FIRST EDUCATION

Robotics Engineering Explorations *FIRST*® Education

FIRST® Robotics Engineering Explorations

Teacher Guide — Build and Program Manipulators

Unit 5

TABLE OF CONTENTS

Activity 1: Ball Grabber

Driving Questions

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

Objectives

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

Materials

Each team will need:

- Engineering Notebook
- Robot
- Kit of parts
- Laptop
- Gamepad
- Options for robot actuators

Getting Started

BEFORE THE START OF CLASS:

- Ensure each team's kit of parts has options for an actuator:
  - XRP
    - User Guide
  - *FIRST*® Tech Challenge – it is suggested that students use a 180-degree servo.
    - REV Programmable Servo
    - TETRIX® servo
  - *FIRST*® Robotics Competition
  - Servos are less common in *FIRST* robotics competitions. A common motor for smaller applications might include:
    - AndyMark – Snow Blower Motor
    - AndyMark – Everybot Intake 2022
- Programming links and tools for each team:
  - XRP
    - XRP – Users Guide – Arm
  - *FIRST* Tech Challenge
    - *FIRST* Tech Challenge Docs – Controlling a Servo Blocks
    - REV Duo Documentation – Servos
  - *FIRST* Robotics Competition
    - *FIRST* Robotics Competition WPILib – Motors – Servos
    - *FIRST* Robotics Competition WPILib GitHub – Encoder
    - *FIRST* Robotics Competition WPILib GitHub – Arm Subsystem
    - *FIRST* in Michigan – Virtual Robotics Studio – Programming in Teleop

DURING CLASS:

- Guide teams to look at their kit of parts.
- Research the types of motors and servos available.
- Consider how the motors and servos may be used to corral or move a ball for their ball game challenge.
- Guide teams to the programming and technical resources to learn more about their motors.

Student Tasks

TASK 1: PREPARING YOUR SERVO OR ACTUATOR

Design and Prototype:

- Students should draw out a design of how they would like to corral the ball on the ground using a small actuator such as a servo or smaller motor in driver-controlled mode. Students should consider their parts kit and how they might quickly assemble parts to test out a few ideas to see how they work. Students should draw out three easily executable ideas for corralling the ball.
  - XRP
    - XRP Discourse – Project Ideas
  - *FIRST* Tech Challenge Resources
    - REV Duo Documentation
    - REV Duo Documentation – Choosing an Actuator
    - *FIRST* Tech Challenge Docs – Controlling a Servo Blocks
  - *FIRST* Robotics Competition Resources
    - NASA Robotics Alliance Project (Motors page 60)
    - *FIRST* Robotics Competition WPILib – Using Motor Controllers
- Students should refer to their manufacturer's resources to ensure they have the supplies to mount their actuator to their robot. Students should utilize program resources to learn more about their 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 done entirely within your programming tools?
- When students have brainstormed and researched the problem of mounting their actuator, have them look at algorithms in their programming tools that will give them a good starting point to develop their final algorithm.

TASK 2: CONFIGURING AND TESTING AN ACTUATOR

Design and Prototype:

- Students will need to do lots of testing with their initial prototypes. See this guide from *FIRST* Robotics Competition on prototyping for helpful resources.
  - Team Resources – Prototyping
- Students have learned the importance of hardware setup in their programming tools. They should update their wiring diagram with where their actuator hardware is mounted and connected within their control system.
- Their programming tools ensure the hardware variables are declared with the correct data and within the proper code structure.
- Students should use an algorithm for the actuator to move in driver-controlled mode using the programming tools templates according to their design plan.

Test and Improve:

- Ensure students know to be ready to stop their program as a fail-safe if their robot is not operating currently.
- Please encourage students to gather data in their testing, such as start and stop angles, to compare that with their desired results.

TASK 3: BALL-GRABBING ROBOT

Design and Prototype:

- Students should mount their initial prototype as a ball grabber on the robot. Depending on your robot kit of parts, they may need to fabricate parts for mounting.
- Students should note any challenges and obstacles they overcame in their Engineering Notebook.
- Have them record any initial testing they did to overcome those obstacles.

Test and Improve:

- Students should practice collecting and trying to score balls with the actuator or servo using the ball game rules they created previously.
- Students should draw out any ideas they might have for improving the robot's ball handling after testing.

Guiding Questions

- What is an actuator and a servo?
- What parts do we need to attach to your servo to mount it onto your robot?
- What is the purpose of a wiring diagram? Why do you need to keep your wiring diagram up to date?
- How do you set up new hardware?
- How do you use a program?
- How does the sample program use variables? What are they? What do they do?

Teacher Reflection Questions

- What did my students learn during the Getting Started section of the activity?
- Do my students understand the purpose and function of an actuator?
- Were my students able to find all the pieces needed to attach their actuators?
- Could my students easily edit their programming to incorporate an actuator?

Student Artifacts

In their Engineering Notebook:

- Record their responses to the questions from the Getting Started section of the activity.
- Update their robot's wiring diagram to show the servo they've connected.
- Record their responses to the questions from Task 3.

Checkpoint

- Have students list all the parts needed to attach their actuator to the robot.
- Have students explain how to edit their robot's hardware setup.
- Ask students to explain the importance of an up-to-date wiring diagram.
- Ask students to explain how the sample program they used works.

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?

Objectives

- Students should improve their ball grabber design.
- Students will add additional improvements to make the design more efficient.
- Students will use conditionals to improve the automation of the mechanism using a touch sensor or limit switch.

Materials

Each team will need:

- Engineering Notebook
- Robot
- Computer
- Gamepad
- Paper
- Tape

Getting Started

BEFORE THE START OF CLASS:

- Identify sensors available for your students to use in their parts kit.
- Step up deadlines for testing and improvement.
- Provide resources for programming sensors such as touch sensors or limit switches.

DURING CLASS:

- Students will identify ways they can improve their robot performance with additional sensors using specific motor positions, limit switches, or a touch sensor.
- They will learn to operate a motor to a specific position using a button on the joystick.

Student Tasks

TASK 1: PUSH A BUTTON, SPIN A SERVO

Brainstorm and Explore:

- Students should use brainstorming skills to consider improving their algorithms' capabilities using variables and logic.

Design and Prototype:

- Before students begin programming, they should create a pseudocode. Consider having students act out the code and think through it.
- Students will need links to the resources below to develop their code in their programming tools.
  - XRP
    - XRP Users Guide
  - *FIRST* Tech Challenge
    - *FIRST* Tech Challenge Docs – Controlling a Servo Blocks
  - *FIRST* Robotics Competition Resources
    - *FIRST* Robotics Competition WPILib – Basic Programming – Joystick
    - *FIRST* Robotics Competition WPILib – Examples – Motor Control
    - *FIRST* Robotics Competition WPILib – Examples – Relay

Test and Improve:

- Students should focus on the following questions to help them improve their algorithms:
  - 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:

- In this lesson, students will practice Core Values and *Gracious Professionalism®* and *Coopertition®* by collaborating with another group on their algorithms. They will share their algorithms with another group and discuss the differences and how they have overcome obstacles.
- They will build on each other's knowledge to see if they can improve the efficiency of their algorithms and robot performance.

Test and Improve:

- Students should record each trial and determine if they are continuing to make progress in the Engineering Design Process to meet their design criteria.

TASK 3: AUTONOMOUS ACTUATOR

Brainstorm and Explore:

- In this lesson, students will evaluate their algorithms to ensure they continue to improve feedback and control.
- Students may have previously used time as part of the process of their algorithm. Time often can decrease efficiency and be unreliable.

Design and Prototype:

- Students should develop pseudocode before developing the algorithms in their program.
- They should consider using sensors and variables to improve the feedback process and increase reliability.

Test and Improve:

- Students should record their data and test the effectiveness of their algorithms.

Suggested Extensions/Modifications

- Extension: Control your servo using your gamepad's x, y, a, and b buttons.
- Extension: Control your servo with the triggers and bumpers on your gamepad.
- Extension: Control your servo with the x-axis of one gamepad stick and the y-axis of the other.
- Modification: Instead of creating a new OpMode in the first task, copy the OpMode you used in the last activity.

Guiding Questions

- How were you able to 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?

Teacher Reflection Questions

- Can my students create programs that control a servo using a gamepad?
- Are my students able to develop autonomous programs that control a servo?
- Do my students understand the range of input values their servo can understand?
- Were my students able to create functional programs for each task?
- Were my students able to use math blocks to control the range of their gamepad's stick output values?

Student Artifacts

In their Engineering Notebook:

- Record their answers to the questions from Tasks 1–3.
- Record the programs they created in Tasks 1–3.

Checkpoint

- Ask teams to explain the algorithms for their actuators.
- Ask teams to explain why they changed the output range for their gamepad's sticks.

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?

Objectives

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

Materials

Each team will need:

- Engineering Notebooks
- Pens or pencils
- Laptop or smart device for Internet research

Getting Started

BEFORE THE START OF CLASS:

- Ensure all teams have their Engineering Notebooks ready.
- Prepare resources for teams to research robotic arms. Teams can use the Internet, or you can prepare materials for them before class.
- Spend some time researching robotic arms to prepare for class discussions.

DURING CLASS:

- Teams will be investigating robotic arms through research.
- Teams should discuss how they see their ball game robot interacting with the world around them.
- Students will explore the topics of torque and power and why they are relevant to robot arms.
- In the Getting Started section of the student activity, teams are introduced to robotic arms through three examples: the robotic arms on a Mars rover, manufacturing robots, and manufacturing processes. Students are likely familiar with robotic arms but may not understand how they perform tasks. Ask teams to think about how their arms function and how they use them to perform basic tasks. Teams should understand that an arm contains joints and an end effector that interacts with other objects.

Student Tasks

TASK 1: RESEARCH

Identify the Problem:

- Teams will start this activity by investigating the common subsystems you might find on *FIRST* robots.
- Researching the three subsystems, such as a lift, intake, or shooter, will help students understand common subsystems they might find on the robot.
- Teams should focus on the design of each of the subsystems as they conduct their research.
- Prompt teams to consider the Engineering Design Process used in this course as they consider how their research arms were designed.
- Teams will use the internet or the materials you've prepared before class to research the arms covered in the Getting Started section.
- Each arm is a subsystem for a different purpose. Teams should identify each subsystem's purpose as they conduct their research.
- After researching each subsystem, teams will answer questions and create labeled sketches of each subsystem.

TASK 2: REAL-WORLD INTERACTIONS

Identify the Problem:

- Each team designed their ball game robot on the game they designed.
- Teams have had time to think about electronic components such as motors and sensors but have yet to investigate ways a robot can interact with its environment to solve the ball game challenge.
- Before moving forward, teams should look back at their initial designs for their ball game robots and consider how they imagined they would interact with the world.
- Before teams think about subsystems for their ball game robot, they must identify precisely how their robot would need to interact with the game elements.

Design and Prototype:

- Teams should reflect on their notes on their ball game robot to reacquaint themselves.
- Teams might have new ideas for their ball game robot's design or methods for scoring more points. If teams want to update their design, they may do so in the next task.
- Teams should discuss a few possible methods for their ball game robot to interact with the field and game elements.
- In the next task, teams will design a manipulator for their ball game robot. In this task, their goal is to understand what that manipulator and subsystems need to do.

TASK 3: PROTOTYPING AN ARM

Design and Prototype:

- Now that teams have additional ideas about their ball game robot, it is time for them to bring concepts to life by prototyping.
- Teams will work with the Engineering Design Process they used in the earlier units.
- Teams should look back in their Engineering Notebook for their notes on the Engineering Design Process before using quick materials to develop a proof of concept to improve their design ideas.
- You may need to provide additional materials such as cardboard, wood, or other craft supplies that will enable them to develop a proof of concept quickly.
- If you have items such as cordless drills, they can sometimes be used to test a concept without the time it might take to build and program a subsystem fully.
- Teams should also look back at their initial ball game robot design to decide if there is more than one subsystem they would like to prototype.

Test and Improve:

- After students have developed a proof of concept, it is time for them to test it.
- Students should consider what data they can collect in the process to use that data to make decisions on their final products.

Guiding Questions

- How can we do more complex actions with our ball game robot?
- What is the purpose of a robotic subsystems?
- How is a robotic arm similar to a human arm?
- How are they different from a human arm?
- How would your ball game robot interact with its the game elements and field while working to solve your community problem?
- Would your ball game robot be able to do its job without a robotic arm or other subsystems?
- Now that you've worked with a robot, can you think of any design improvements you could make to your original ball game robot design?
- How would engineers use the Engineering Design Process to design the three arms you researched in Task 1?

Suggested Extensions/Modifications

- Extension: Ask teams to find examples of robotic arms other than the ones mentioned in the Getting Started section of their activity.
- Extension: Ask teams to redesign their community robot to include two types of sensors, at least two servos, and a robotic arm.
- Extension: Ask teams to find a way to solve their community problem without using a robotic arm.
- Modification: Present teams with some information about robotic arms rather than asking them to research the arms themselves.
- Ask teams with similar community problems to work together to design a robotic arm.

Teacher Reflection Questions

- Were my students engaged with the examples of robotic subsystems outlined in the Getting Started section of their activity?
- Were my students able to research robotic subsystems effectively?
- Were my students able to make meaningful connections between their research on subsystems and their design for their ball game robot?

Student Artifacts

In their Engineering Notebook:

- Record their answers to the questions from the Getting Started section and Tasks 1–3 in this activity.
- Sketch each of the arms they researched in Task 1.
- Sketch the arm they designed for their community robot in Task 3.
- If teams updated the design of their community robot, they should sketch the new design.

Checkpoint

- Do my students understand the importance of robotic arms?
- Were my students able to research robotic arms effectively?
- Were my students able to apply their research from Task 1 to their work in Task 2 and Task 3?
- Did my students make meaningful improvements to their community robot?
- Would the robotic arm my students designed effectively assist their community robot in addressing their community problem?

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?

Objectives

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

Materials

Each team will need:

- Engineering Notebook
- Kit of parts
- Robot
- Laptop or smart device for Internet research
- Manipulator supplies

Getting Started

BEFORE THE START OF CLASS:

- Ensure teams have their kit of parts ready.
- Teams will choose the suitable actuators and manipulators for their design. Plan accordingly, knowing which parts you have that you might be able to guide students to use.
- Helpful resources for understanding how to constrain motion and support motion:
  - REV Duo Documentation – Supporting Motion
  - REV Duo Documentation – Constraining Motion

DURING CLASS:

- Teams will start researching types of motors and the amount of torque, speed, and power required.
- They will learn the basics of motors used on *FIRST* robots and their different applications.
- While teams will not build their arm until the next activity, they may need to modify the robot they've been using to ensure adequate support for their manipulators.
- In the Getting Started section of the student activity, teams are asked to apply principles of torque and speed to choose the suitable motor for the subsystems they are designing. Choosing the best motor and gearbox combination for the job can mean the difference between a mechanism working well or not.

Student Tasks

TASK 1: RESEARCH

Brainstorm and Explore:

- In this activity, students will research to determine their motors' capabilities. You will want to have the specific motors they identified in the previous scavenger hunt and any other links they might need. The manufacturer of the motor will have the details students are looking for under the specifications of the motor.
  - XRP – The motor data for XRP motors is somewhat limited. Utilize the Sparkfun and Discourse sites to look for any available motor data.
    - XRP Discourse Group – Robot Hardware
    - Sparkfun – XRP Product Site
    - Note: Many *FIRST* Tech Challenge Competition motors are usable in *FIRST* Robotics Competition; however, *FIRST* Robotics Competition motors are not legal for *FIRST* Tech Challenge Competition.
    - REV Duo Documentation – Choosing and Actuator

- *FIRST* Tech Challenge
  - [REV Duo Documentation – HD Hex Motor]
  - [REV Duo Documentation – Core Hex Motor]
  - [Pitsco – TETRIX MAX TorqueNADO® Specification]
- *FIRST* Robotics Competition
  - [REV – NEO 550 Brushless Motor Data Sheet]
  - [AndyMark – CIM Motor Data Sheet]
  - [AndyMark – CIM Sport Gearbox]
  - [AndyMark 775 RedLine Motor]
  - [AndyMark – Snow Blower Motor]

Design and Prototype:

- As students complete their research, keeping a table of the motors and available gearboxes that they can evaluate and use for different applications on their robot is valuable. Students should place a table similar to the following to reference their 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:

- Students will mount their motors to the manipulator they designed – plan for time for them to mount and need to make corrections. Guide students with the following questions for reinforcement.
  - 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?
- Ensure that students use their programming tools to understand how to add the motors to their programming environment.

Test and Improve:

- As students mount and test their motor skills with a manipulator, ensure that they 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. Be sure they record their testing results.

TASK 3: IMPROVE YOUR DESIGN

Design and Prototype:

- In the last activity, students designed an arm for their ball game robot based on the tasks that it needs to perform. In this activity, they will continue to develop their manipulator or arm. Guide students in their design process with the following questions:
  - 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 essential parts of the Engineering Design Process. Students will learn more about working with their 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 need to be made. Students will use the list to make improvements in their next iteration cycle.

Guiding Questions

- 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?

Suggested Extensions/Modifications

- Extension: Encourage teams to use at least two gears in their arm's design.
- Extension: Ask teams to consider using both servos in the grabber portion of their arm.
- Modification: Teams may want to rebuild their robot based on the example given in the resources. If they are going to rebuild their robot, encourage them to keep track of their robot's parts as they disassemble and reassemble.

Teacher Reflection Questions

- Do my students understand how motors function and provide torque and speed?
- Are teams able to find the parts they could use to build a manipulator?
- Do teams understand how gears could be used to construct their arm?
- Can teams design an arm using the parts they found in their kit?
- Will my students be able to mount their arms onto their robots in the next activity?

Student Artifacts

In their Engineering Notebook:

- Record their answers to the questions in the Getting Started portion of the activity.
- Record their answers to the questions from Task 1.
- List all the parts they decided to use in their arm during Task 2.
- Sketch the arm they've built and label all the parts they've used.

Checkpoint

- Were my students able to understand the construction of a robotic arm in terms of the steps in the Engineering Design Process?
- Did my students find relevant information while researching their motors?
- Were my students able to identify parts from their kit that they could use to build an arm?
- Were my students able to build an arm for their robot?
- Are my students prepared to mount their arms onto their robots in the next activity?

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?

Objectives

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

Materials

Each team will need:

- Engineering Notebooks
- Laptop
- Robot
- Kit of parts
- Gamepad
- Pairing and Configuration Reference Guide

Getting Started

BEFORE THE START OF CLASS:

- Ensure that all teams have their Engineering Notebooks ready.
- Research different types of project management become familiar with project management styles.

DURING CLASS:

- Students will learn about different project management types and styles and how they are used in the business industry.
- They will determine a method that suits them best for managing their tasks and improving their robot performance.
- In the Getting Started portion of the student activity, students reflect on FIRST Core Values and how teamwork is essential for working on a team to solve problems. Project management can be essential to improving teamwork and team communication skills.

Student Tasks

TASK 1: PROJECT MANAGEMENT STRATEGIES

Brainstorm and Explore:

- In this activity, students will research different project management techniques and terminology used in many 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 project quicker. This doesn't mean that it is a straight-line process. Developing projects is very similar to the Engineering Design Process. It requires iteration and keeping track of what has been accomplished and what needs to be accomplished.
- Students will research the following project management techniques and record them in their Engineering Notebook:
  - Scrum
  - Waterfall
  - Kanban
  - Scrumban
  - Lean

Design and Prototype:

- Teams should choose a method for managing their projects and tasks from the research they completed.

TASK 2: IMPROVE, IMPROVE, IMPROVE

Brainstorm and Explore:

- In the previous lesson, students learned about and chose a project management tool to manage their tasks. In this lesson, they will practice project management techniques to improve their robot. This iteration is designed with more pressure to accomplish deadlines quicker as their ball game robot competition is fast approaching.

Test and Improve:

- Students should complete their tasks on their project management list and ensure they mark down their accomplishments. Students should include their tasks, what they have learned, and any challenges or roadblocks. Students may start to identify areas where they might need to gain additional knowledge from mentors to understand the problem more.
- At this point, you could offer students an extended amount of time to improve their robots through the iteration cycle and using project management. This can take as long as you have planned before their competition.

Suggested Extensions/Modifications

- Extension – Ask teams to pick previous projects and activities and break down how they would handle them differently with project management techniques.
- Extension – Ask students to list professions that would require project management certification.

Teacher Reflection Questions

- What project management tools did students learn about?
- What project management techniques did the teams use while designing their robots?
- Did the students explain how they could apply project management skills to other aspects of their lives?

Student Artifacts

In their Engineering Notebook:

- Record their research on project management.
- Record their responses to the prompts in the tasks.
- Record their responses to the reflection questions.

Checkpoint

- Were students able to do research of project management?
- Were students able to apply project management techniques as a team?