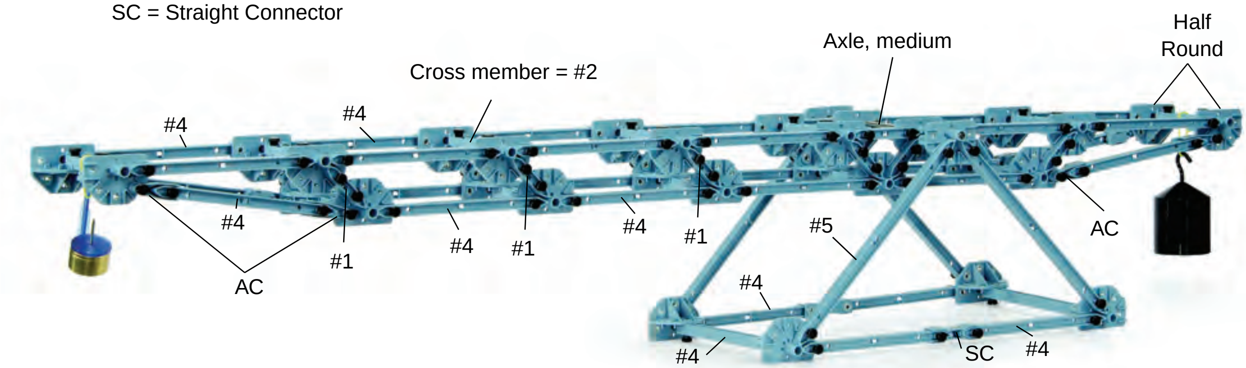
If desired, the forces that are created by the car traveling around the loop may be measured with Load Cells as shown below.



Mechanisms: Levers

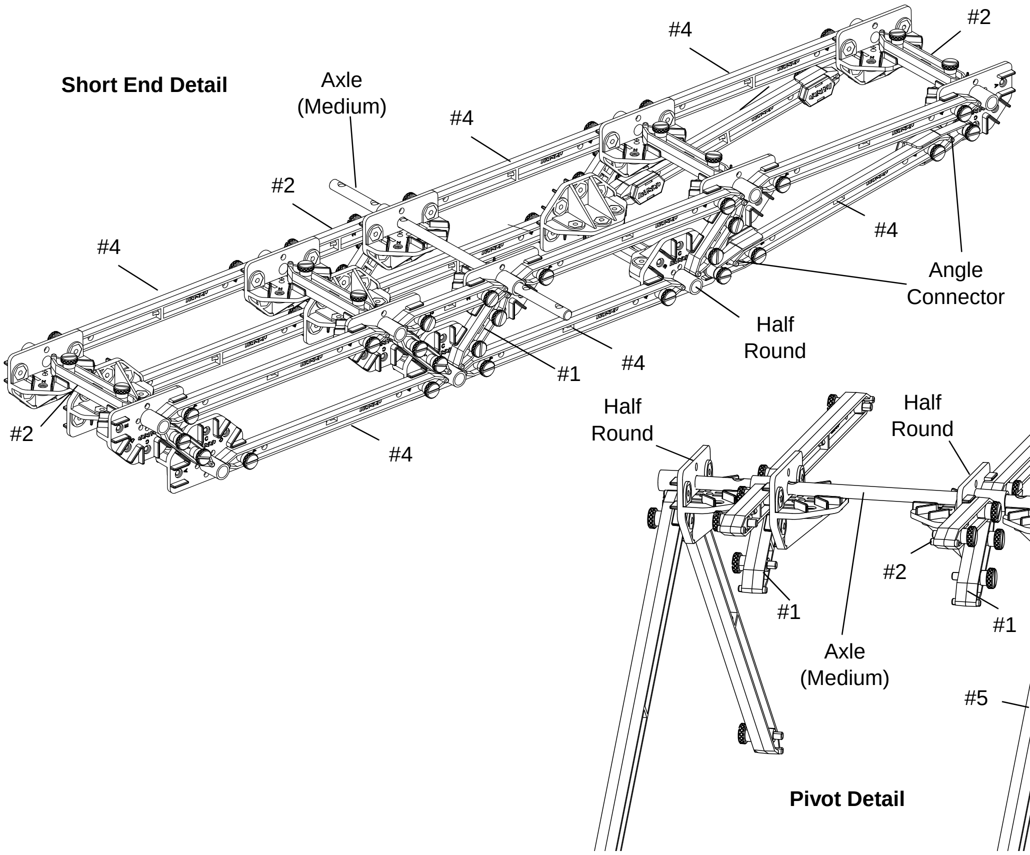
Utilizing the axles, students can build lever mechanisms of various ratios and explore how the location of the fulcrum determines mechanical advantage. As pictured below the use of a force sensor (PS-2104) along with a mass set (SE-8759) allows a wide range of load situations to be explored.

AC = Angle Connector
SC = Straight Connector



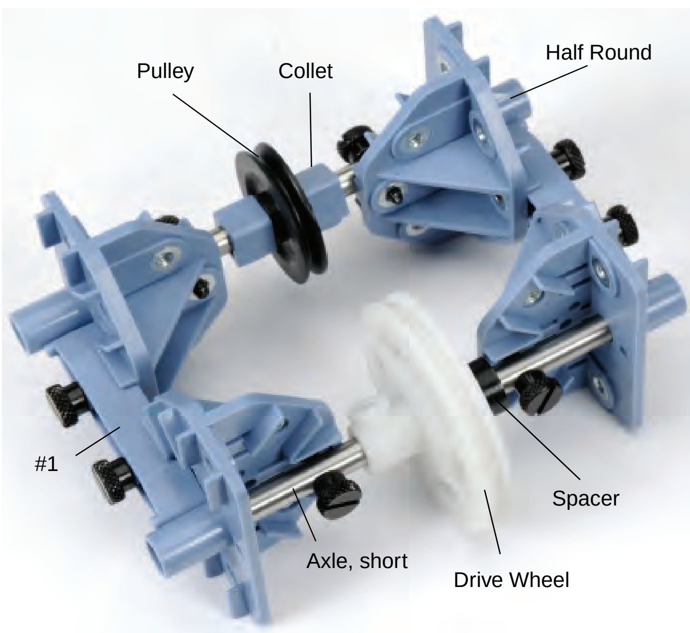
Extra Equipment	Model
Hooked Mass Set	SE-8759
Mass and Hanger Set	ME-8979

Lever Details



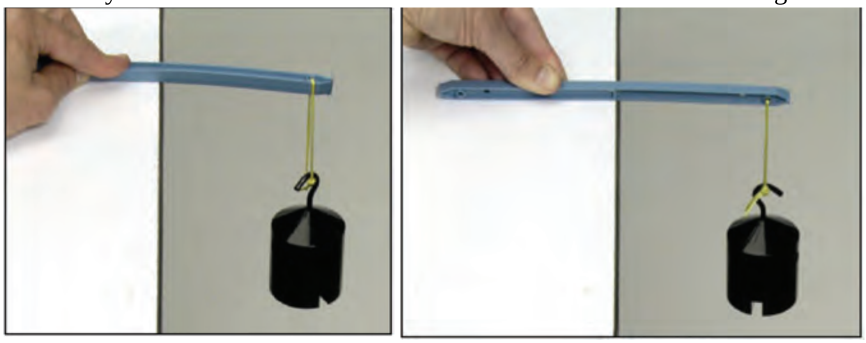
Mechanisms: Pulleys

Students can build structures that incorporate pulleys and explore the forces that are generated by and exist in a multiple sheave pulley system. By using Cord Tensioning Clips, a Load Cell may be inserted into any segment of a cord to measure forces that exist during a pull. Students can also explore the role that friction plays in rotating mechanisms by measuring the decreasing effectiveness the occurs when added sheaves are used beyond the optimal number.

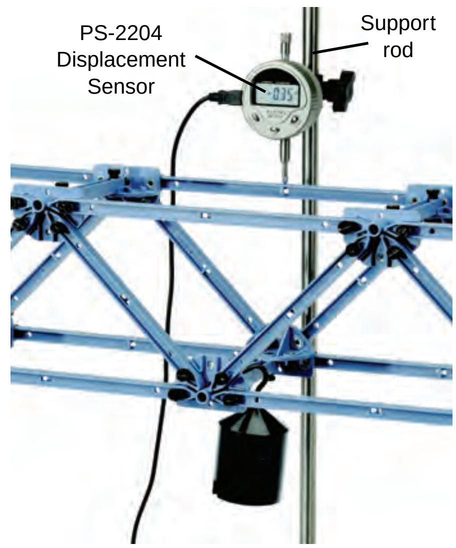


Properties of Materials: Properties of I-Beams

Students can be introduced to the major influence that material shape plays in strength of structures. The I-beams in the structures kit may be loaded in either the normal or transverse direction as a single beam.

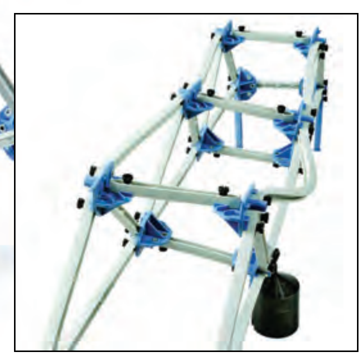


If a Force Sensor (PS-2104) or a Displacement Sensor (PS-2204) is used, students can quantify the differences in performance based on orientation and with the additional information of the section modulus and beam deflection formula derive the modulus of elasticity of the material used for the beams.



Properties of Materials: Bridges with Low Modulus Beams

As illustrated below, the Flexible I-Beam Set (ME-6985) allows the building of structures that fail due to elastic buckling of longer compression members. With some care the long columns may be loaded as slender members and the critical length found.



Technical Support

For assistance with any PASCO product, contact PASCO at:

Address:	PASCO scientific 10101 Foothills Blvd. Roseville, CA 95747-7100
Phone:	916-786-3800 (worldwide) 800-772-8700 (U.S.)
Fax:	(916) 786-7565
Web:	www.pasco.com
Email:	support@pasco.com

For more information about the High School Physics Structures Set and the latest revision of this Instruction Manual, visit:

www.pasco.com/go?ME-7000

Patents Pending The following PASCO products have patents pending:

ME-6983 Structures Cast Beam Set	ME-6991 Bridge Set	ME-6996 Cord Lock Spares
ME-6985 Flexible I-Beam Set	ME-6992A Advanced Structures Set	ME-6997 Round Connector Spares
ME-6987 Flat Beams Set	ME-6993 Truss Set Members	ME-6998 Axle Spares
ME-6989 Physics Structures Set	ME-6994 Truss Set Screws	ME-6999A Angle Connector Spares
ME-6990 Truss Set	ME-6995 Road Bed Spares	ME-7000 High School Physics Structures Set

PS-2198 Load Cell Amplifier	PS-2204 Displacement Sensor
PS-2199 Load Cell and Amplifier Set	PS-2205 Dual Load Cell Amplifier
PS-2200 100 N Load Cell	PS-2206 Load Cell and Dual Amplifier Set
PS-2201 5 N Load Cell	