Structure

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Introduction to the Structure Subsystem

The parts in the VEX Structure Subsystem form the base of every robot. These parts are the "skeleton" of the robot to which all other parts are attached. This subsystem consists of all the main structural components in the VEX Design System including all the metal components and hardware pieces. These pieces connect together to form the "skeleton" or frame of the robot.

In the VEX Robotics Design System the majority of the components in the Structure Subsystem are made from bent sheet-metal. These pieces (either aluminum or steel) come in a variety of shapes and sizes and are suited to different functions on a robot. Different types of parts are designed for different applications.
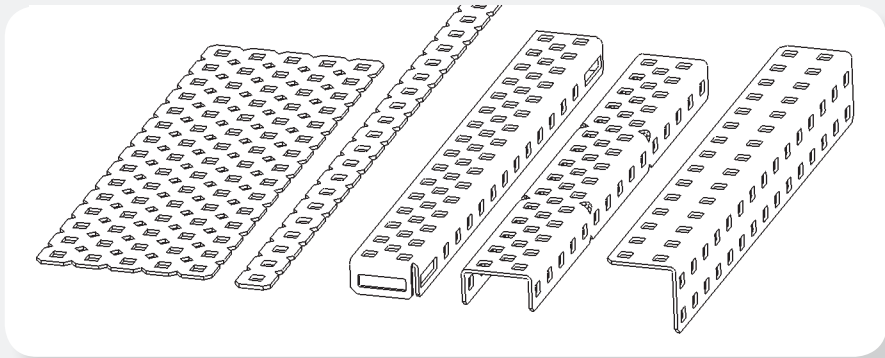
The VEX structural pieces all contain square holes (0.182″ sq) on a standardized 1/2″ grid. This standardized hole-spacing allows for VEX parts to be connected in almost any configuration. The smaller diamond holes are there to help users cut pieces using tin-snips or fine-toothed hacksaws without leaving sharp corners.

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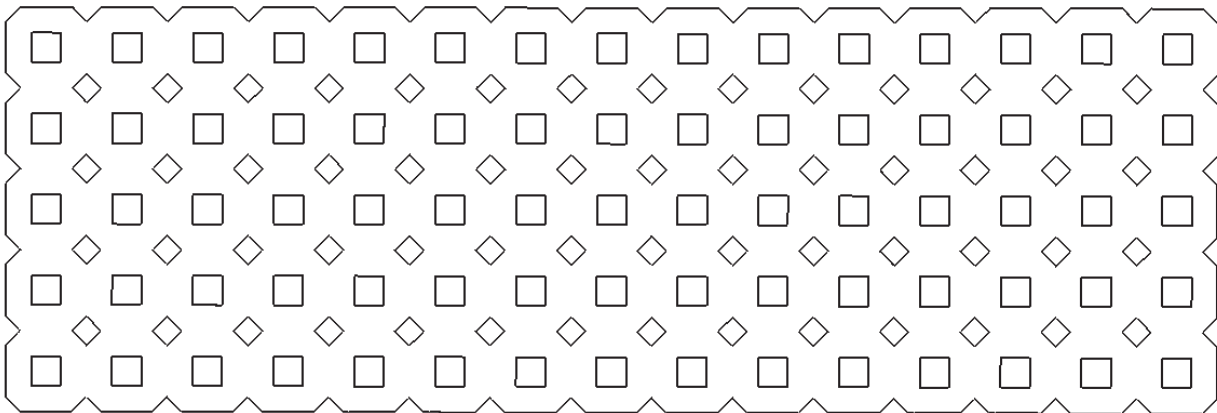
Introduction to the Structure Subsystem, continued

VEX square holes are also used as "alignment features" on some components. These pieces will "snap" in place into these square holes. For example, when mounting a VEX Bearing Flat there are small tabs which will stick through the square hole and hold it perfectly in alignment. This allows for good placement of components with key alignment requirements. (It would be bad if a bearing slipped out of place!) Note that hardware is still required to hold the Bearing Flat onto a structural piece.
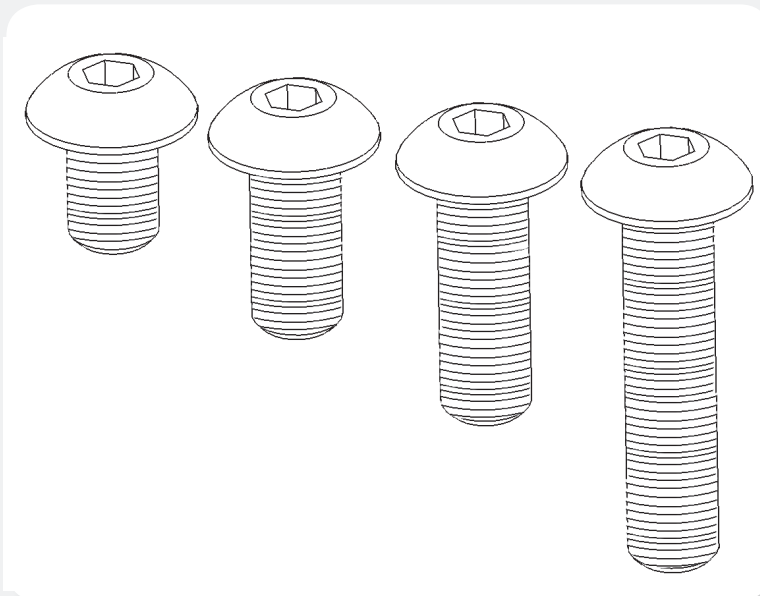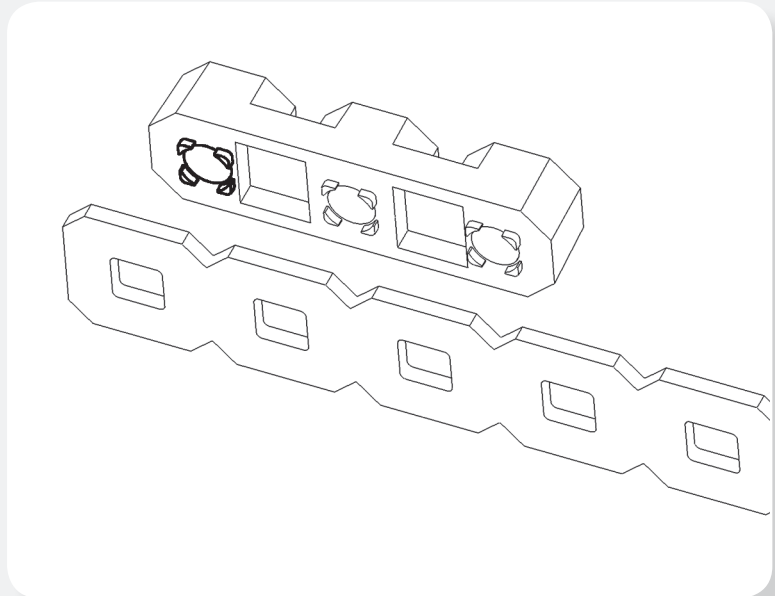
Hardware is an important part of the Structure Subsystem. Metal components can be directly attached together using the 8-32 screws and nuts which are standard in the VEX kit. The 8-32 screws fit through the standard VEX square holes. These screws come in a variety of lengths and can be used to attach multiple thicknesses of metal together, or to mount other components onto the VEX structural pieces.

Allen wrenches and other tools are used to tighten or loosen the hardware.

Note: There are two types of screws that are part of the VEX Robotics Design System.
- Size 8-32 screws are the primary screws used to build robot structure.
- Size 6-32 screws are smaller screws which are used for specialty applications like mounting the VEX Motors and Servos.

# Introduction to the Structure Subsystem, continued

HINT:
Attach components together with multiple screws from different directions to keep structural members aligned correctly and for maximum strength!
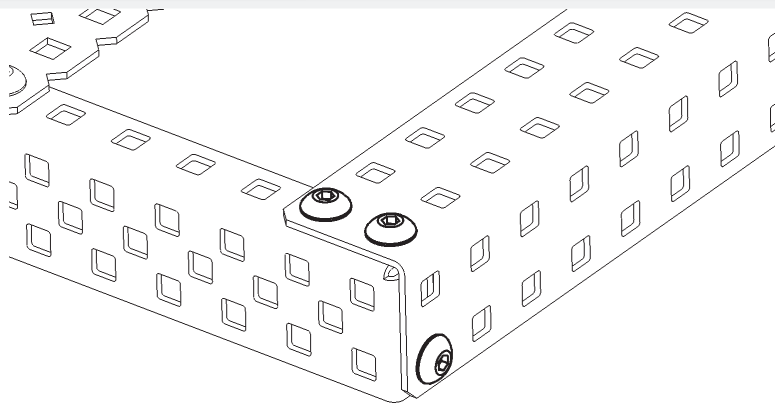
When using screws to attach things together, there are three types of nuts which can be used.
- Nylock nuts have a plastic insert in them which will prevent them from unscrewing. These are harder to install, as you need to use an open-ended wrench to tighten them up. These nuts will not come off due to vibration or movement.
- KEPS nuts have a ring of "teeth" on one side of them. These teeth will grip the piece they are being installed on. This means you do not NEED to use an open-ended wrench to tighten them (but it is still recommended). These nuts are installed with the teeth facing the structure. These nuts can loosen up over time if not properly tightened; however they will work great in most applications.
- Regular nuts have no locking feature. These basic hex nuts require a wrench to install and may loosen up over time, especially when under vibration or movement. They are very thin and can be used in some locations where it is not practical to use a Nylock or KEPS nut.
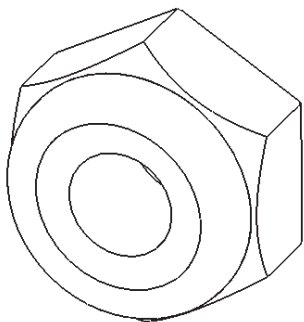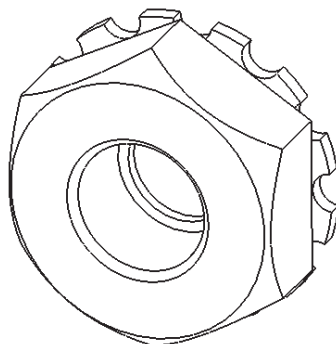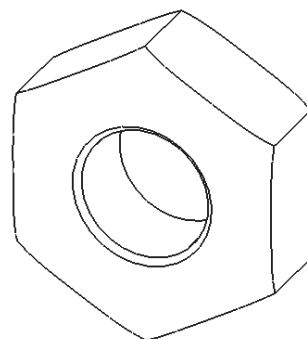
**Nylock Nut**   **KEPS Nut**   **Regular (Hex) Nut**

WARNING: It is important to be careful when tightening screws. The allen wrenches may round or "strip out" the socket on the head of the screw if they are not fully inserted into the socket.

Use care when tightening screws to prevent stripping out the head of the screw!
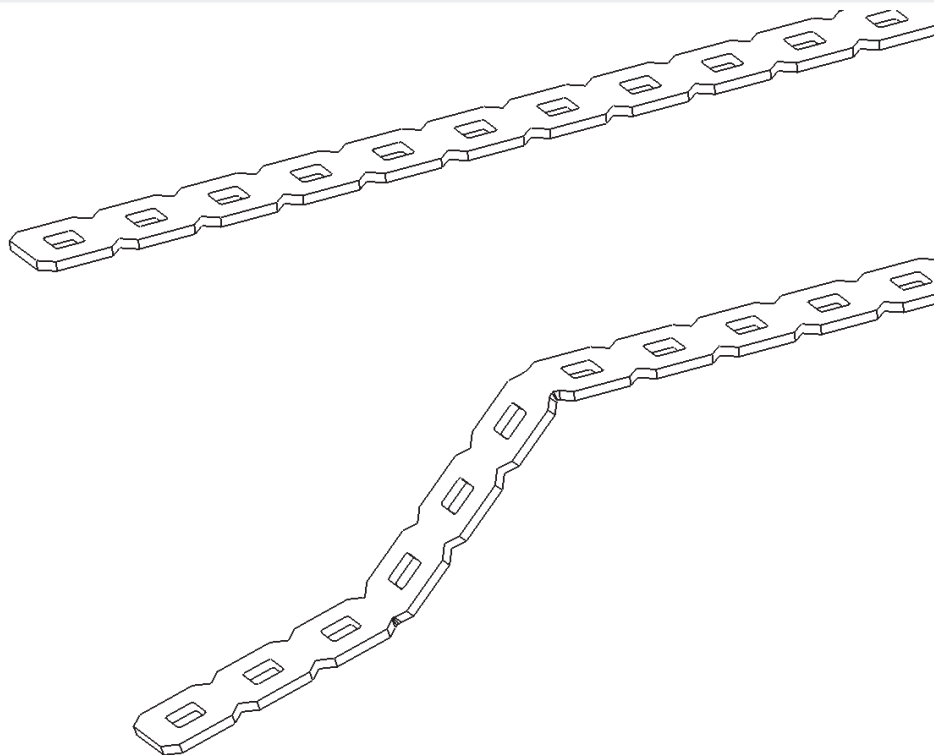
Introduction to the Structure Subsystem, continued

Components can also be offset from each other using 8-32 threaded standoffs; these standoffs come in a variety of lengths and add great versatility to the VEX kit. These standoffs work great for mounting components in the VEX system as well as for creating structural beams of great strength.
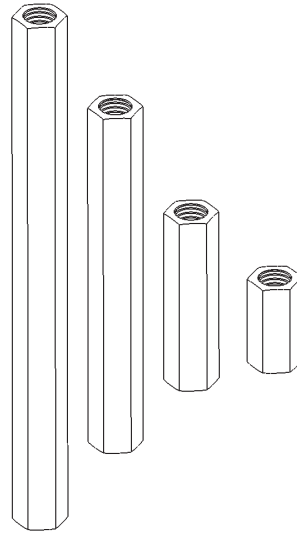
One of the key features of many VEX structural parts is their ''bend-able'' and ''cut-able'' nature. Users can easily modify many of these structural parts into new configurations better suited for their current needs. Flat plates can be bent into brackets. Many metal components can be cut to custom lengths. These parts were DESIGNED to be modified.

Note: It is almost impossible to fully flatten a piece once it has been bent.

Introduction to the Structure Subsystem, continued

The VEX structural components come in a variety of shapes and sizes. Each of these structural shapes may be strong in some ways but weak in others. It is very easy to bend a piece of VEX Bar in one orientation, but it is almost impossible to bend it when it is in another orientation. Applying this type of knowledge is the basis of structural engineering. One can experiment with each piece and see how it can be used to create an extremely strong robot frame!
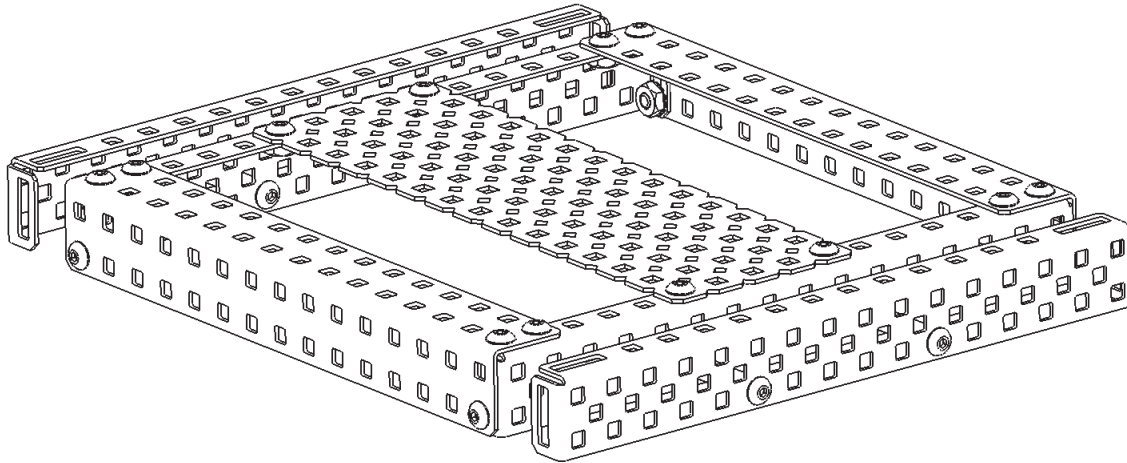
When designing a robot's structure, it is important to think about making it strong and robust while still trying to keep it as lightweight as possible. Sometimes overbuilding can be just as detrimental as underbuilding.

The frame is the skeleton of the robot and should be designed to be integrated cleanly with the robot's other components. The overall robot design should dictate the chassis, frame, and structural design; not vice-versa.

Design is an iterative process; experiment to find out what works best for a given robot.

Concepts to Understand
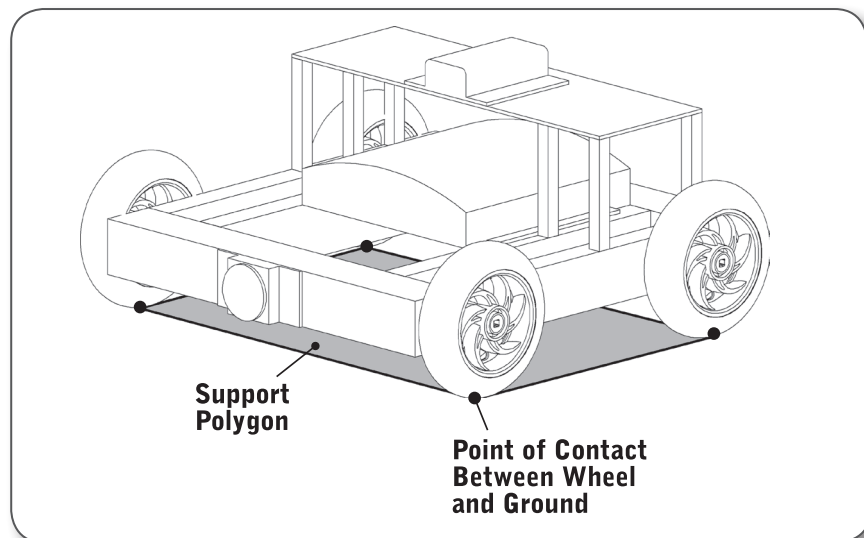
Stability: Center of Gravity Considerations

Center of Gravity

You can think of the robot's center of gravity as the "average position" of all the weight on the robot. Because it is an average of both weight and position, heavier objects count more than lighter ones in determining where the center of gravity is, and pieces that are farther out count more than pieces that are near the middle.
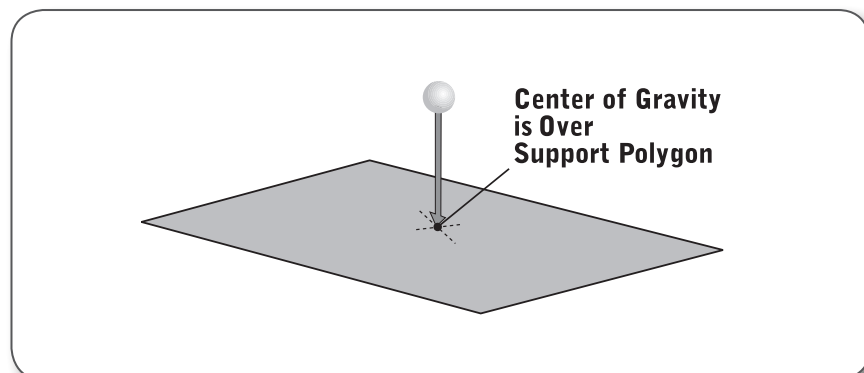

Center of Gravity
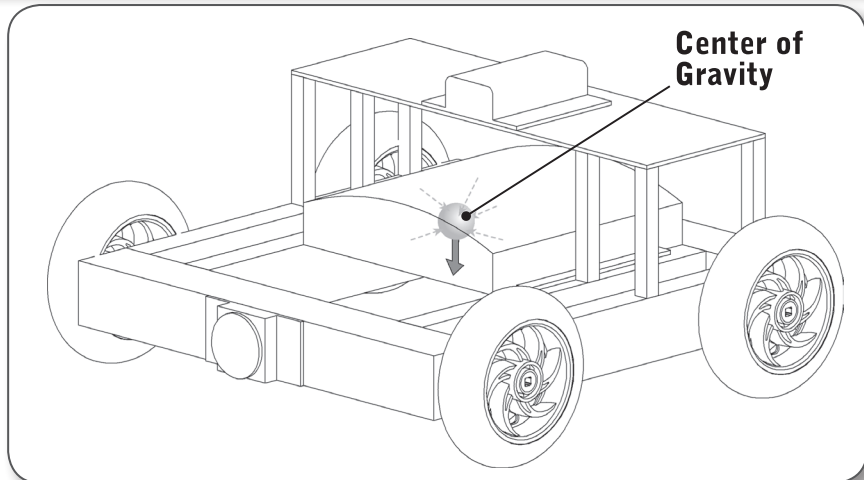
Support Polygon

The support polygon is the imaginary polygon formed by connecting the points where your robot touches the ground (usually the wheels). It varies by design, but there is always one support polygon in any stable configuration.

Support Polygon

Point of Contact Between Wheel and Ground

Stability

The rule for making a robot stable is very simple: the robot will be most stable when the center of gravity is centered over the support polygon. Your robot will encounter much more complex situations than just standing still; you need to take these into account when making your design.
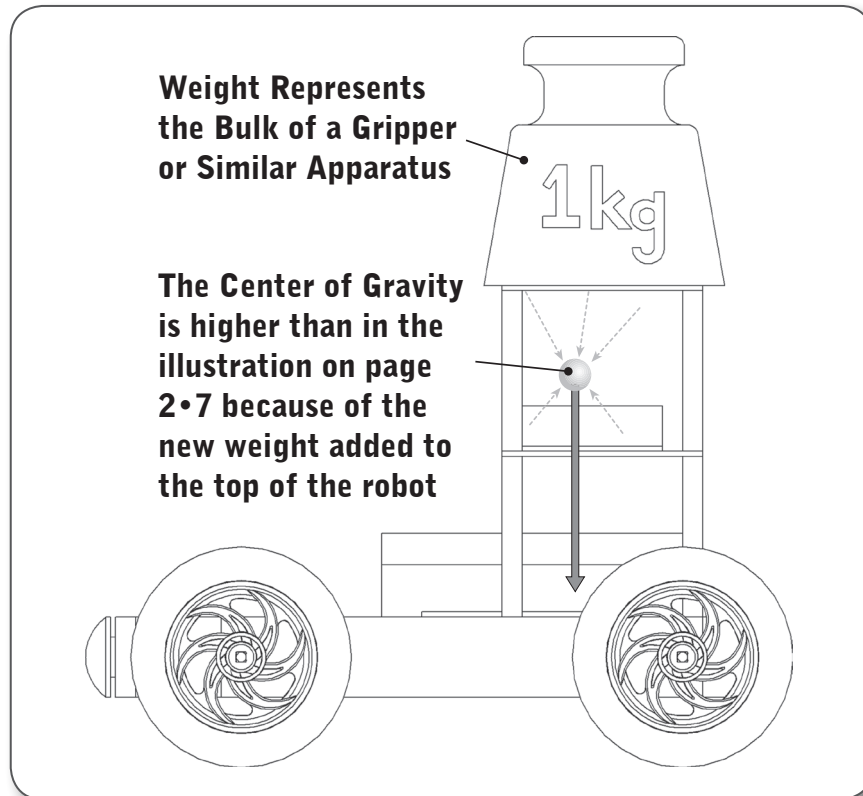

Center of Gravity is Over Support Polygon
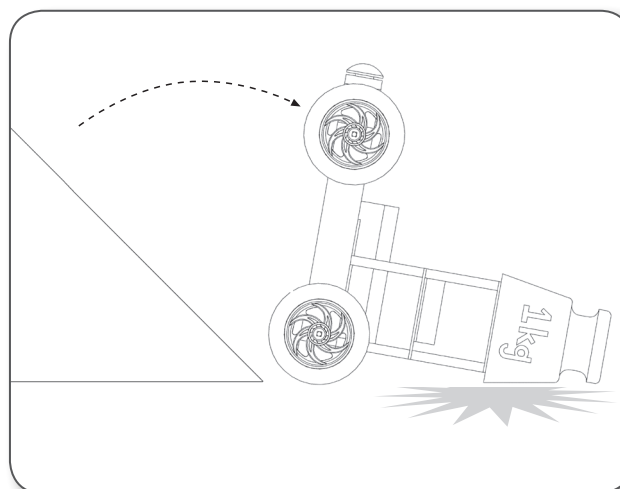
Concepts to Understand, continued

Stability: Center of Gravity Considerations, continued

EXAMPLE 1: Towerbot
This robot was built very tall so that it would be able to reach a hanging goal for a challenge. However, along the way, it had to first climb a ramp.

Weight Represents the Bulk of a Gripper or Similar Apparatus

The Center of Gravity is higher than in the illustration on page 2•7 because of the new weight added to the top of the robot

Notice that the robot's center of gravity is no longer over the support polygon. This robot would fall over as soon as it started up the ramp.
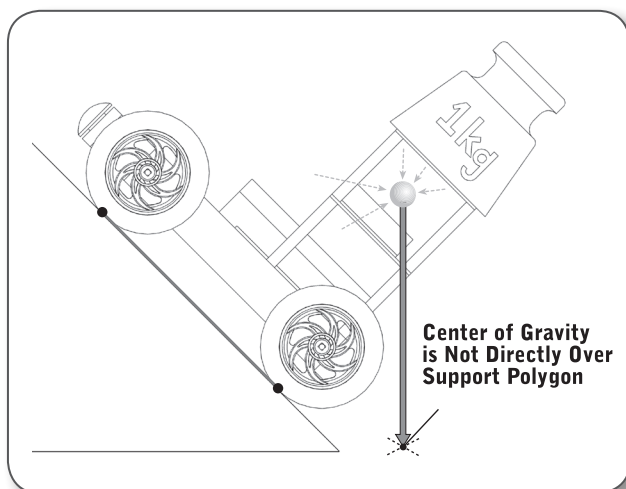
Center of Gravity is Not Directly Over Support Polygon

Inventor's Guide

vEx

Concepts to Understand, continued

Stability: Center of Gravity Considerations, continued

EXAMPLE 1: Towerbot, continued

To fix this problem, you must lower the robot's center of gravity so that it does not move as far when the robot is on an incline. In general, it is advantageous to have your robot's center of gravity as close to the ground as possible!

Center of Gravity is now lower than in the illustration on page 2•8 because the weight is mounted lower
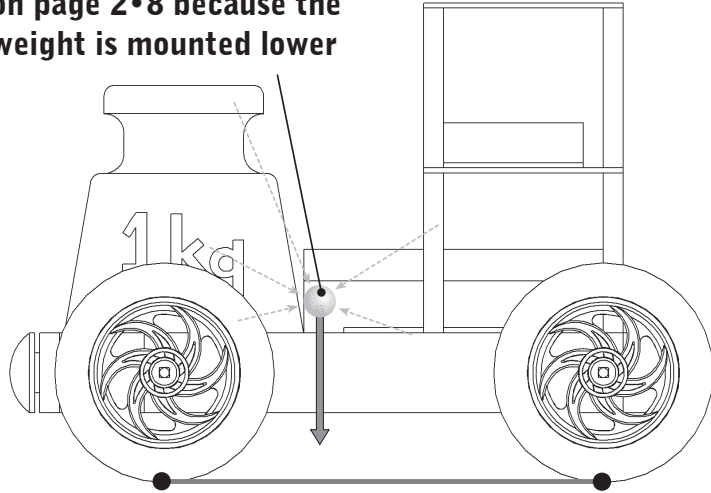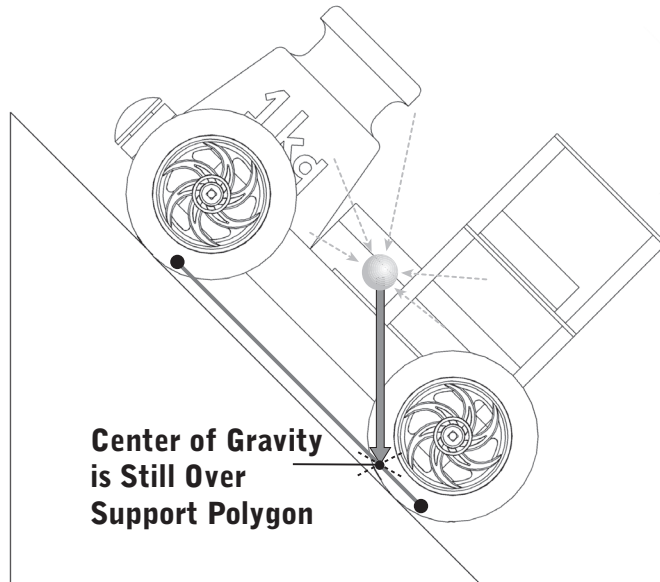
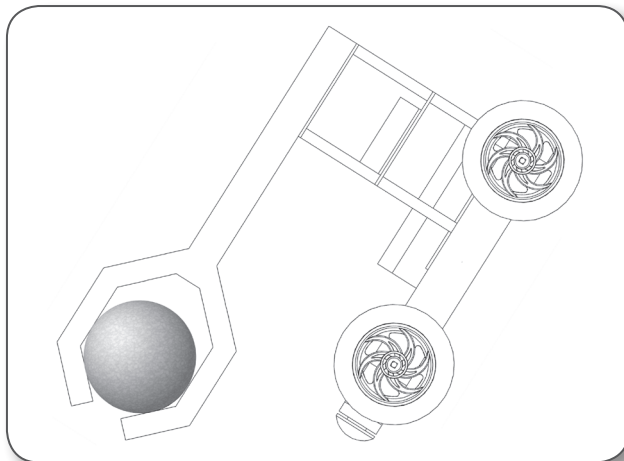**Center of Gravity is Still Over Support Polygon**

Concepts to Understand, continued

Stability: Center of Gravity Considerations, continued

EXAMPLE 2: Grabberbot
This robot is designed to pick up a heavy object using the gripper claw on the front, and transport the object to another location.

When the robot picks up the object, it effectively adds the object's weight to the robot's structure. The combined robot-ball structure now has the new center of gravity (shown below), which is outside the support polygon. The robot tips over as a consequence.

Center of Gravity is Directly Over Support Polygon (but not by much)

Heavy Weight Near Front of Robot Moves Center of Gravity Far Forward
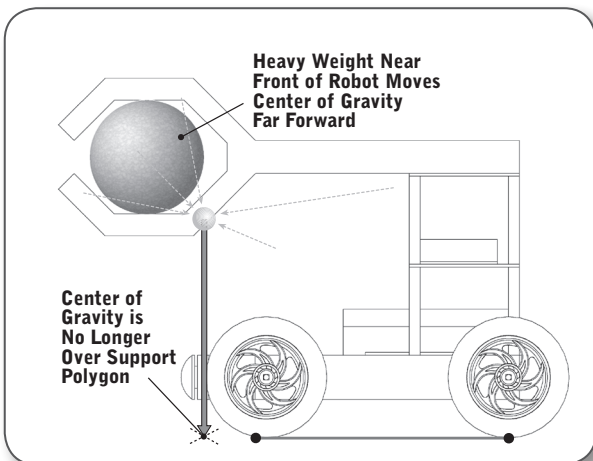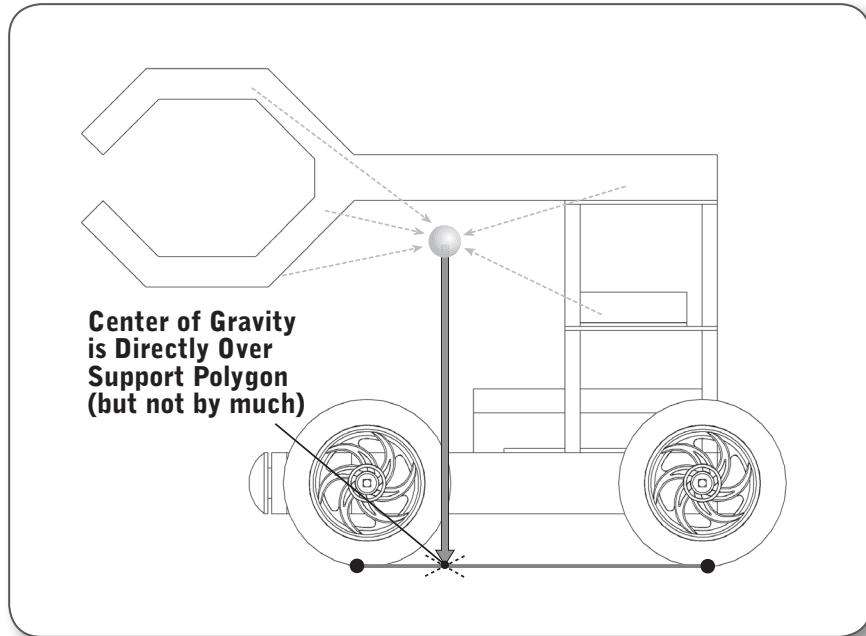
Center of Gravity is No Longer Over Support Polygon

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vEx

Concepts to Understand, continued

Stability: Center of Gravity Considerations, continued

EXAMPLE 2: Grabberbot, continued

There are many solutions to this problem. Depending on the specifics of the challenge, some or all of these modifications could work:

Moving the center of gravity back by moving the gripper farther back on the robot

Weight Still Pulls Center of Gravity Forward, but Not as Far as Before

Center of Gravity Remains Over Support Polygon
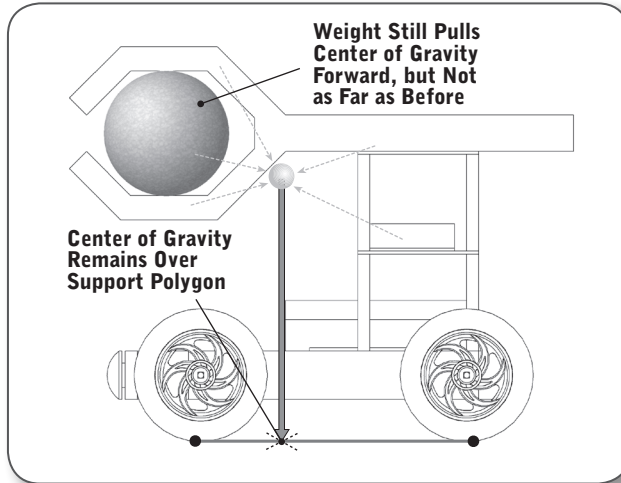
Extending the support polygon by adding more wheels farther out

Center of Gravity is Over Newly Extended Support Polygon

Moving the center of gravity back by adding counterweights on the back of the robot

Additional Weight Pulls Center of Gravity Back Toward Center

1 kg

Center of Gravity Remains Over Support Polygon
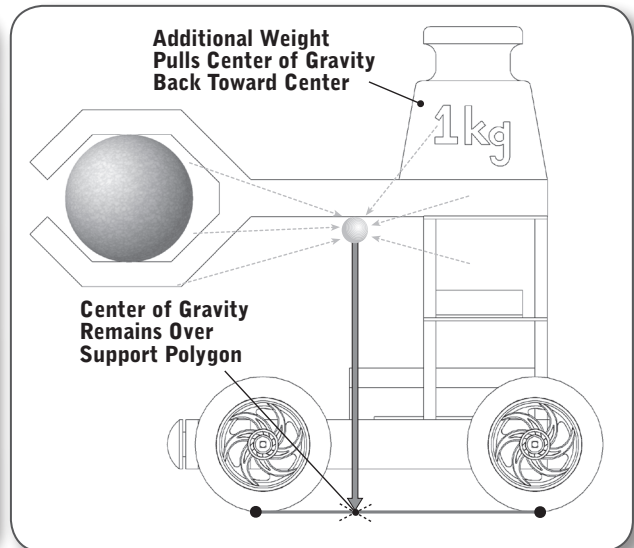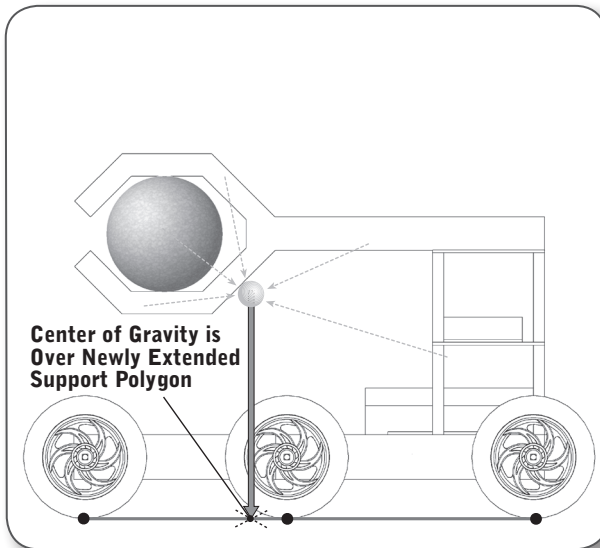
Concepts to Understand, continued

Robust Fabrication

Fasteners

The most common problem with robots that fall apart or lose pieces easily is that groups of parts are not joined securely enough and separate from each other and move around.

EXAMPLE 1:
Arm Extension

A robot needs to be able to reach a goal that is high off the ground. The goal is so high that a single long piece will not reach it. Two pieces must be joined together to reach the desired height.

This attachment uses a single screw to join the two bars. As you can see, it has a problem when weight is applied to it: the extension bar rotates around the screw. Also, if this screw were to come loose or fall out for any reason, the entire arm would come crashing down.

Single Screw

Arm Rotates Too Easily Around This Point

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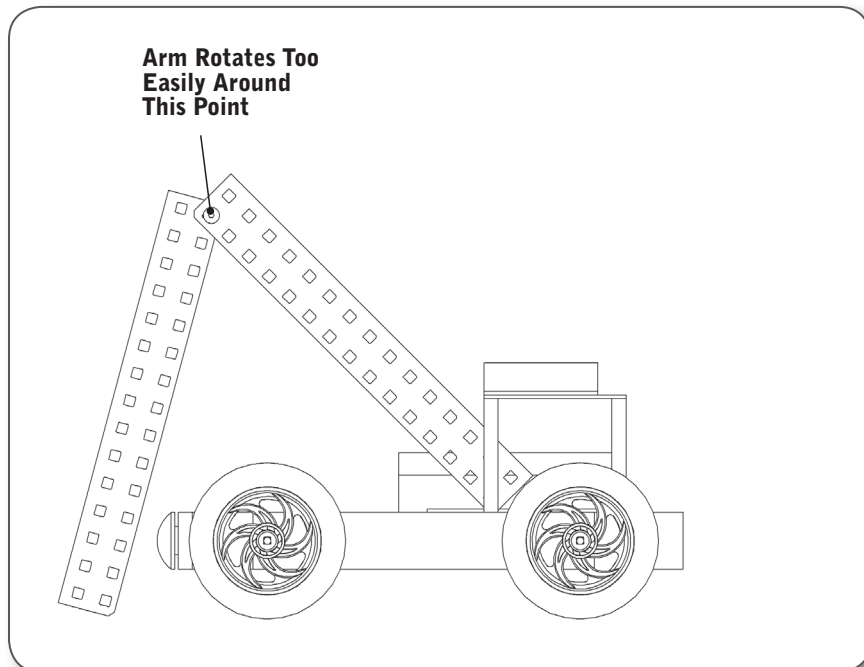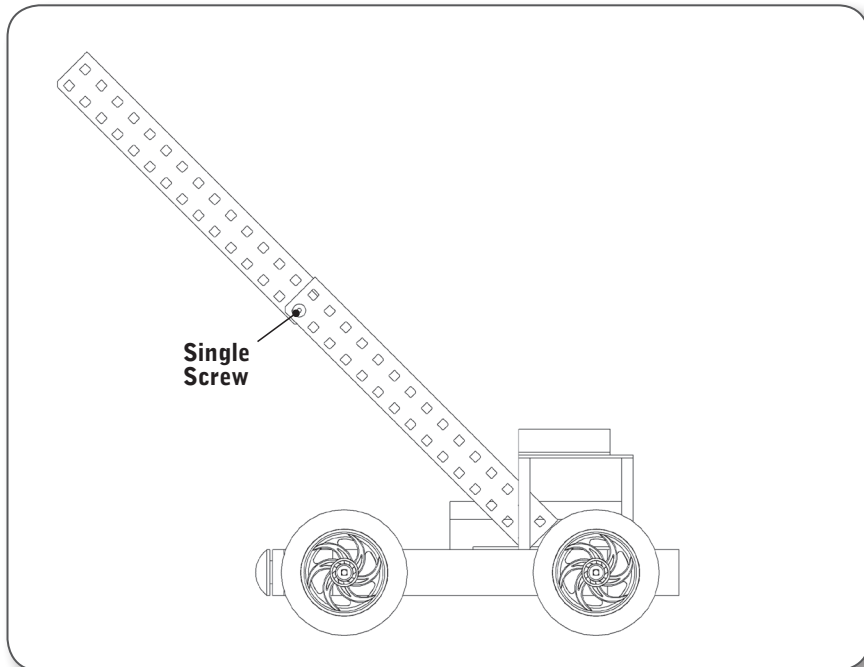
Concepts to Understand, continued

Robust Fabrication, continued

**EXAMPLE 1, continued:
Arm Extension,
continued**
By using two screws, this design removes the possibility of rotation around either one of them. Additionally, the design is more resilient.

**Two Screws
Eliminate
Rotation**
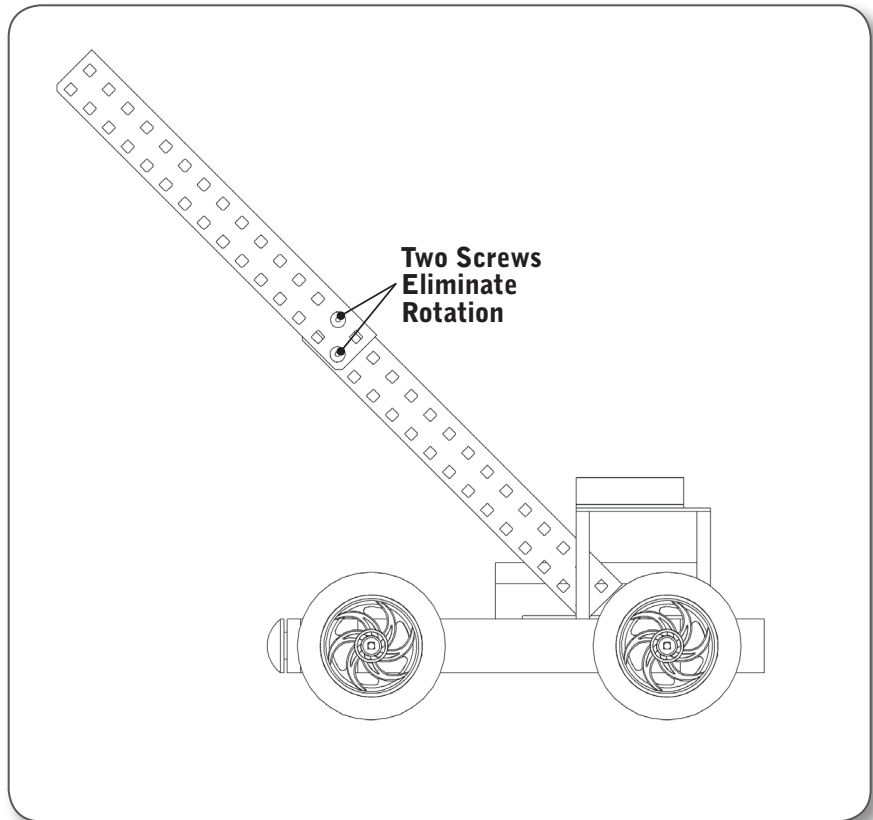
Concepts to Understand, continued

Robust Fabrication, continued

EXAMPLE 2:
Bracing

The extended bars are now attached firmly to each other, and the long arm is mounted on your robot. However, the long arm is going to generate huge stresses at its mounting point because it is so long, especially when the arm is used to lift a load.

Long Lever Arm Causes Great Strain on Mounting Point

Single Screw Mounting Point

Large Stress on Weak Mounting Point Causes Structural Failure
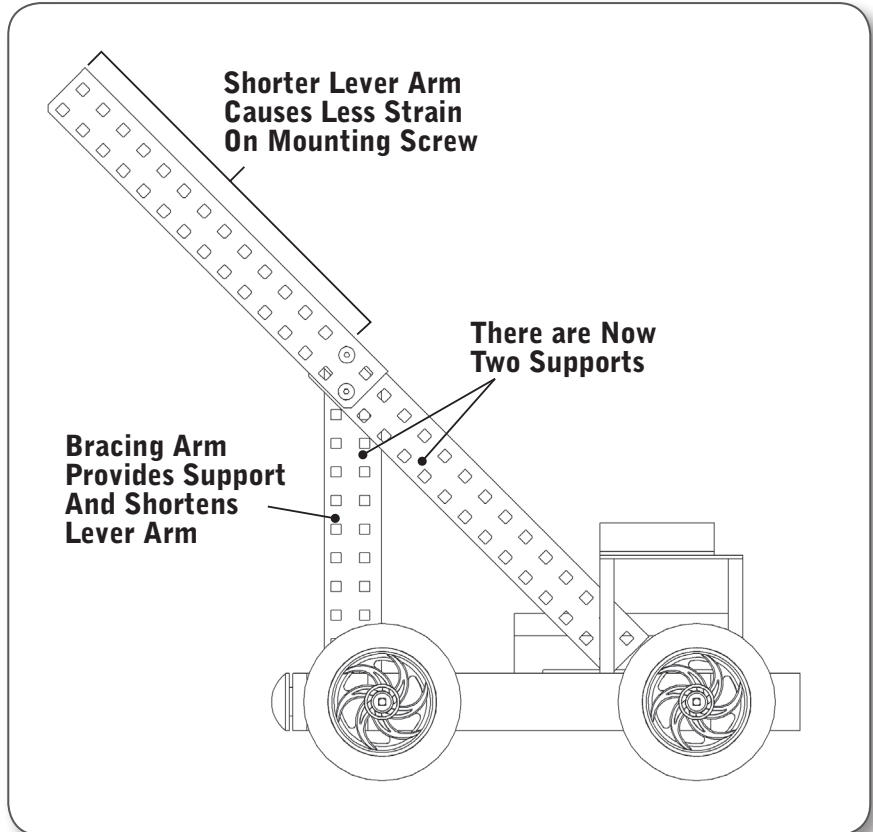
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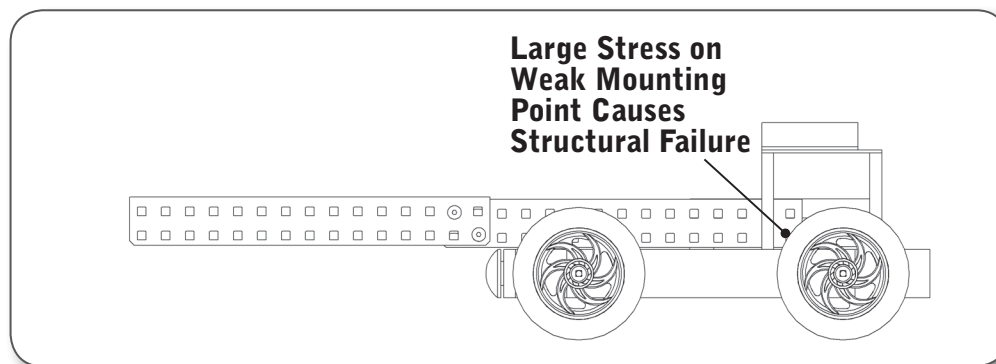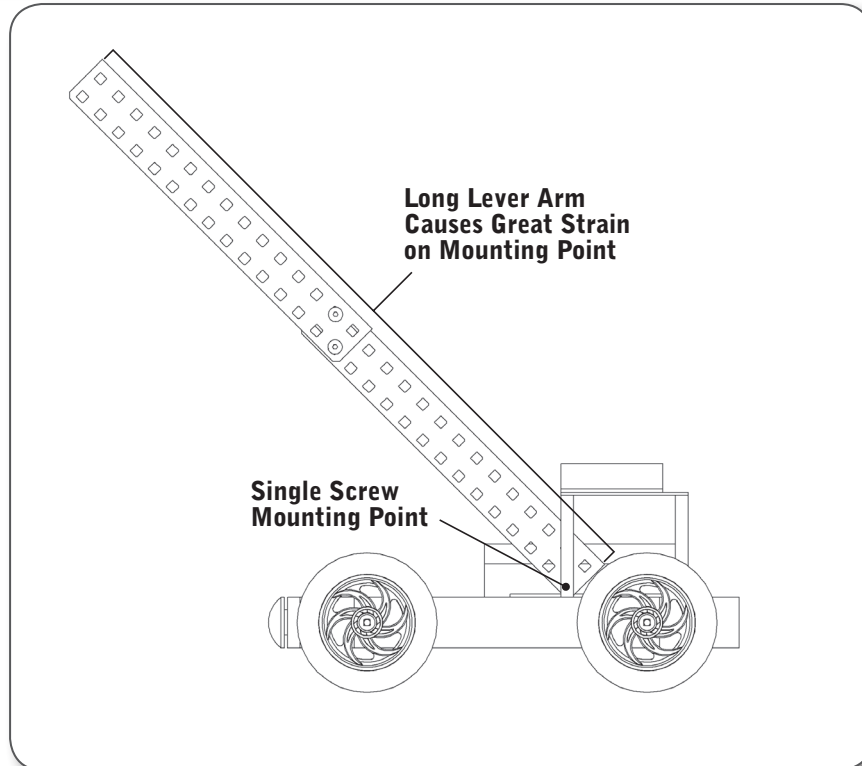
Concepts to Understand, continued

Robust Fabrication, continued

EXAMPLE 2:
Bracing the Bars,
continued
In order to keep the arm from falling down, you will need to brace it. You could use a second screw to hold it, like you did with the arm itself, but because the arm is such a long lever arm, that screw would actually be in danger of deforming or breaking. A better solution would be to give the structure support at a point closer to the end, thus reducing the mechanical advantage that the arm has relative to the supports.

The arm is now more stable and better able to withstand stresses placed on it from both its own weight, and any external forces acting on it. The bracing arm has both decreased the mechanical advantage from the long lever arm, and spread the load over two supports instead of just one.
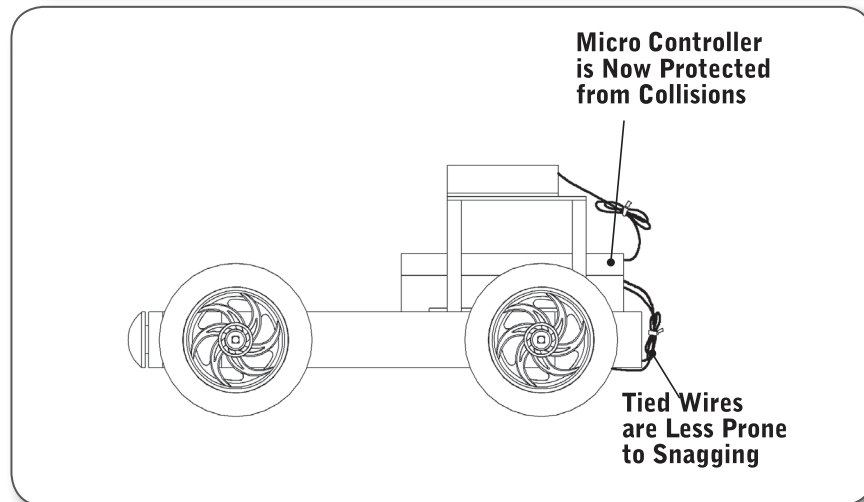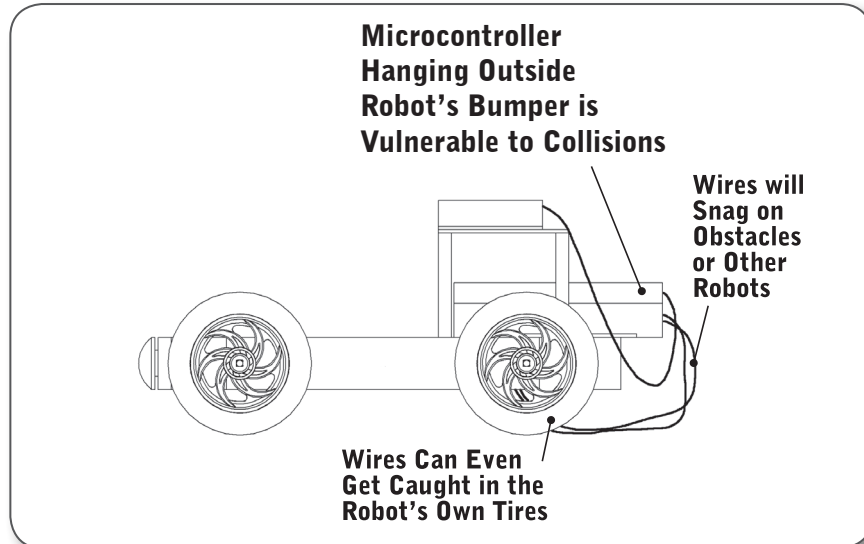

Shorter Lever Arm Causes Less Strain On Mounting Screw

There are Now Two Supports

Bracing Arm Provides Support And Shortens Lever Arm

Concepts to Understand, continued

Exposure and Vulnerability

There are certain parts of a robot that are more fragile than others. Always plan the structural design to protect these parts from unwanted physical contact if possible.

The design in the example at the right is asking for trouble. The VEX Microcontroller is a sensitive piece of electronic equipment, and it can be a poor design decision to put it somewhere it could be damaged by a simple physical impact. In particular, this design leaves the back of the VEX Microcontroller exposed in such a way that a passing robot or a careless driver could smash the entire rear connector panel, potentially damaging the radio control and power connections. Also, the wires are a mess. Wires should be secured and protected, because if one of those wires were to snag on another robot (or even on the robot's own wheels!), the connector would be forcibly removed from its port. Not only would this disable the robot on the field, but it could cause permanent damage to the cable or the ports on the VEX Microcontroller.

Adjusting the position of the controller so that it is not likely to get hit by anything, and cleaning up the wires (the kit comes with wire ties/tie wraps/zip ties) will reduce the chance of damage to the sensitive electronic components on the robot. As a bonus, it looks a lot cleaner as well.

Microcontroller Hanging Outside Robot's Bumper is Vulnerable to Collisions

Wires will Snag on Obstacles or Other Robots

Wires Can Even Get Caught in the Robot's Own Tires

Micro Controller is Now Protected from Collisions

Tied Wires are Less Prone to Snagging

TIP:
For the best protection ensure all robot components that can be damaged are well shielded and inside robot structure. Route wires inside the robot and away from all moving components.

Subsystem Interactions

How does the Structure Subsystem interact with...

...the Motion Subsystem?

• The motion and Structure Subsystems are tightly integrated in many robots designs. The Motion Subsystem can't be constructed without certain structural components (like the chassis rails) to provide support. By the same token, the Structure Subsystem must be designed largely to accommodate the motion components.

...the Power Subsystem?

• The Structure Subsystem generally provides a safe, protected place to attach the battery.
• The battery is often the heaviest component on a VEX robot. Battery placement will effect the robot's center of gravity, and must be considered to ensure the robot is stable. The easiest way to change the robot's center of gravity is to move the battery.

...the Sensor Subsystem?

• The Structure Subsystem provides a mounting and stabilization platform for sensors on the robot. Often, sensors need to be held in a specific position to function properly, and the Structural Subsystem must be designed to accommodate these needs.

...the Control Subsystem?

• The Structure Subsystem will generally provide a place to mount the RF Receiver module on the robot. In some cases, you will need to construct a piece to hold the Antenna Holder in a safe place. The Antenna Holder and Sleeve should hold the antenna away from all structural components. It should be vertical, and positioned above the robot to avoid reducing the robot's ability to receive signals from the transmitter.

... the Logic Subsystem?

• The Structure Subsystem holds the Logic Subsystem's Microcontroller in place. Since the Microcontroller is a very delicate and important part of the robot, the Structure Subsystem will also protect the Microcontroller by keeping it in a secure spot.
• The Structure Subsystem does not plug into the Microcontroller in any way; however, the Structure Subsystem does need to accommodate and protect the wires that run between the Microcontroller and other pieces.

User Structure Notes