FIRST EDUCATION

Robotics Engineering Explorations FIRST® Education

FIRST® Robotics Engineering Explorations

Student Guide — Build and Program Manipulators

Unit 5

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Activity 1: Ball Grabber

Driving Questions

- What is an actuator?
- How do we use the actuators in our kit?

What Will I Be Doing?

- I will learn about actuators.
- I will design a mechanism that can corral or grab a ball from the ground.
- I will investigate the actuators in my kit of parts that could be used to grab a ball.
- I will add an actuator to my robot's hardware map.
- I will utilize a sample code for an actuator.
- I will use a gamepad to control my actuator.

Getting Started

- To get your robot moving, you attached motors to drive your wheels. You may or may not have added additional motors to your robot yet. Additional electronic components in your kit are designed to transfer motion similar to the drive wheels that can help you manipulate objects.
- A servo is a type of motor or actuator that can move components to set angles. Servos are a type of actuator that you can use to create additional mechanisms on your robot. One important concept you will want to consider before using a servo is the right amount of power and control for your robot to accomplish its action. Many different types of servos and motors can move parts. Using your manufacturer resources and programming tools, research the different types of actuators and their application.
- Actuators can be used in lots of different ways. You could use actuators to move an extrusion up and down or back and forth to create a grabber. You could also use an actuator to raise a flag or wave a sign.
- It is suggested to start with a smaller actuator to learn the basics before moving on to larger ones. These are often called servos. They are typically lower-power actuators that execute actions that do not require a lot of speed. They can run on a 5-volt signal without much power and perform small actions such as triggering a latch, waving a flag, or corralling a ball.
  - What other types of electronic devices have you seen servos used in?
  - What types of actuators do you have in your current robot design? Which types of actuators might be used in each application?
  - How would a robot designed to walk on legs use servos?
  - How could a servo be used in a vehicle such as a car or a plane?

WHAT'S NEXT?

- Gather your team.
- Grab your supplies (Engineering Notebook, robot, kit of parts, options for robot actuator, laptop, and gamepad).

HOW WILL I DO IT?

- Choose an uncomplicated action from your ball game challenge, such as corralling the ball on the floor. Consider how you might use a servo or other motor for this application. What might using a servo or motor to move the ball into a collector look like?

Task 1: Preparing Your Servo or Actuator

DESIGN AND PROTOTYPE:

- Before you start, draw out a design of how you would like to corral the ball on the ground using a small actuator such as a servo or smaller motor in driver-controlled mode. Consider your kit of parts; how might you quickly assemble parts so you can test out a few ideas to see how they work? Draw out three easily executable ideas for corralling the ball.
- Before using a servo or other actuator, refer to your manufacturer's resources to ensure you have the needed supplies for mounting it to your robot. Continue to discover the resources to learn more about your servo or actuator. Consider the following questions:
  - What degrees of motion does the actuator have?
  - How much force is needed for the actuator to complete its task?
  - How much speed is needed for the actuator to complete its task?
  - Does the actuator have the ability to be programmed to different degrees (360, 180, 90)?
  - Is the programming process achieved with an additional calibration tool? Or is it done entirely within your programming tools?
- When you have designed and prototyped the problem of mounting your actuator, look at algorithms in your programming tools that will give you a good starting point to develop your final algorithm.

Task 2: Configuring and Testing an Actuator

DESIGN AND PROTOTYPE:

- The process of corralling a ball might take some experimentation. Before you mount your actuator on the robot, you should plan out some testing ideas to see how it works and how it will interact with the ball to be able to grab it. So, plan out a safe way to test the design of your mechanism with the actuator. Your testing method will depend on your kit of parts and available options.
- You have learned the importance of hardware setup in your programming tools. Update your wiring diagram to show where your actuator hardware is mounted and connected within your control system.
- In your programming tools, ensure the hardware variables are declared with the correct data and within the proper code structure.
- Write an algorithm for the actuator to move in driver-controlled mode using the programming tools and templates according to your design plan.

TEST AND IMPROVE:

- Test your hardware setup and the sample code. Be sure you have another student near the Stop button on your robot in case the servo or actuator does not operate the way you intend. Be sure to record any specific struggles or challenges you might have. For instance, the servo might have started or stopped in an incorrect position. Record each test along with changes made to the algorithms.
- After your servo is configured, add the component to the wiring diagram you've created for your robot in your Engineering Notebook.

Task 3: Ball-Grabbing Robot

DESIGN AND PROTOTYPE:

- Now that you have programmed your servo and done some initial testing, it is time to implement the ball grabber onto the robot.
- Take some time to mount the mechanism with the actuator on the robot.
- Be sure to utilize any lessons learned in the previous tasks.
- After the mechanism is added to the robot, start testing it to see how it interacts with other parts of the robot.

TEST AND IMPROVE:

- Using the ball game rules you created previously, practice collecting and trying to score balls with the actuator or servo.
- Draw out any ideas for improving the robot's ball handling after testing.

Reflection

- How might the sensors we learned about in the last unit improve the ease of driving and manipulating the ball?
- Are there mechanical improvements that need to be made to improve the handling of the ball?
- How did iteration play a role in improving the ball grabber?
- Aside from vehicles and manufacturing plants, where would actuators be used in the real world?
- Were you able to get the robot to grab a ball?
- Could you connect the actuator and get it operating using the programming tools?

Checkpoint

In your Engineering Notebook:

- Record your answers from the Getting Started section of the activity.
- Record your responses to the Engineering Notebook prompts in Tasks 1-3.
- Record your responses to the reflection questions.

Activity 2: Iterate, Feedback, and Improve

Driving Questions
- How do we improve the robot mechanically and through programming?
- How can we improve our designs to perform better?
- How can programming enable our robot to have more control?
- How can sensors improve the automation process?

What Will I Be Doing?
- I will improve my ball grabber design.
- I will add additional improvements to make the design more efficient.
- I will use conditionals to improve the automation of the mechanism using a touch sensor or limit switch.

Getting Started
- Now that you've experimented with your ball grabber and put it on your robot, the next step is to improve its efficiency. Your robot uses motors to drive its wheels and move around. To get information from the world around it, it will use sensors. Adding feedback to your Driver Station with telemetry can help you understand how to improve the efficiency of your ball grabber design. Consider how your robot could sense that the ball is in the position for the actuator to move. Not just with the human eye and the driver guessing it is in place, but the robot knows that the object is in the best position for the actuator to take control.

WHAT'S NEXT?
- Gather your team.
- Grab your supplies (Engineering Notebook, robot, laptop, gamepad, tape, paper).

HOW WILL I DO IT?
- In this activity, you will create two driver-controlled modes and one autonomous mode.
- You will be customizing your code so that you can improve the accuracy of your actuator. Whether you are using a servo designed to move to a specific position or have encoders on a motor that will enable you to control the position, having control accuracy is essential.
- To improve the accuracy of your actuator, it is essential to understand the type of data the motor needs to receive to go to or maintain a position. The algorithms to achieve this will vary according to your type of motor and the number of positions you would like the actuator to have.

Task 1: Push a Button, Spin a Servo
BRAINSTORM AND EXPLORE:
- In previous activities, you learned about variables and operators. Using your programming tools and the resources from your manufacturer, research how you might create algorithms for your actuator to have the most accuracy in maintaining a position. Algorithms can often be improved using variables and logic. Another aspect to consider is you only have certain buttons on your gamepad. How might you be able to create Boolean logic that can use these buttons to move the actuator to a specific position?

DESIGN AND PROTOTYPE:
- Create a pseudocode or flow chart of what the algorithm might look like to achieve several positions using buttons on the gamepad that will enable your ball grabber to operate with the most accuracy.

TEST AND IMPROVE:
- Create a new copy of your program and name it "Actuator_Positions." First, use programming templates to test the template code to ensure your hardware and software communication is operating correctly. Ensure you are ready with the Stop button if the template code is dangerous for your robot design. Take note of where the template code positions are on the robot.
- Make any modifications to the code that will enable the algorithm to work for your specific robot hardware and design. Make a note of any specifics such as:
  – What position will your servo start at?
  – What position does each button on your gamepad represent on the robot?
  – How is the logic in your algorithm designed to know the position of the actuator?
  – Could you use variables to store the position?
  – Can you use operators such as averages or ranges to improve efficiency and accuracy?

Task 2: Collaborate, Iterate, and Improve

BRAINSTORM AND EXPLORE:

- Throughout the course, you have learned about *FIRST®* Core Values and utilizing *Gracious Professionalism®* and *Cooperitition®*. These principles can be just as crucial in the learning and design process as they are in competition. Using your algorithms from the last lesson, pair up with another team in your class. Share your algorithms and the lessons learned with them.
- Perfecting accuracy and efficiency can take many trials. Building on other teams' lessons, research ways you might improve your algorithms or your robot's mechanical design to increase its efficiency. Many of these resources are found in ideas from the manufacturer and your programming tools.

TEST AND IMPROVE:

- As you test out different ideas, ensure you record each trial. This process can help you identify patterns in data that might help you solve future problems or overcome your current problems.

Task 3: Autonomous Actuator

BRAINSTORM AND EXPLORE:

- Now that you know how to control your actuator in driver-controlled mode using gamepad buttons, you will probably need to be able to move this same actuator into autonomous mode to score more points.
- Consider the activities you have completed in previous lessons. How might you utilize sensors to get the robot to move the actuator to a more accurate position within an autonomous routine? In autonomous programming, you can have many different inputs to control the output. You previously have used time, as well as sensors. As a team, weigh the pros and cons of using time versus a sensor to control the position output of your actuator.
- Consider the following questions:
  - How could you use variables to create different conditions to alter the program flow based on input versus time?
  - Could multiple sensors be used to trigger different variables that could provide more input for your robot?

DESIGN AND PROTOTYPE:

- Design an algorithm using pseudocode or a flow chart that uses variables and sensors to control the position of your actuator. When you have a pseudocode as a template, write in the algorithm you have refined using the programming tools for your robot.

TEST AND IMPROVE:

- As you test out different ideas, ensure you record each trial. This process can help you identify patterns in data that might help you solve future problems or overcome your current problems.

Reflection

- How could you improve the efficiency of your algorithms using variables and logic?
- How can using variables to store data help you improve the accuracy of an actuator?
- How does the data a motor needs affect how you create the algorithm?

Checkpoint

- In your Engineering Notebook:
- Record your answers to the question from Tasks 1–3.
- Record the programs you created in Tasks 1–3.

Activity 3: Robot Arms

Driving Questions

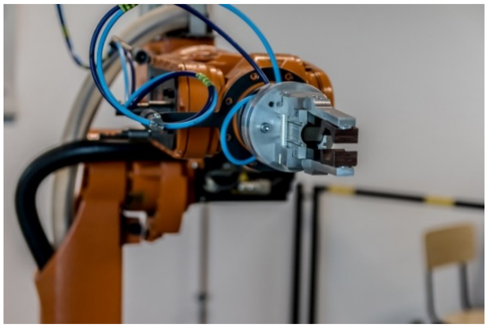
- How can we do more complex actions with our ball game robot?
- What is a robotic arm?
- Where are robotic arms used in manufacturing?
- How do we choose the correct motors for the robot arm?

What Will I Be Doing?

- I will learn about robotic arms.
- I will define how my ball game robot could be improved with a robotic arm.
- I will compare manufacturing robot capabilities to our ball game robot capabilities.

Getting Started

- Remember the Mars rover that you helped to free? In past activities, you've investigated some complex sensors and components that the rover would use to view its surroundings and move around. When the rover can "see" and move around the surface of Mars, how would it interact with the alien world around it? What is the purpose of sending a robotic rover to Mars, and how would the robot achieve its goals?
- One of the purposes of missions to other planets is to study their geology, which is analyzing the rocks and minerals of the planet. The rover needs to be able to drill, shovel, and sieve those minerals to perform geological tests. Rovers are equipped with a unique robotic arm that is designed to accomplish drilling, shoveling, and sieving. The robotic arms you might find on the Mars rover are similar to many industrial robots used in manufacturing.
- Industrial robots have several parts and can be divided into five elements. When you divide a robot into parts that achieve different functions, they can be called subsystems. The arm and the end effector are the two main subsystems of many industrial robots. Within many industrial robots, you will have different joints and actuators. A joint could be classified as how the parts go together. The axles, spacers, and mounts allow certain areas to be constrained and others to move. Think of this as a hinge joint that you might have in your elbow. Industrial robots may have several joints on the arm with an end effector. The end effector is the end of the arm that interacts with something to move, sense, or manipulate the job the robot is designed to complete.



- Robotic arms can be used in many different situations and are central to skills you may use in a future job or career. Understanding additional components of industrial robotic arms can help you with your future career. These same components can also be found on your *FIRST* robot.
- Actuators or motors power the joints in a robotic arm. Industrial robots contain internal sensors that help them determine the degree or position of the motor that might achieve an action. Just as your robot has a control system with a battery, role, and wires, an industrial robot could have the same control system.
- Industrial robots may have a single arm that is designed to perform one function. Your *FIRST* robot may be designed to complete many functions and operate like an entire manufacturing floor. They might have conveyor systems, lifts, and arms. Each component will have a different way of interacting with a game element and is considered a subsystem. In this course, you may focus only on a single arm or shoot for the Moon with a shooting ball. That is up to your team and how you designed your ball game robot.
- In your Engineering Notebook, sketch a robotic arm and its parts.
- Using the design for your ball game robot, identify the parts of the arm and the end effectors that will enable you to score points in your ball game.
- Identify different types of manipulators and subsystems that *FIRST* robots may have.

WHAT'S NEXT?

- Gather your team.
- Grab your supplies (Engineering Notebook, laptop, pens or pencils)

HOW WILL I DO IT?

- To familiarize yourself with some of the designs and functions of robotic arms, you will start this activity by researching the three types of robotic arms mentioned in the Getting Started section. After researching different arms, you will discuss how your ball game robot will use an arm and an end effector to achieve an action. When you have decided the function of the arm in your ball game, use the Engineering Design Process to design a manipulator or system of manipulators that could help you improve your ball game robot.

Task 1: Research

IDENTIFY THE PROBLEM:

- In this task, you will be researching the three types of robotic manipulators or subsystems that are commonly used on robots in *FIRST* competitions. The arms and manipulators perform very complex tasks, so take some time to research what each subsystem does and how it functions. You should pay special attention to the design of each manipulator or subsystem, considering how it moves and functions. As you research each of the subsystems, think about the following and record your answers in your Engineering Notebook:
  - What were the subsystems designed to do? What materials are the subsystems made of?
  - What problems did the engineers designing the systems need to overcome?
  - Sketch the systems and label their parts.

Task 2: Real-World Interactions

IDENTIFY THE PROBLEM:

- The design for your ball game robot likely requires the robot to interact with the game element. Up to this point, you've been asked to think about how your ball game robot will move, how it would see the world around it, and how it could use servos or smaller actuators. When designing your ball game at the beginning of this course, how did you think it would interact with the ball? Before you think about additional manipulators for your robot, you should think about what that manipulator would need to do.

DESIGN AND PROTOTYPE:

- Look back in your Engineering Notebook to the notes you took while designing your ball game robot. Now that you've built a robot and worked with all sorts of electronic components, you might have new ideas for what your ball game robot should look like. You might have even thought of a new way to solve your ball game challenge!
- Take some time to think about how your ball game would interact with the ball game element while it works to score points. Discuss a few methods that your robot could interact with its environment with your team and then answer the following questions in your Engineering Notebook:
  - What must your robot do to score the most points in your ball game?
  - How will your robot interact with game elements and field?
  - Would your robot need manipulators to solve your ball game robot?

Task 3: Prototyping an Arm

DESIGN AND PROTOTYPE:

- Now that you know how your ball game robot will score points, the next step is to do a proof of concept of your idea. Proof of concepts are design elements that take a short time to determine if a design would work. Consider supplies you might have available to create a proof of concept. This is created so you can quickly determine if the concept works without building the entire component. Take some time as a team to experiment and develop a proof of concept for any arms or manipulators you will want to have for your ball game robot.

TEST AND IMPROVE:

- Now that you have developed a proof of concept for your ball game robot manipulators, it is time to test them. Anytime you are testing, you will want to control the variables that could influence the test and take data to determine which concept may be the most accurate. Test and record any important notes about the manipulator concepts for which you developed a proof of concept.

Reflection

- How would a robotic arm help you solve your ball game challenge?
- Would your ball game robot be able to score points without an arm?
- Would your ball game need something other than a robotic arm to interact with its surroundings?
- What did you learn from your research on robotic arms?
- Did you make any changes to the original design of your robot?
- After working on your robot over the past few units, have you thought of new ways to solve your ball game robot?

Checkpoint

In your Engineering Notebook:

- Record your answers from the Getting Started section of the activity.
- Record your responses to the Engineering Notebook prompts in Tasks 1-3.
- Record your responses to the reflection questions.

Activity 4: Actuating Your Manipulator

Driving Questions

- How are the motors in our robotics kit different?
- How do we ensure we choose the correct motor to make our manipulator work?
- How can we integrate the proof of concept into our robot?

What Will I Be Doing?

- I will determine the motors' power and torque differences in my robotics kit.
- I will determine which motor is the correct one for the job.
- I will integrate the manipulator and motor into my ball game robot design.

Getting Started

- In the last activity, you developed and tested a proof of concept using the Engineering Design Process. The next step of the process is to take your proof of concept and integrate the manipulator(s) into your ball game challenge. There may be a few questions you would like to ask before integrating the proof of concept into the ball game robot:
  - What kit of parts items do I have that can help me integrate the proof of concept into the ball game robot?
    - Many of your kit of parts items will include axles, spacers, structural elements that can be used to link things together, and actuators that can enable you to program and integrate them into your robot. There are essential tips you might consider when taking your proof of concept into your robot design. You will want to consider whether the manipulator has a good structural design, which will prevent the component from bending or moving when it is not supposed to. This is considered a supporting motion. The next concept is how the components will transform motion. The parts that are supposed to move must be allowed to move freely, but those that shouldn't do not. The resistance to movement is often called friction. The structural components of the robot should be designed to maximize friction or not move, while the parts that are supposed to move should move freely with little friction.
  - What motors or actuators should I use to operate my manipulator?
    - Motors and actuators are designed to exert force over a distance. Many of your motors take electrical power and turn it into rotational force that can exert a certain amount of torque. Torque is the rotational force that the motor can exert. It takes power from the electrical system and uses electromagnetic energy to create that force. The amount of conversion of that electromagnetic into force to the output shaft allows your motor's axle to move. Your motors have different torque capabilities, so it is essential to choose the motor with the appropriate amount of power and torque for the motor to achieve the job.

WHAT'S NEXT?

- Gather your team.
- Grab your supplies (Engineering Notebook, robot, laptop, kit of parts) and manipulator supplies.

HOW WILL I DO IT?

- Before you start working on your robot's manipulators, you should look at some parts in your kit that you haven't used yet. In your parts kit, you will have different types of motors and actuators that can be used to complete different tasks. In the first section, you will research your motors to ensure you can choose the right one. Consider this like choosing the right add-ons for an avatar in your favorite video game. There are perfect combinations to make the robot manipulator work efficiently.

Task 1: Research

BRAINSTORM AND EXPLORE:

- It is essential to research and understand how parts you have available might be used to design manipulators. In your kit of parts, the manufacturer often has specific resources that will guide you in using their product. Many motors or actuators you might have available can have different purposes. Motors with high torque and low speed or revolutions per minute (RPM) are used for things like a robot arm where you might lift a lot of mass. You might want a high-speed motor with less torque to shoot a ball in other situations. In any design situation, a perfect combination of torque and speed will help your robot accomplish the task it is designed to do.
- When choosing a suitable actuator, you might have two choices. What motor do I use? What gearbox do I add to the motor to get the desired output for the job?
- The desired output is often expressed using free speed (RPM), RPM, and stall torque. Different gear ratios based on the original motor's input RPM and stall torque can achieve this desired output. Research the motors you have available for your kit of parts.

DESIGN AND PROTOTYPE:

- As you complete your research, keeping a table of the motors and available gearboxes that you can evaluate and use for different applications on your robot is valuable. Place a table similar to the following that can be a quick reference for your available parts, gear ratios, speed, and torque.
- Motor Data Table:

MOTOR PART	RATIO	STALL TORQUE	FREE SPEED RPM

Task 2: Real-World Interactions

DESIGN AND PROTOTYPE:

- After you have chosen the motor and/or gearbox that is the best combination of speed and torque for your motor, it is time to mount it to your robot. As you mount the motor, it is important to consider a few things we learned before:
  - Is the motor mounted securely?
  - Are the components that are supporting the motion of the motor secure?
  - Are you preventing a loss of motor power due to undesired friction?
- After you have mounted the motor, ensure you have added the motor to your hardware setup in your programming tools.

TEST AND IMPROVE:

- As you mount and test your motor with a manipulator, document the process and lessons learned. Details about spacing, gear ratios, and beginning placement of the motor or arm can be essential to success while testing. Record your testing results for your first trial.

Task 3: Improve Your Design

DESIGN AND PROTOTYPE:

- In the last activity, you designed an arm for your ball game robot based on the tasks that it needs to perform. What material did you imagine using while designing your ball game robot's arm? Industrial robot arms are made of metal with multiple motors and servos. Your robot's arm may be much simpler. When you are improving an arm or manipulator for your robot, consider the following:
  - Does your manipulator grab the ball?
  - Does it move to a position that easily enables you to score points?
  - How will you control each of the manipulators?
  - Do you need to use extra wires to reach each part of the robot?
  - What is needed in your programming tools to set up the additional actuators or motors you have added?

TEST AND IMPROVE:

- Testing and improving through iteration are important parts of the Engineering Design Process. You learn more about working with your parts through testing and identifying failure points or where the robot is not operating the way you intended. Take time to test and identify the areas where improvements should be made. This list of items to be improved can go into your next iteration cycle.

Reflection

- Is the manipulator operating efficiently?
- What can be done to improve its efficiency?
- What type of test can you create to determine if the efficiency is in programming or mechanical design?

Checkpoint

In your Engineering Notebook:

- Record your answers from the Getting Started section of the activity.
- Record your responses to the Engineering Notebook prompts in Tasks 1-3.
- Record your responses to the reflection questions.

Activity 5: Project Sprints

Driving Questions

- How can a project sprint help to improve iteration cycles?
- How does a project sprint help us keep track of tasks that need to be completed?
- How can project sprints help us improve teamwork and innovation?

What Will I Be Doing?

- I will learn about project sprints.
- I will create a task list for a project sprint.
- I will keep track of tasks and monitor their progress.

Getting Started

- In previous lessons, you have learned about *FIRST* Core Values, including teamwork and innovation. Sometimes, working in a team can be difficult. It is hard to communicate so that everyone knows what is going on, the progress of tasks, and what needs to be completed. There are many careers where project management skills are needed, even jobs in project management.
- The essence of project management is keeping the outcome and goals of a project on track. There are different methods you might use or have heard of. Different fields of study may have specific project management certifications you might get in that field.

WHAT'S NEXT?

- Gather your team.
- Grab your supplies (Engineering Notebook, robot, kit of parts, Pairing and Configuration Reference Guide, laptop, and gamepad).

HOW WILL I DO IT?

- In this lesson, you will research different types of project management and possible tools you might use to manage your project to ensure that the design process stays on track. You will then use the list of robot improvements from the last activity to conduct your project management sprint.

Task 1: Project Management Strategies

BRAINSTORM AND EXPLORE:

- In this activity, you will research different project management techniques and terminology used in many different industries. Most industries will use an agile project management style, from manufacturing to game design. The term agile represents quickness, lightness, and ease of movement. Project managers want agile techniques to help them complete their projects quicker; this doesn't mean it is a straight-line process. Developing projects is often very similar to the Engineering Design Process. It requires iteration and keeping track of what has been accomplished and what needs to be accomplished.
- Research the following project management techniques and record them in your Engineering Notebook:
  - Scrum
  - Waterfall
  - Kanban
  - Scrumban
  - Lean

DESIGN AND PROTOTYPE:

- After you have researched each type of project management technique, place your task list from the previous lesson into a template for the project management type.
- Discuss which method you think will work best for your team in managing the task needed for your robot.

Task 2: Improve, Improve, Improve

BRAINSTORM AND EXPLORE:

- Your ball game competition will be upon you in just a short amount of time. Now consider all you need to have done to meet your game strategy. Is your robot ready? Can you score the points you set out to score? Create the next cycle of objectives to be completed and use the project management techniques you learned in the last lesson so you can make as much progress on your robot as possible. Combining the Engineering Design Process and project management can help you get the most out of your time, resources, and your robot.

TEST AND IMPROVE:

- Complete the tasks and testing that are on your project management list and be sure to mark down your accomplishments. Include what tasks are done and what you have learned. Identify any challenges or roadblocks your team has and areas where you might need to gain additional knowledge from mentors to understand the problem better.

Reflection

- What project management tools did you learn about?
- What project management techniques were you able to use as a team while designing your robot?
- Explain how you could you apply project management skills to other aspects of your life.

Checkpoint

- In your Engineering Notebook:
- Record your research on project management.
- Record your responses to the prompts in the tasks.
- Record your responses to the reflection questions.