FIRST EDUCATION

Robotics Engineering Explorations *FIRST*® Education

FIRST® Robotics Engineering Explorations
Teacher Guide — Build a Bot

Unit 2

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Activity 1: A Robot Skeleton

Driving Questions

- What is a frame?
- What is a chassis?
- How do we build a frame from the parts in our robotics kit?
- How will the chassis design help our team compete in the ball game?

Objectives

- Teams will learn about the purpose of a chassis.
- Teams will put together a basic frame using parts from their robotics kits.
- Teams will investigate modifications to the chassis to help the robot be more successful in the ball game.

Materials

Each team will need:

- Engineering Notebooks
- Pens or pencils
- Access to the Internet for research
- Robotics kit
- Tools necessary to build robot

Getting Started

BEFORE THE START OF CLASS:

- Review the guides and parts needed for building a frame. If you have time, consider building some parts yourself, but providing the guides with the needed resources is the only requirement.

XRP	*FIRST*® TECH CHALLENGE	*FIRST*® ROBOTICS COMPETITION
Building the XRP	REV Channel Drivetrain	AndyMark 6 Wheel Drop Center “Chassis Building & Assembling” video
	REV Extrusion Chain Drivetrain	AndyMark Frame Opening Kit
	TETRIX® Flex-Build Robot Chassis	AndyMark Mecanum and ToughBox

DURING CLASS:

- Ask students to get into their teams and gather their supplies.
- Encourage teams to discuss what they think the purpose of a chassis is and whether it’s essential.
- Teams look back at the ball game they designed. Some students might have trouble locating or reading what they recorded throughout the last unit. Remind students of the importance of a well-organized Engineering Notebook and ensure they are mindful of their notes as they move forward.
- This is each team’s first time building with their robotics kit, so remind them to keep their supplies neat and ensure they put everything back in their kit when finished.
- The exercise aims to get them thinking about the first iterations of frames and chassis. Teams should be able to differentiate between frames and chassis. Frames provide the basic structure of a machine, and chassis includes the parts needed to mount components such as wheels and motors. The chassis of a vehicle can vary depending on the vehicle’s purpose.
- When teams are working through the Getting Started section, they should think about what they need to achieve with the cart they are building.

Student Tasks

TASK 1: CHASSIS KNOWLEDGE

Identify the Problem:

- Teams are asked to think about vehicles they've seen recently and imagine what their chassis look like.
- Before teams move on to researching chassis, they should try and engage with their preconceived ideas of their importance, how they are made, and what they are made of.
- In this activity, teams focus on four-wheel chassis, but this task is an opportunity to look beyond the traditional four-wheel design. Looking at the two-wheel chassis of a motorcycle or the chassis of an 18-wheeled semitruck will help illustrate how the purpose of a vehicle dictates the shape of its chassis.

Brainstorm and Explore:

- Teams create a KWL chart (Know, Want to Know, and Learned). In their charts, they should have a column for what they know about chassis, what they want to know, and what they learned after doing research.
- Teams should start with the first two columns. The first column should have at least five facts the team knows about chassis before they start their research.
- When teams have a list of questions about chassis prepared, they can use the Internet to find answers for themselves.
- While teams research chassis, ask them to focus on where and how chassis are assembled. Many companies that manufacture chassis use robotic assembly lines to do so.

TASK 2: A CHASSIS FOR THE BALL GAME

Identify the Problem:

- Using what they've learned from their research on chassis, teams begin thinking of ways to design a chassis to help them solve their ball game.
- Teams review their notes on the Engineering Design Process and tasks for the robot to do in the ball game in their Engineering Notebooks.
- Ask teams to think about the critical role a chassis plays in the design of their robot.

Design and Prototype:

- As teams design their robot's chassis, they should answer some questions to help them as they draw from their research from the previous task.
- In their Engineering Notebooks, teams answer the following questions:
  - How will your chassis help your robot support all the parts necessary to complete its job?
  - If your robot needs to carry heavy loads, how can you design your chassis to ensure it doesn't bend or break?
  - What size does your robot need to be to do its job?
  - What parts in your robotics kit would you use to create a chassis for your ball game?
- After teams have answered the guiding questions, they sketch an example of a chassis for their robot in their Engineering Notebooks. Their sketch should include a list of parts and tools they need to assemble their chassis. Students should have a clear method for part organization and management. For example, group parts are labeled, and areas for storage are labeled.

TASK 3: ROBO-BONES

Brainstorm and Explore:

- Teams investigate the necessary parts to build upon their frame to make a chassis. Their chassis should include everything they need for mounting wheels.
- Before they work with all the components required to mount wheels, teams should familiarize themselves with the essential parts necessary to build a frame.
- Students have encountered all the parts they will use in their frame during the scavenger hunt in a previous activity.
- Students should build a frame to support their robot for the ball game. Remind teams that one of the *FIRST* Core Values is teamwork. Ask teams to be sure all team members have a chance to contribute to building the frame.

Design and Prototype:

- Teams need the following parts to build their robot frame: structural elements, brackets, and other fasteners connect the structural elements.
- Consider providing teams with the chassis-building resources that correspond to the parts in their robotics kit and other parts you will supply. Provide guidance on where students should store their assembled chassis after each class period.
- When they've completed building their frames, teams sketch what they've built and label all the parts they used.

Guiding Questions

- Why are frames and chassis an essential part of a vehicle’s design?
- How are modern chassis made and what are they made of? Why?
- How does the design of your robot’s chassis affect the way it will function?

Suggested Extensions/Modifications

- Extension – If teams complete their frames quickly, ask them to create as many different frame configurations as possible. They may want to use parts other than the ones listed in the guide.
- Extension – Ask teams to explain how robotic assembly lines manufacture chassis.
- Modification – Provide teams with some images of wooden carts that they can draw from while designing a frame and chassis in the Getting Started section.
- Modification – If teams struggle with designing a frame or chassis for the cart in the Getting Started section, pair them with another team or provide them with specific building instructions.
- Modification – Brainstorm some facts about chassis as a class for teams to put in the “What We Know” column of their KWL chart in Task 1.

Teacher Reflection Questions

- Do my students understand the differences between chassis and frames, and can they explain the importance of both?
- Were my students able to use the guide to build a chassis?
- Do my students know how to use the tools needed to build their chassis?

Student Artifacts

- In their Engineering Notebook, students should have recorded:
- A sketch of the frame they designed for the farmer’s cart in the Getting Started section.
- Answers to the questions about the farmer’s cart chassis and a sketch of the design.
- A KWL chart to organize their knowledge of chassis in Task 1.
- Answers to the questions about their robot chassis in Task 2 and a sketch of the design.
- A sketch of the frame they built in Task 3 with labeled parts.

Checkpoint

- Have students explain the function of chassis and frames.
- Ask students to explain what they learned in their research on chassis.
- Throughout the activity, check the sketches teams make of the various chassis and frame designs. Ensure their sketches are precise and the chassis/frame components are labeled correctly.

Activity 2: Get Your Chassis Moving

Driving Questions

- Why are different wheels used for different jobs?
- How do we mount wheels to our chassis using the robotics kit?
- What sorts of wheel configurations can you create from the robotics kit?

Objectives

- Teams will look at different types of wheels and learn how their purpose affects their design.
- Teams will learn how to design a chassis and mount wheels using their kit of parts.
- Teams will build a chassis, test two different wheel configurations, and investigate the pros and cons of each arrangement.

Materials

Each team will need:

- Engineering Notebooks
- Pens or pencils
- Robotics kit
- Access to the Internet to research different types of wheels

Getting Started

BEFORE THE START OF CLASS:

- Ensure all teams will have access to the Internet so they can research different types of wheels in use today. They will be looking at various wheels and need to consider how a wheel's design relates to its purpose.
- Consider providing the following robotics manufacturer resources, depending on the parts in teams' robotics kits.

XRP	*FIRST* TECH CHALLENGE	*FIRST* ROBOTICS COMPETITION
Building the XRP	REV Wheels	AndyMark Wheels
	TETRIX Wheels	

- Remind teams to record any relevant information in their Engineering Notebooks.

DURING CLASS:

- Encourage teams to research as many types of wheels as possible. Knowing about the design of different kinds of wheels will help them when they investigate the design of their kits' wheels.
- Prompt students to look back at their Engineering Notebook notes as they think about the parts they will need for their chassis.
- Remind students to keep track of their parts to ensure nothing is lost as they build. If teams assign roles to themselves (who will oversee the kit, who will assemble the parts, who will take notes, and so on), it will decrease the chance of a piece getting lost as they progress through their builds.
- In the Getting Started section, teams are asked to think about the different types of wheels used today. Students should be able to make connections between the form (size, materials used, etc.) and the function of a wheel. If teams are having trouble making the connection, ask them to compare the physical characteristics of the wheels of a sports car to those of a bus. The following questions may help students as they investigate the functional differences between different types of wheels:
  - Why are bus, tractor, and truck wheels larger than car wheels?
  - Why are the tires of a bicycle narrow?
  - How does wheel thickness affect a vehicle?

Student Tasks

TASK 1: DIFFERENT WHEELS FOR DIFFERENT JOBS

Identify the Problem:

- Teams have investigated a few types of real-world wheels and now move on to the wheel types available to them in their kit of parts.
- Some wheels used in *FIRST* are uncommon, and teams might have difficulty discerning their purpose.
- Traction wheels are much more like the wheels that students are familiar with. They have rubber tires and, as their name suggests, are used to provide traction while moving.

Design and Prototype:

- When teams have found their wheels, they should look through their kit for the parts they need to mount their wheels to a frame.
- Teams already know the parts they need for a frame from the last activity, but they have also encountered all the pieces they will need to mount wheels found during the scavenger hunt activity in the previous unit.
- Mounting motors in different configurations can be found in the chassis guides previously provided.
- Teams should list all the parts they will use in their Engineering Notebooks.
- Have students pay attention to details when managing their parts. For instance, sometimes shaft collars will not have screws in them; they should be put in and managed before moving on with the kit, or your parts might be lost.
- Ask students to ensure they are using spacers in their builds. Using spacers won't occur to many teams, but without spacers, wheels might rub against other parts and won't spin as well.

TASK 2: WHERE DO MY WHEELS GO?

Identify the Problem:

- Ask teams to think about how their robot should be designed to solve their ball game. They should consider what the robot needs to accomplish. Teams may design their robot to have more than two pairs of wheels.
- As they create their robot, teams should consider innovative ways to use their kit's parts.

Design and Prototype:

- The robotics kit you use has build guides that can be useful for using the kit in the way its manufacturer intended. Share the guide corresponding to the kit your class is using.

XRP	*FIRST* TECH CHALLENGE	*FIRST* ROBOTICS COMPETITION
Building the XRP	REV Channel Drivetrain	AndyMark 6 Wheel Drop Center "Chassis Building & Assembling" video
	REV Extrusion Train Drivetrain	AndyMark Frame Opening Kit
	TETRIX Flex-Build Robot Chassis	AndyMark Mecanum and ToughBox
	FIRST Tech Challenge Build Guides	Kitbot Chassis

- Note: If you're using the XRP, the chassis has one basic design. It requires CAD skills to modify and 3-D print a new chassis with a new design. You can go with the basic design and skip the part of designing different chassis. See the team resources for CAD for available software (*FIRST* Tech Challenge, *FIRST* Robotics Competition).
- As teams reviewed their kit's parts, they likely thought about basic four-wheel designs.
- Teams design a chassis and decide where to mount their wheels.
- If teams have trouble designing their chassis, ask them to lay out the parts they consider using.
- Teams should sketch their design in their Engineering Notebooks and clearly label all the parts they've used.
- After teams have created their sketch, they should answer the following questions in their Engineering Notebooks:
  - What are the benefits of having three wheels instead of four?
  - How did you decide where to mount your wheels?
  - Did you encounter any challenges while you were designing your two chassis?
  - Which of your two designs would better solve your ball game? Why?

TASK 3: FROM BRAINSTORMING TO BUILDING

Design and Prototype:

- In this task, teams move from the Brainstorm and Explore step of the Engineering Design Process to the Design and Prototype step.
- This is only the second time teams have worked to assemble parts in their kit, so this task might take much more time than the previous tasks. Try to remind teams to take their time as they are building and to keep track of all the parts they are using.
- Ensure that teams use teamwork and divide tasks among the team. They should ensure everyone has a job and feels included in the build.

Test and Improve:

- Referencing their sketch as a guide, teams begin building their chassis.
- Teams should gather all the needed materials and lay them out across their workspace to be easily accessible.
- By referencing the list of parts outlined in their sketches, teams should be able to take the components they plan to use out of their kit and put the kit aside to give themselves more room to work with.
- When teams have assembled their first chassis, they should test it by putting it on the floor, pushing it, and observing how it moves. If teams are unhappy with how their chassis rolls, they can change their design and record those changes in their Engineering Notebooks.
- After testing the first configuration, they should make changes to test their second configuration.
- Teams will add parts to their chassis in the next activity, so they should leave their build assembled, return all loose parts to their kit, and put the kit and chassis away.
- After their materials have been put away, teams reflect on the following questions and record their responses in their Engineering Notebooks:
  - Did you have to change your chassis after you performed the roll test?
  - Did you encounter any challenges as you were building your chassis?
    - What were they?
    - How did you work through them?
  - What can you do in the future to avoid the challenges you encountered?
  - Now that you've tested your chassis, which design is better suited to the ball game? Why?

Guiding Questions

- Are your wheels secured to your chassis?
- How might wheel placement affect your robot's ability to perform in the ball game?

Suggested Extensions/Modifications

- Extension – Ask students to design a wheel that a sports car would use in the winter.
- Extension – Ask students to design a set of wheels for an airplane/aircraft.
- Extension – Ask students to design a two-wheel chassis using the parts available in their kits.
- Modification – If students have trouble envisioning the purpose of some wheel types, have them investigate other robots that have used them.
- Modification – Pair up teams that are having difficulty designing their chassis.

Teacher Reflection Questions

- Did my students find the Getting Started activity engaging?
- Are my students able to use the Engineering Design Process effectively?
- Do my students understand the relationship between the design of a wheel and its function?
- Can my students find the parts they need to build a chassis in their kit?

Student Artifacts

- In their Engineering Notebook, students should have recorded:
- Answers to the questions about the types of wheels they researched in the Getting Started activity.
- Responses to the questions about the types of wheels available to them in their parts kit.

- A sketch of their chassis with all the parts labeled and answers to the questions about their sketch.
- Whether or not they made changes to their chassis and why.
- Answers to the questions at the end of Task 3.

Checkpoint

- Have teams explain how the type of wheel a vehicle uses affects its ability to move.
- Have teams explain how they move from the Brainstorm and Explore step of the Engineering Design Process to the Design and Prototype step.
- Have teams explain how the placement of their chassis wheels would affect their ability to move.

Activity 3: Mounting Motors

Driving Questions

- How will the robot move?
- How do we mount motors onto the chassis?
- Where should we mount motors on the chassis?

Objectives

- Teams will investigate the parts added to a chassis that make a vehicle move.
- Teams will examine the different motors available to them in their robotics kit.
- Teams will learn how to mount motors onto their chassis.
- Teams will decide where to place their motors on their chassis and mount them.

Materials

Each team will need:

- Engineering Notebooks
- Pens or pencils
- Robotics kit
- Safety equipment
- Tools for assembling robots
- Chassis assembled in the previous activity
- Access to the Internet to research motor types and how they transfer motion to wheels

Getting Started

BEFORE THE START OF CLASS:

- Ensure all teams have their chassis ready to be worked on.
- Look at the types of motors teams have available in their kit. Many kits will have specific instructions for mounting motors and wheels or managing gearboxes. Refer to your manufacturer's resources and give these to the students if there are specific requirements.

XRP	*FIRST* TECH CHALLENGE	*FIRST* ROBOTICS COMPETITION
Building the XRP	REV Motors and Servos	AndyMark Motors
XRP Specifications	TETRIX TorqueNADO® Motors	

- Example directions:
  - *FIRST* Tech Challenge REV UltraPlanetary
  - AndyMark Gearbox Assembly

DURING CLASS:

- Give teams time to research the different types of motors in their robotics kits.
- Ask teams to look at their available motors. After identifying their motors and possible gearing, they will use the build guide and manufacturer resources to ensure assembly and mounting occur correctly.
- As teams look through their kit for the parts, they will need to mount motors to their chassis, ensure teams keep track of all the parts being removed from the kit so that nothing is lost.
- When teams go to mount their motors onto their chassis, they might find that things don't line up correctly. Plan to give teams extra time for building, as they might need to make corrections to their chassis as the activity progresses.
- Teams will not connect their motors to a battery until later, so they won't get their motors moving yet. To test how their motors transfer motion to their wheels, they should gently rotate their wheels to avoid damaging their motors.

- In the Getting Started section, teams are asked to think about the engines of vehicles. In past activities, teams focused on basic frames and chassis, and in Activity 2 they propelled their chassis with a push. By the end of this activity, teams should have motors mounted on their chassis and able to connect their motors to wheels.
- To prepare students for their work with motors, they will use the Internet to research how engines are attached to chassis and how those engines transfer motion to a vehicle's wheels. While the motors they use will be directly connected to their wheels rather than moving a drivetrain like traditional vehicles, learning about drivetrains will give them a better understanding of how engines are used in most modern cars.

Student Tasks

TASK 1: THE RIGHT MOTOR FOR THE JOB

Identify the Problem:

- There are different types of motors in the team's kit of parts. In most robot kits, you will find three categories of motors:
  - Motors with high power are used for drive system purposes or manipulators that require a lot of power.
  - A medium-level motor provides a balance of power and torque for manipulators.
  - Low-power servos can have a high torque but low speed.
  - Students should investigate the motors in your kit of parts.
- Students should use the motors that are suggested in the chassis build guides – those with more power and speed, requiring a gearbox or gearing to use as chassis motors. Refer students to the directions in the guides to assemble their gearbox and gear for their chassis.
- Teams won't attach batteries to their chassis until the next activity, so they won't be able to run their motors after connecting them.

Design and Prototype:

- Before teams move on to mounting their motors onto their chassis, they need to look at the pieces available to them in their kit of parts.
- Have students reflect on the following questions in their Engineering Notebooks:
  - Are your motors like any of the motors you came across in your research?
    - If they are, what motors are they like?
    - What characteristics do they have in common?
  - What parts do you need to mount the motors onto your chassis?
  - How might overtightening or under-tightening a gearbox affect the motor?

TASK 2: WHERE SHOULD MY MOTORS GO?

Brainstorm and Explore:

- Motors are a crucial element of a team's robot. If a motor is not mounted correctly, it might not work as the team intended or come loose while in use.
- Before a team mounts their motors, they should understand how the motor will be attached to the frame. Refer students to the build guides for mounting their motors.
- Prompt students to consider where there might be a lot of vibration that could cause the motor to come loose. Where might they create problems, such as a gearbox if it is tightened too much?
- Teams should consider which wheels should be attached to their motors. Prompt students to observe that the wheels connected to the motors should have good contact with the ground. Discuss how weight and the wheel type can affect contact with the ground and the traction the wheels will have.

Design and Prototype:

- Before teams start mounting their motors, they should spend some time thinking about their motor placement.
- The position of a team's motors on their robot's chassis will affect how the robot moves and its center of gravity.
- When teams know where to place their motors on their chassis, they should create two sketches of motor configurations.

TASK 3: MOTOR UP

Design and Prototype:

- When teams have decided where to place their motors and understand how those motors will make their wheels move, they should move on to mounting the motors onto their chassis.
- As teams mount their motors, they might need to make changes to their chassis' overall design to account for their motors' size.
- Ensure teams keep track of all the parts they use, especially if they remove parts of their chassis.

Test and Improve:

- Teams should pick one of the motor configurations they sketched in the previous task and mount their motors based on their design.
- As teams were unaware of motor size when designing their chassis, there might not be enough room for both motors to be mounted across from each other. Motors do not need to be mounted symmetrically for a robot to move, but students might run into issues steering their robots later if the motors are staggered on their chassis.

Guiding Questions

- Are your motors secured to your chassis?
- Are your wheels secured to your motors?
- How might motor speed and torque affect your robot's ability to perform in the ball game challenge?

Suggested Extensions/Modifications

- Extension – Ask students to explain how they envisioned their robot moving and how they could change the design based on the parts available in their kit.
- Modification – Allow teams with difficulty mounting their motors to work with a team that has successfully mounted motors.

Teacher Reflection Questions

- What did my students learn during the research in the Getting Started portion of the activity? Did that knowledge help them during the activity?
- Were my students able to mount their motors onto their chassis?
- Were my students able to achieve their goals during this activity?

Student Artifacts

In their Engineering Notebook, students should have recorded:

- Answers to the questions from the Getting Started section.
- Answers to the questions in Task 1.
- Sketches of two configurations for motor placements on their chassis.

Checkpoint

- Have students list the parts they need to mount their motors.
- Ask students to ensure their motors are securely mounted onto their chassis.
- Ask students to ensure that, when their motors turn, they won't be rubbing against any of the stationary parts of their chassis.

Activity 4: Power and Control

Driving Questions

- How do we power our robot?
- What is a control system and what does it do?
- How do we connect all the electronic components of my robot?

Objectives

- Teams will learn about vehicles that use electricity to power their motors.
- Teams will investigate wiring diagrams.
- Teams will attach the battery from their kit of parts to their robot chassis.
- Teams will attach the control system from their kit of parts to their robot chassis.
- Teams will use wires to connect their motors to their control system and battery.

Materials

Each team will need:

- Engineering Notebooks
- Pens or pencils
- Robotics kit
- Assembled chassis with wheels, motors, and gears
- Examples of wiring diagrams or access to the Internet to research wiring diagrams

Getting Started

BEFORE THE START OF CLASS:

- Ensure all teams have an assembled chassis with motors, gears, and wheels.
- Share with students this example of a motor controller wiring diagram: Sparkfun: DRV8835 Dual Low-Voltage H-Bridge IC.
- Ask students to reflect on the simplified schematic. Ask the following questions:
  - What do they think the schematic represents?
  - What symbols are present?
- Have students glance through the rest of the pages down to page 9. Ask students to look at the functional block diagram.
  - What is the schematic representing?
  - What symbols are present?
  - How is an electrical current flow controlled for a DC motor?
- Explain to students that this is how the electronics in the robot control the current output. It shows how the circuit knows if a motor should be turned on or off and the current it should receive. A schematic helps with understanding the electrical current and switches in electronics.
- Direct students to their wiring diagrams for their robotics platform and ask them to draw a simplified schematic for how the current will flow on their robot.

XRP	*FIRST* TECH CHALLENGE	*FIRST* ROBOTICS COMPETITION
Building the XRP	REV Control Hub Wiring Diagram	WPILib Intro to Robot Wiring

- Take some time to familiarize yourself with the different wires that come with the motors the teams will use. Students need to keep a record in the Engineering Notebook of which motor or sensor is plugged into which port. It will help them in troubleshooting if their robot has communication issues later.

DURING CLASS:

- Ask teams to think about how their robot will know where to send power.
- As teams go to mount their battery, ensure they secure it in place. Keeping their battery secure will help them avoid issues when their robot moves around in the next unit.

- Remind them to keep track of their parts and take their time when assembling to ensure everything fits together correctly and no pieces are misplaced.
- For *FIRST* competitions, there are wiring resources that can help students learn good wiring techniques and prevent wiring failures.
  - *FIRST* Tech Challenge Wiring Guide
  - *FIRST* Robotics Competition Wiring
    - Robot Wiring, WPILib
    - "VRS 11: Wiring: Mounting the Battery / Wiring the Robot" video later by *FIRST* in Michigan
    - "VRS 12: Software: Installing & Preparing the Robot" video by *FIRST* in Michigan
    - "How to Wire a Robot" video by *FIRST* Robotics Competition
    - "NI Supplier Video - Wiring Essentials" by *FIRST* Robotics Competition

Student Tasks

TASK 1: THE SOURCE OF YOUR POWER

Identify the Problem:

- The robot teams are building will use the battery that comes in their kit as a power source.
- Teams should have charged their batteries in the previous activity. (The XRP uses replaceable AA batteries, or you can purchase rechargeable ones.)
- If students haven't charged their batteries yet, ensure teams plug them in at the end of this activity. The batteries need to be charged for only two hours and should then be unplugged; leaving the batteries charging for too long may damage them.

Design and Prototype:

- To mount their batteries onto their chassis, teams might need additional supplies depending on their kit. Some kits come with battery holders; other holders will need to be designed and fabricated.
- Hook-and-loop fasteners are often used to secure the battery for *FIRST* competitions, which is often found in robotics kits. Wiring guides and chassis build guides often have guidance for the battery holder; the links to these were in the previous lessons.
- Check to ensure that all students have a method to secure their battery to the robot and that there are no pinch points in the wiring.

TASK 2: THE CONTROLLER

Identify the Problem:

- The controller that comes in the kit of parts acts the same way a controller would in an electric car. The controller will process all the commands the team will send to their robot.

Design and Prototype:

- Students should consider where the wires will run out of each controller port and what path they will take to reach the motors. They'll consider the orientation or direction in which the controller is mounted. When they have decided where to mount their control system, they should attach it to their chassis. Teams will often use plexiglass or wood to mount their control systems.
- Caution: Most control systems are sensitive to electrostatic discharge. They should not be mounted directly on metal.
- When teams have successfully secured their control system to their chassis, they should answer the following questions in their Engineering Notebooks:
  - Why are the inputs of an electric car not plugged directly into its motor?
  - Create a quick sketch of your chassis after you've mounted your control system.
  - How does the orientation of the control system matter? Did you have to make any modifications or changes as you mounted it?

TASK 3: ALL THE WIRES

Identify the Problem:

- Wiring in electronic projects is critical. If teams can't wire their robot correctly, it will not function.
- Explain to teams that wiring in robot projects is similar to wiring in a building, like in a city's electricity grid to lights and outlets. The wiring in robots or sophisticated electronics sends electricity and information.

Design and Prototype:

- Provide students with the appropriate resource for wiring with the kit of parts you are using.
- For *FIRST* competition, there are wiring resources that can help students learn good wiring techniques and prevent wiring failures. See links at the beginning of this activity.

Guiding Questions

- Could wiring diagrams help to you execute your ball game robot design?
- Would a wiring diagram help to execute my ball game robot design?
- What parts do you need to mount your battery and controller?
- How can you test your robot to see if your battery and controller are secure?

Suggested Extensions/Modifications

- Extension – Have students compare the way gas-powered and electric cars use motors.
- Extension – Draw a classroom wiring diagram and explain the symbols used.
- Extension – Explain the difference between the wiring in a building and the wiring in a robot.
- Extension – Ask students to try to draw a wiring diagram for a smartphone.
- Modification – Provide teams with a very simple wiring diagram with a legend of the symbols.

Teacher Reflection Questions

- What did my students learn during the Getting Started section? Did that knowledge help them during the activity?
- Were my students able to mount their batteries and controller?
- Do my students understand the function of the controller?

Student Artifacts

- In their Engineering Notebook, students should have recorded:
- Answers to the questions from the Getting Started section.
- A sketch of their chassis after they've mounted the battery in Task 1.
- Why they chose to mount the battery where they did.
- Answers to the questions at the end of Task 2.
- A sketch of their chassis after they've mounted the controller.
- A wiring diagram of their robot showing the motors and control system.

Checkpoint

- Have students list all the parts they need to mount their battery, controller, and power switch.
- Have students explain the wiring diagrams and their importance.
- Have teams explain the similarities between an electric car and the robot they've built.

Activity 5: Fine-Tuning

Driving Questions

- How can we improve the design of our robot?
- Are all the parts of our robot secure?
- Is our robot ready for programming?

Objectives

- Teams will learn more about the final steps of the Engineering Design Process.
- Teams will find ways to improve the way their robot is built.
- Teams will make changes to their robot to prepare for programming.

Materials

- Each team will need:
- Engineering Notebooks
- Pens or pencils
- Robotics kit
- Assembled chassis

Getting Started

BEFORE THE START OF CLASS:

- Ensure all teams have their assembled robot and kit of parts ready.
- Remind teams to keep important information in their Engineering Notebooks.
- Let teams know that this will be their last chance to work on the design of their robot structure. At the end of this activity, their robots should be ready for programming.
- In later units, teams will add sensors and an arm mechanism to their robot. Let teams know they should leave space on their chassis for additions.

DURING CLASS:

- As teams think of ways to evaluate their robot, prompt them to look at the notes they've taken in their Engineering Notebooks. Throughout this unit, they should have recorded detailed notes on their robot's Engineering Design Process steps. Refamiliarizing themselves with the stages of their robot's assembly will help them focus on specific aspects of their build that they might be able to improve.
- Teams won't be able to run their motors until the next unit, but they can run basic tests by gently rotating the wheel attached to each motor. Ask teams to be mindful of the force they apply to their motors to avoid damaging them.
- In the Getting Started section, students begin thinking about the Test and Improve step of the Engineering Design Process in the context of a car manufacturer. Before cars are put into mass production, their designers must ensure they are safe and perform as intended.
- While teams are thinking about the tests a car goes through before it is ready for sale, you can show them test videos of car safety or performance tests to help them visualize the process of some commonly performed tests.

Student Tasks

TASK 1: YOUR FRAME

Design and Prototype:

- Teams first look at their robot's frame. Since the frame was the first thing they worked on in this unit, they might want to refer to their notes.
- A range of design options are available to the teams in their kit of parts, which means the shape and size of the frame will vary between teams. Before teams think about changing their frame, they should consider the role a frame plays in the robot's performance.

Test and Improve:

- At this point, teams won't know how powerful their motors are or how fast their robot will move. As they design a test to evaluate their frame, teams should think about how their robot's frame would hold up under stresses like high-speed collisions.
- Teams should create a test they can perform on their robot to help them evaluate their frame's design. They will then record and explain the test they've developed in their Engineering Notebooks.
- Teams should perform their test and record their results.
- If teams decide to redesign their frame, they should sketch their new design and explain why they made the change.

TASK 2: MOTORS, WHEELS, AND GEARS

Design and Prototype:

- To succeed in future activities, every team's robot will need to be able to move without difficulty.
- Teams should already know that the traction wheels should be attached to their motors to provide traction. Other wheels with less friction should be attached to the front of a robot to ensure the robot can turn.
- A common way *FIRST* competition robots maintain traction is with six wheels and a dropped center wheel, all wheels having tread or traction.
- As teams design a test to evaluate their motor and wheel configuration, they should consider how they want their robot to move.

Test and Improve:

- Before teams change their wheel and motor configuration, they should design and implement a test to evaluate their current setup.
- The test that teams design should address the speed and balance of their robot.
- When teams have decided on a test, they should record the details in their Engineering Notebooks.
- While one team member implements the test, another team member should record the results in their Engineering Notebook.
- If teams decide to change their design based on their test results, they should first sketch their new design in their Engineering Notebook and explain why they've decided to make changes.

TASK 3: CONTROLLER, BATTERY, AND WIRING

Identify the Problem:

- As teams worked with their electronic components (wiring, controller, battery) in the last activity, they should recall their rationale for the placement of each part.
- While teams aren't running power through their electronic components to test functionality, they can design a test that checks whether the battery, controller, and wires are securely attached to their chassis.
- Teams might run into issues with their electronic components in the next unit that they can't address yet.

Test and Improve:

- Before teams make any changes to the configuration of their electronic components, they need to design a test to evaluate their current setup.
- The first step of the test for all teams should be switching the power on and ensuring the controller's light turns on. If the light doesn't turn on, they should ensure their battery is charged before making any changes.
- The test teams perform might also address the placement of the battery and controller on their chassis. The battery is one of the more substantial parts of their robot, and its placement affects the robot's center of gravity.
- When a team has decided on the test, they evaluate their electronic components. They should record and explain their test in their Engineering Notebook.
- Teams should assign one team member to complete the test while another team member records the test's results.
- Suppose teams decide they are going to change the configuration of their electronic components. In that case, they should sketch their new design in their Engineering Notebook and record why they've decided to make changes.

Guiding Questions

- How do car manufacturers make sure their designs are ready for mass production?
- What do you think your robots are going do in the coming units?
- How can you improve the design of the robot you've built?
- How can you use the final step of the Engineering Design Process to improve your robot's design?

Suggested Extensions/Modifications

- Extension – Ask students to think of an industry other than car manufacturing where testing hardware would be critical.
- Extension – Have teams explain how they can use the sketches in their notes to help them design tests for their robots.
- Modification – Provide teams with examples of the tests a car manufacturer might run on their designs before moving to mass production.
- Modification – If a team is having trouble designing tests to evaluate their robot's design, pair them with a team that has already created a test.

Teacher Reflection Questions

- What did my students learn during the Getting Started section? Did the knowledge help them?
- Could my students design tests for their frames, wheels, motors, and electronic components?
- Were my students able to improve their robots based on the tests they designed?
- Did my students utilize the notes and sketches they recorded from past activities during their tests?

Student Artifacts

- In their Engineering Notebook, students should have recorded:
- Responses to the questions about the car manufacturer in the Getting Started section.
- The test they designed in Task 1 to evaluate their frame.
- The results of their test from Task 1, whether they decided to change their frame as a result of the test, and, if so, why.
- The test they designed in Task 2 to evaluate their wheels and motors.
- The results of their test from Task 2, whether they decided to change their frame as a result of the test, and, if so, why.
- The test they designed in Task 3 to evaluate their electronic components.
- The results of their test from Task 3, whether they decided to change their frame as a result of the test, and, if so, why.

Checkpoint

- Have teams explain the importance of the Test and Improve step of the Engineering Design Process.
- Have teams explain the importance of the sketches they've been recording in their Engineering Notebooks.
- Have teams explain the similarities between the tests a car manufacturer performs on their designs and the tests they created for their robot.