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Build a Zippy Line-following Robot (BlueBot Project #3)

https://www.sciencebuddies.org/science-fair-projects/project-ideas/Robotics_p023/robotics/line-following-robot (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Robotics_p023/robotics/line-following-robot)

PDF date: 2019-12-03

Experimental Procedure

Note: This engineering project is best described by the **engineering design process,** as opposed to the **scientific method.** You might want to ask your teacher whether it's acceptable to follow the engineering design process for your project before you begin. You can learn more about the engineering design process in the Science Buddies Engineering Design Process Guide (http://www.sciencebuddies.org/engineering-design-process/engineering-design-process-steps.shtml).

Assembling Your BlueBot Chassis

1. Follow the instructions in the video to assemble your robot chassis.
   a. Note that your kit does come with printed directions for assembling the chassis, but we recommend watching the video so you fully understand how all the parts fit together.
   b. Note that we recommend using double-sided foam tape to attach the battery holder to the top of the chassis, as shown in Figure 5. The printed directions recommend putting the battery holder in-between the two chassis plates, but this makes it harder to change the batteries.

https://www.youtube.com/watch?v=SBeGl_IgWwY (https://www.youtube.com/watch?v=SBeGl_IgWwY)

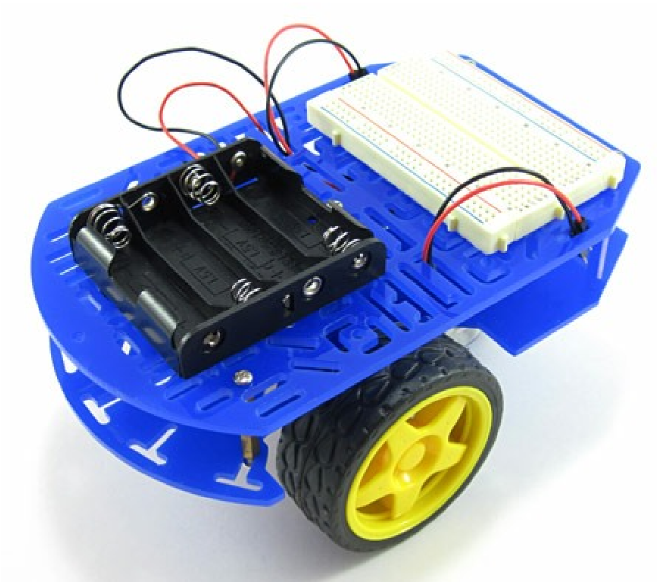


Figure 5. A completed BlueBot chassis with breadboard and battery pack on top.

Assembling Your Circuit

If you purchased your kit before December 2, 2019, use these instructions (https://www.sciencebuddies.org/Files/14079/4/Robotics_p023-Procedure-2018-09-10.pdf) to complete your assembly.

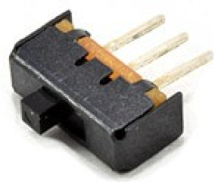
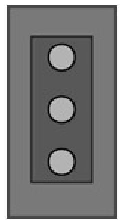
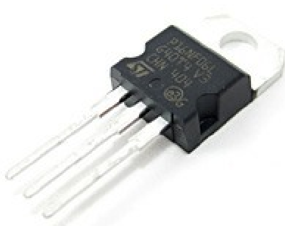
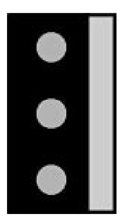
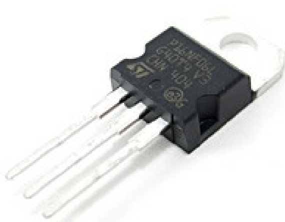
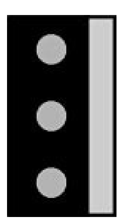
1. To build your circuit, you will need to know how to use a breadboard. Watch the video and see the Science Buddies reference How to Use a Breadboard (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-breadboard).

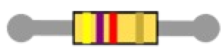
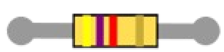
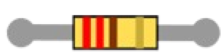
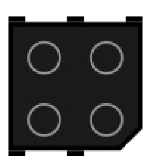
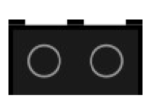
https://www.youtube.com/watch?v=6WReFkfrUIk (https://www.youtube.com/watch?v=6WReFkfrUIk)

2. Now that you know how to use a breadboard, you are ready to assemble your BlueBot circuit. Table 2 shows a list of all the components in the circuit and where they go on the breadboard. You can download and print a PDF (https://www.sciencebuddies.org/science-fair-projects/Robotics_p023-table2-checklist.pdf) of this table—complete with checkboxes to track each step—to use while you are building your robot. You can also view a slideshow (#breadboard-slideshow) that shows breadboard diagrams of the circuit. Follow along in the table and/or slideshow to build your circuit one component at a time. Your finished circuit should look like the one in Figure 6 (#figure6).

Pay attention to these notes:

a. Remember to push all components *firmly* into the breadboard.
b. All references to orientation (up, down, left, and right) assume you have the breadboard "right-side up," so the writing is facing you.
c. Your jumper wire kit comes with an assortment of colors, and the colors may vary. It does not matter what color jumper wires you use. Your colors do *not* need to match the colors in the diagrams.
d. You will use male-female jumper wires to connect the IR sensors to the breadboard. These wires act like "extension cords" that allow you to attach the sensors to the front of your robot, so they can look down at the ground in front of the robot. You *do* need to keep track of the wire colors when connecting the IR sensors, since you need to connect the four pins in the right order.
e. Insert the batteries *last*. If you see or smell smoke when you insert the batteries, you have a short circuit somewhere. Immediately remove the batteries and recheck your wiring.

Component	Picture	Symbol	Breadboard holes	Note
Power switch			F1, F2, F3	Direction in which it is facing does not matter, but make sure to slide switch down (toward row 30, away from row 1), this is the "off" position.
Jumper wire			J2 to (+) bus	Color does not matter.
Jumper wire			Left side (+) bus to right side (+) bus	Color does not matter.
Jumper wire			Left side (-) bus to right side (-) bus	Color does not matter.
MOSFET			C11, C12, C13	Writing should face to the left, large silver tab should face to the right. Note: the writing on your MOSFET might not match the picture exactly. This is OK.
MOSFET			C18, C19, C20	Writing should face to the left, large silver tab should face to the right. Note: the writing on your MOSFET might not match the picture exactly. This is OK.
				

Component	Picture	Symbol	Breadboard holes	Note
Jumper wire			A13 to (-) bus	Color does not matter.
Jumper wire			A20 to (-) bus	Color does not matter.
Diode			A12 to (+) bus	Gray band must face to the left. Optional: Shorten the leads.
Diode			A19 to (+) bus	Gray band must face to the left. Optional: Shorten the leads.
4.7k Ω resistor			A11 to (-) bus	Direction does not matter. Make sure you pick the right color bands! (yellow, purple, red, gold)
4.7k Ω resistor			A18 to (-) bus	Direction does not matter. Make sure you pick the right color bands! (yellow, purple, red, gold)
220 Ω resistor			A5 to (+) bus	Direction does not matter. Make sure you pick the right color bands! (red, red, brown, gold)
220 Ω resistor			A25 to (+) bus	Direction does not matter. Make sure you pick the right color bands! (red, red, brown, gold)
Top IR sensor			Black wire to (-) bus Red wire to (+) bus Blue wire to B5 Green wire to B11	There is a *small* notch in one corner of the black plastic case. Place notch in bottom right with pins facing you. Counter-clockwise from the top left, connect blue, black, green, and red wires.
Bottom IR			Black wire to (-) bus Red wire to (+) bus	There is a *small* notch in one corner of the black plastic case. Place notch in bottom right with pins

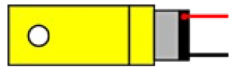
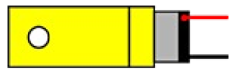
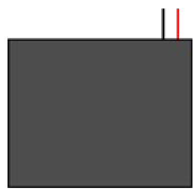
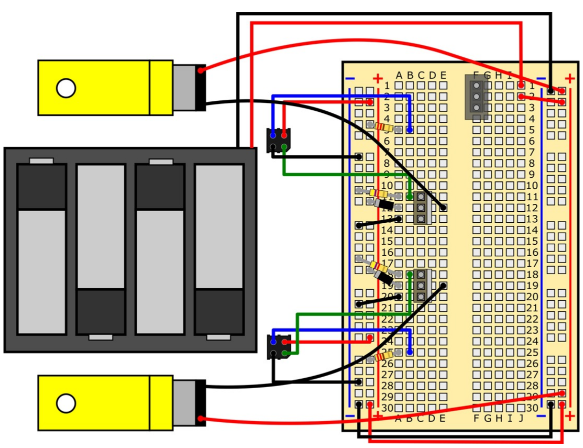
Component	Picture	Symbol	Breadboard holes	Note
sensor			Blue wire to B25 Green wire to B18	facing you. Counter-clockwise from the top left, connect blue, black, green, and red wires.
Top motor			Red lead to (+) bus Black lead to E12	When the robot is driving forward, this is the "right" motor.
Bottom motor			Red lead to (+) bus Black lead to E19	When the robot is driving forward, this is the "left" motor.
Battery holder			Red lead to J1 Black lead to (-) bus	Do not insert batteries until circuit is complete.
AA battery			N/A	Insert into battery holder. Make sure (+) signs on batteries line up with (+) signs in battery holder.

Table 2. List of circuit components and locations. A printable PDF version (https://www.sciencebuddies.org/science-fair-projects/Robotics_p023-table2-checklist.pdf) is available.



Slideshow with step-by-step instructions viewable online.

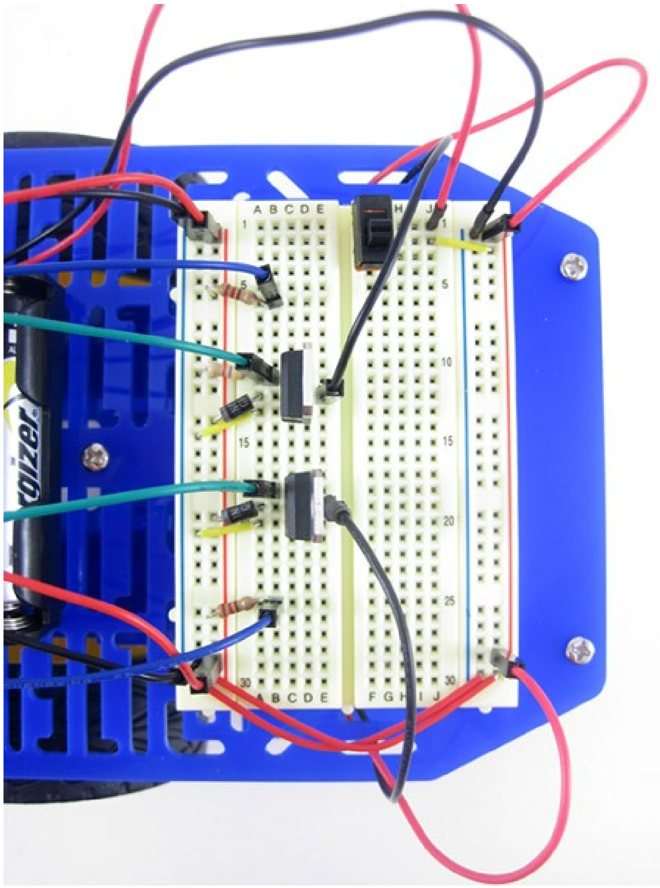


Figure 6. Your completed circuit should look like this.

3. Use popsicle sticks or building toys like LEGOs or K'nex to mount the IR sensors to the front of your robot, as shown in Figure 7. Use double-sided foam tape to attach the sensors and do *not* permanently glue them in place yet, as you may need to adjust them later. The sensors should be about 2 cm apart and 1 mm off the ground. Adjusting the exact position of the sensors to get your robot working will be part of the engineering design process.

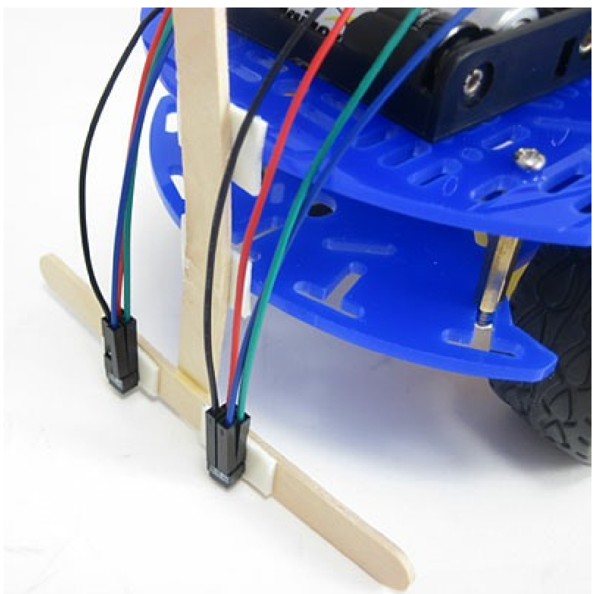


Figure 7. Sensors mounted to the front of the robot using double-sided foam tape and popsicle sticks.

Testing Your Robot

You are finally ready to start testing your robot! Remember that now you will need to follow The Engineering Design Process (http://www.sciencebuddies.org/science-fair-projects/engineering-design-process/engineering-design-process-steps) to get your robot working. Follow these steps to learn how to use your robot.

1. Double-check your circuit against the breadboard diagrams in the previous section. Remember that just *one* misplaced wire can prevent the circuit from working properly.
2. Hold the robot's chassis in one hand, so the wheels are off the ground and the IR sensors are up in the air (not close to any surface).

a. Turn the robot's power switch "on" by sliding it up, toward row 1 on the breadboard.
b. One at a time, hold a piece of white scrap paper in front of each of the IR sensors. Slowly move the paper toward the sensor until it is almost touching. This should cause the wheel on that side of the robot to start spinning. Check Table 3 to see what you should do next.

Observation	What to Do
I see or smell smoke.	Immediately turn your robot off. You have a short circuit somewhere. Recheck your wiring against the breadboard diagrams in the previous section.
Each wheel spins forward when I hold a piece of white paper in front of the IR sensors.	Your robot works! Move on to the next step.
One or both wheels spin backwards when I hold a piece of white paper in front of the IR sensors.	Reverse the red and black wires of the motor if the wheel is spinning backwards.
The wheels do not spin at all when I hold a piece of white paper in front of the IR sensors.	You have an error somewhere in your circuit. Go back and double-check your wiring against the breadboard diagrams. Be especially careful that you connected the IR sensors correctly.
The wheels still do not spin at all even when I double check my wiring.	See the Help (#help) section for more detailed troubleshooting information.

Table 3. Troubleshooting procedure for the first time you turn on your robot.

3. Turn your robot off for now. For your first test, you will see if it can follow a straight line.
   a. Create a straight line on a piece of white posterboard using a thick black marker or electrical tape, as shown in Figure 8.
   b. Place your robot down at one end of the line, with the IR sensors straddling either side of the line.
   c. Turn the robot on. It should drive forward and stay over the line. You may notice that if it starts drifting to one side, it corrects itself and turns back toward the line.
   d. If your robot does *not* stay over the line, you may need to adjust the IR sensors. This is where the engineering design process comes in, because there is no single "right answer." A general rule of thumb is that the sensors should be as far apart as your line is thick (for example, 2 cm apart if you draw a 2 cm thick line with a permanent marker), and about 2–3 mm off the ground. However, the exact distances can depend on things like lighting in the room (sunlight contains some infrared light, which can affect the sensors) and the surface you are using (some posterboard has a "glossy" surface, which is more reflective than posterboard with a "matte," or dull, surface). So, you may need to adjust the sensor spacing until you can get your robot to work.
   e. You can test how well your sensors are working by holding your robot just above the paper (so the wheels are not touching the ground). When you hold the sensors over the white paper, the wheels should spin forward. When you hold them over the black line, the wheels should stop.

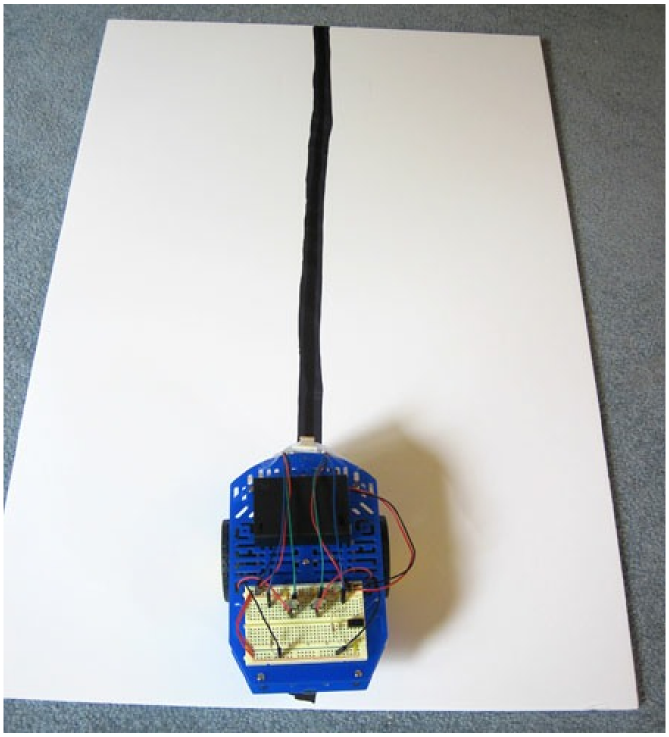


Figure 8. A straight line to test your robot's line-tracking abilities.

4. Now see if your robot can follow a curved line. Create a line with some *gradual* curves like the one in Figure 9. Your robot will not work well with very tight curves or angles. Test to see if your robot can follow the curved line. Can it make the turns, or does it "overshoot" the turns and drive off the track? If your robot overshoots the curves, the easiest thing to try is to *make the line thicker*. This will make it harder for the robot to drive over the line without one wheel stopping. See Table 4 for

more troubleshooting suggestions if your robot will not follow a curved line.

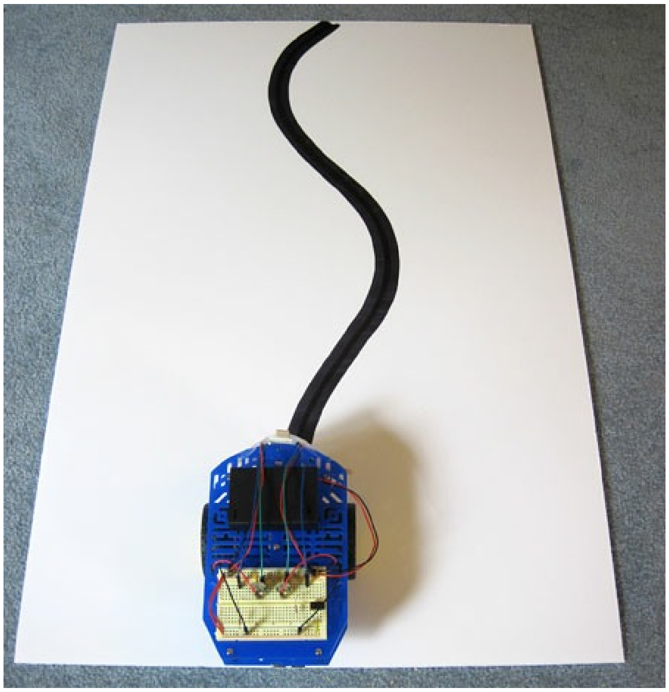


Figure 9. A simple curved line for your robot to follow.

Observation	What to Do
My robot can follow curved lines.	Your robot works! Move on to the next step.
My robot overshoots curved lines and drives off the track.	Try making the line thicker, or make more gradual curves. This will make it harder for the robot to drive over the line without one wheel stopping.
My robot still overshoots turns even when I make the line thicker or make the curves more gradual.	You need to slow your robot down. Go to the Troubleshooting (#troubleshooting) section.

Table 4. Troubleshooting for getting your robot to follow curved lines.

5. Once your robot can follow basic straight and curved lines, you can piece these together to make a larger track, like the one in Figure 10. How complicated of a track can your robot follow? How many "laps" can it complete before it drives off the track? If you run into trouble getting your robot to follow the line, check out the Troubleshooting (#troubleshooting) section.

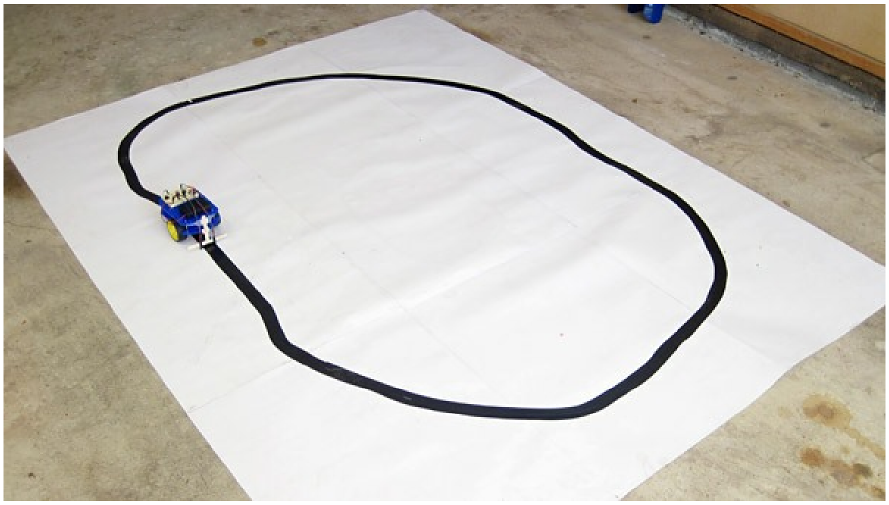


Figure 10. A complete track for a line-following robot.

Troubleshooting: My robot will not follow the line!

One of the most common problems with the line-following robot is that it goes too fast to make turns. It will drive right over the black line and just keep going! If you have space to make a very large track with very gradual turns, this might not be a problem. But, if you have limited space and have to make a track with tighter turns, you might need to slow your robot down. You can do this by supplying less voltage to the motors, which makes them spin slower. To do this, you need to swap out the battery pack *and* two of the resistors in your circuit.

1. Replace the 4xAA battery back with the 3xAA battery pack that is included in your BlueBot kit, as shown in Figure 11. AA batteries provide 1.5 volts (V) each. So, four AA batteries provide 6 V to the motor, while 3 AA batteries only provide 4.5 V. This lower voltage will make the motors slow down.

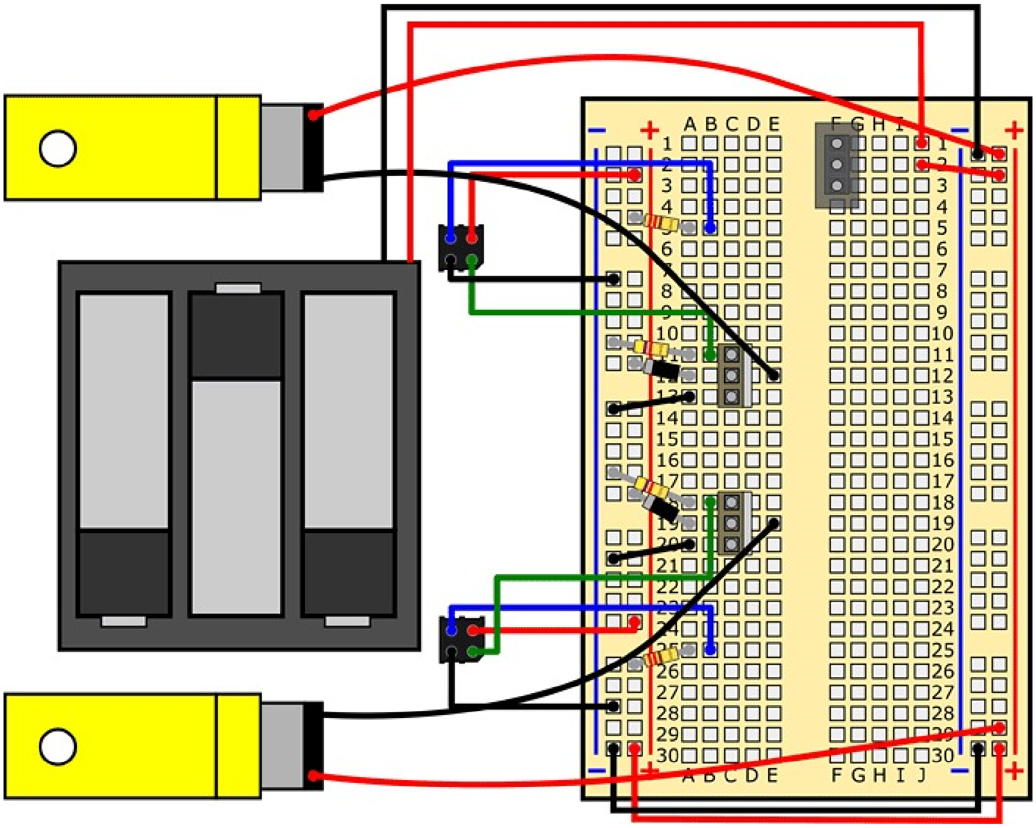


Figure 11. Replace the 4xAA battery pack with the 3xAA battery pack.

2. Replace the 220 Ω resistors (red, red, brown, gold) with 150 Ω resistors (brown, green, brown, gold), as shown in Figure 12.
    a. These are the "current limiting resistors" for the IR LED in the IR sensor. Since you are decreasing the supply voltage to the LED, you also need to decrease the value of the current limiting resistor. Do an internet search for "LED resistor" if you want to learn more about this topic.

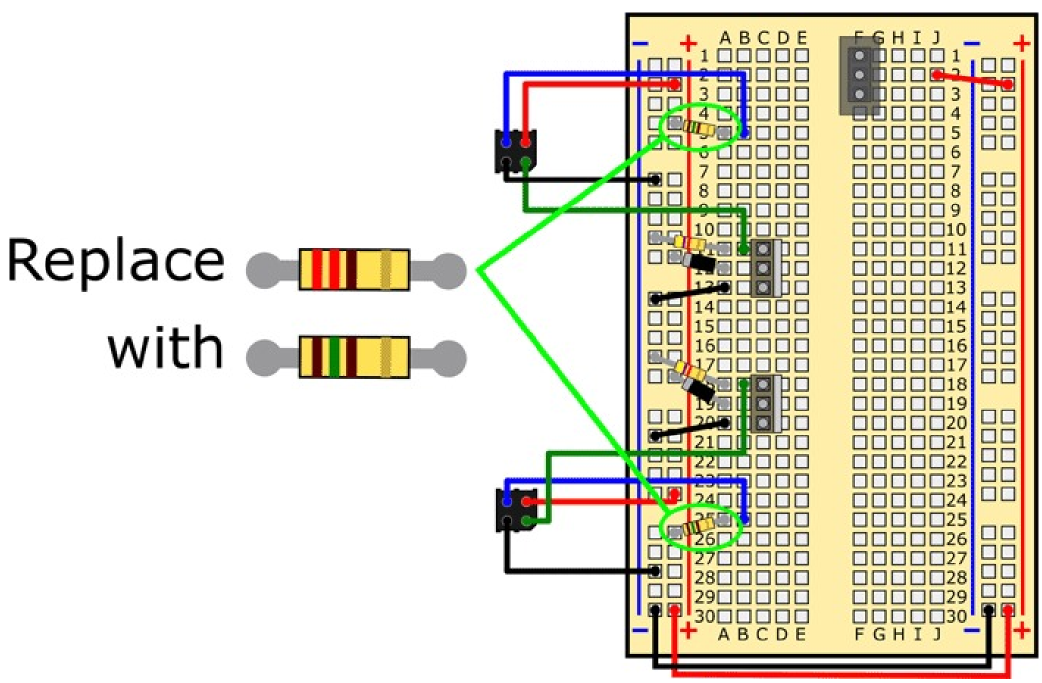


Figure 12. Swap out the 220 Ω resistors for 150 Ω resistors (circled in green).

3. Test your robot again. It should move slower and have an easier time making turns. If it still overshoots turns, remember that you should also try making the line

thicker.

4. Advanced: If your robot is *still* going too fast, you can try slowing it down even more by decreasing the voltage to 3 V. Your BlueBot kit does not include a 2xAA battery pack, so to do this, you will have to remove a battery from the 3xAA pack, and then "short out" one of the connections using a jumper wire, as shown in Figure 13.

Figure 13. To reduce the battery voltage to 3 V, you need to remove one battery from the 3xAA battery holder and insert a jumper wire in its place.

5. Your kit does not include any resistors smaller than 150 Ω. To decrease the current-limiting resistance, you will need to add two *more* 150 Ω resistors next to the two that are already in your circuit, as shown in Figure 14.
    a. This is called putting resistors "in parallel," and it actually *decreases* the total resistance. To learn more about this topic, do an internet search for "resistors in series and parallel."

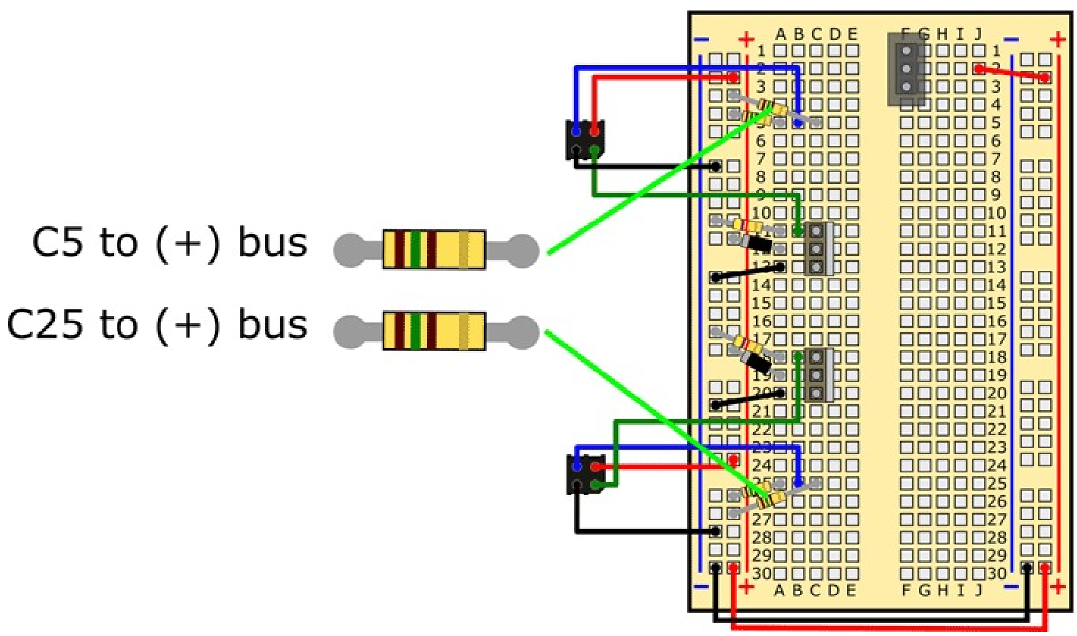


Figure 14. Add two more 150 Ω resistors in parallel to the first two in order to decrease the current-limiting resistance for each LED when the batteries are only supplying 3 V.

6. Test your robot again. It should move much more slowly.

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If you like this project, you might enjoy exploring these related careers:

(http://www.sciencebuddies.org/science-engineering-careers/engineering/robotics-engineer)

Robotics Engineer (http://www.sciencebuddies.org/science-engineering-careers/engineering/robotics-engineer)

Have you watched "The Transformers" cartoon series or seen the "Transformers" movies? Both shows are about how good and evil robots fight each other and the humans who get in the middle. Many TV shows and movies show robots and humans interacting with each other. While this is, at present, fantasy, in real life robots play a helpful role. Robots do jobs that can be dangerous for humans. For example, some robots defuse landmines in war-stricken countries; others work in harsh environments like the bottom of the ocean and on the planet Mars. At the heart of every robot is a robotics engineer who thinks about what a robot needs to do and works with several engineering disciplines to design and put together the perfect piece of equipment. Read more (http://www.sciencebuddies.org/science-engineering-careers/engineering/robotics-engineer)

(http://www.sciencebuddies.org/science-engineering-careers/engineering/robotics-technician)

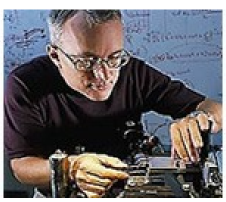
Robotics Technician (http://www.sciencebuddies.org/science-engineering-careers/engineering/robotics-technician)

Robots are no longer futuristic machines. Robots are here and now and are used in manufacturing, health care, service industries, and military applications. They perform tasks that are repetitive and hazardous—things that humans don't want to do or are unsafe to do. But robots are still machines, which means they require humans to build, maintain, program, and keep them functioning efficiently. Robotics technicians work with robotics engineers to build and test robots. They are responsible for installing and maintaining robots and keeping them in working order for their employers. If you are interested in working with robots, your future is here and now. Read more (http://www.sciencebuddies.org/science-engineering-careers/engineering/robotics-technician)

(http://www.sciencebuddies.org/science-engineering-careers/engineering/electrical-electronics-engineer)

Electrical & Electronics Engineer (http://www.sciencebuddies.org/science-engineering-careers/engineering/electrical-electronics-engineer)

Just as a potter forms clay, or a steel worker molds molten steel, electrical and electronics engineers gather and shape electricity and use it to make products that transmit power or transmit information. Electrical and electronics engineers may specialize in one of the millions of products that make or use electricity, like cell phones, electric motors, microwaves, medical instruments, airline navigation system, or handheld games. Read more (http://www.sciencebuddies.org/science-engineering-careers/engineering/electrical-electronics-engineer)



(http://www.sciencebuddies.org/science-engineering-careers/engineering/mechanical-engineer)

Mechanical Engineer (http://www.sciencebuddies.org/science-engineering-careers/engineering/mechanical-engineer)

Mechanical engineers are part of your everyday life, designing the spoon you used to eat your breakfast, your breakfast's packaging, the flip-top cap on your toothpaste tube, the zipper on your jacket, the car, bike, or bus you took to school, the chair you sat in, the door handle you grasped and the hinges it opened on, and the ballpoint pen you used to take your test. Virtually every object that you see around you has passed through the hands of a mechanical engineer. Consequently, their skills are in demand to design millions of different products in almost every type of industry. Read more (http://www.sciencebuddies.org/science-engineering-careers/engineering/mechanical-engineer)

Variations

- There are three other projects you can do with your BlueBot kit. Since you have already assembled your chassis, all you need to do is build a new circuit.
  - Build a Speedy Light-Tracking Robot (BlueBot Project #2) (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Robotics_p022/robotics/light-following-robot)
  - Build a Motion-Activated Guard Robot (BlueBot Project #1) (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Robotics_p024/robotics/guard-robot)
  - Build an Obstacle-Avoiding Robot (BlueBot Project #4) (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Robotics_p028/robotics/obstacle-avoiding-robot)
- A "bristlebot" is a small robot that uses vibration motors instead of geared DC motors, and toothbrush heads instead of wheels. You can put the same circuit you used in this project on a bristlebot to build a miniature version of the robot. Science Buddies has directions for building a light-tracking bristlebot in the Build a Light-Tracking Bristlebot (http://www.sciencebuddies.org/science-fair-projects/project-ideas/Robotics_p012/robotics/build-a-light-tracking-bristlebot) project (the circuit is identical to the one used in the Light-Tracking Bluebot project). Can you adapt the bristlebot to have a line-following circuit instead?
- The Arduino (https://www.arduino.cc/) is a very popular type of *microcontroller* used in robotics. It lets you write a computer program that can read inputs from sensors and use them to control motors. This gives you more precise "control" over your robot's behavior. Can you build a programmable line-tracking robot by adding an Arduino to your chassis? See our Getting Started with Arduino (http://www.sciencebuddies.org/science-fair-projects/references/getting-started-with-arduino) page to learn more.
- Instead of using the plastic chassis that came with your BlueBot kit, you can build your own chassis using materials like foam and cardboard, like the one shown

in Figure 15. The circuit for the robot remains the same—only the chassis is changed. Can you design and build an improved chassis?

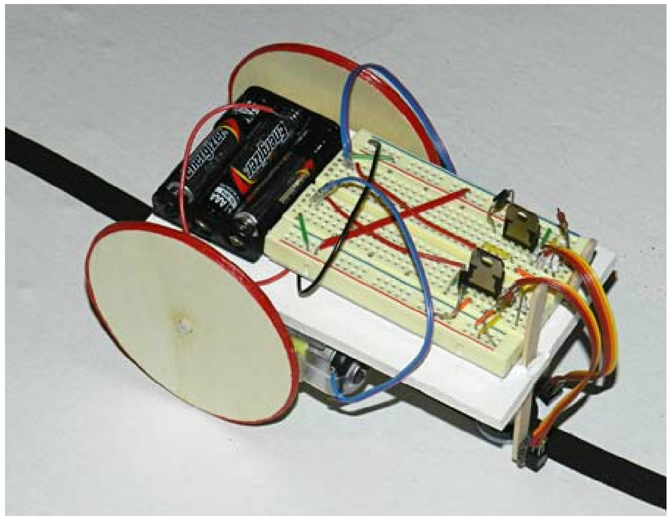


Figure 15. An example of a homemade chassis.

Frequently Asked Questions (FAQ)

If you are having trouble with this project, please read the FAQ below. You may find the answer to your question.

- My robot does not move at all when I put it down on the track and turn it on. What should I do? (#question1)
- Only one of my robot's wheels is spinning. What is wrong? (#question2)
- My robot is going backwards! What should I do? (#question3)
- I have double-checked everything and my robot still does not work. How can I check if something is broken? (#question4)
- How can I get my robot to slow down so it can follow lines more easily? (#question5)
- How does the IR sensor work? (#question6)
- How does a MOSFET work? (#question7)
- How does the circuit work? What is the circuit diagram? (#question8)
- What are the circuit diagram symbols for the components in this project? (#question9)
- How did you make the breadboard diagrams for this project? (#question10)

Q: My robot does not move at all when I put it down on the track and turn it on. What should I do?
A: If your robot does not move at all, try the following:

- Try holding the robot chassis in your hands so the wheels are free to spin. Hold a small piece of white paper in front of one of the IR sensors, and slowly move it back and forth. Then try this for the other sensor.
  - If the wheels start spinning, you know your circuit is working.
  - If the circuit is working properly, but the robot does not move at all when you put it on the floor, the problem is probably the distance of your IR sensors from the floor. They might be too far away or too close. Adjust this distance and then try again.
  - If the wheels do not spin, even when you are holding the robot, there may be a problem with your circuit. Go to the next bullet point.
- Double-check *all* of your breadboard connections. Make sure every lead and jumper wire is firmly pressed into the breadboard. Make sure all of your connections match the breadboard diagrams from the Procedure (#procedure). You can read about other common breadboard mistakes in the the Common Mistakes (http://www.sciencebuddies.org/science-fair-projects/breadboard-tutorial#common-mistakes) section of our breadboard tutorial.
- Make sure all your batteries are properly inserted into the battery holder, with the "+" symbols on the batteries lined up with the "+" symbols inside the holder.
- If you have been using your robot for a long time, or did some of the other BlueBot projects first, your batteries may be dead. Try putting fresh batteries in your robot if none of the other steps work.
- If your robot still does not turn on, follow these steps to see if the problem is with your power switch:
  - Remove the power switch from the breadboard, flip it around, and put it back into the same breadboard holes (F1, F2, and F3). If you are confused about which way to rotate the switch, see this video (https://youtu.be/zkGBW5JSqls).
  - Slide the power switch to the "on" position ("up" towards row 1 of the breadboard) and try testing your robot again. If your robot works after making this change, you can continue with the project, but please contact us at scibuddy@sciencebuddies.org (mailto:scibuddy@sciencebuddies.org?subject=Line%20BlueBot:%20switch%20worked%20when%20flipped) to let us know this happened.
  - If your robot still does not work after flipping the power switch around, bypass the power switch entirely. Connect the battery pack's red lead directly to the breadboard's power bus instead of hole J1. This connects the battery pack directly to the rest of the circuit. To turn the robot off again, you will have to temporarily disconnect this wire.
  - Now, re-try testing your robot. If your robot works, you can continue with the project, but please contact us at scibuddy@sciencebuddies.org (mailto:scibuddy@sciencebuddies.org?subject=Line%20BlueBot:%20switch%20did%20not%20work%20at%20all) to let us know the switch did not work in either direction.
  - If your robot still does not work, even after you have tried the previous steps, the problem is elsewhere in your circuit and not with the power switch. If you are having trouble figuring out what is wrong with your robot, you can ask a question in our Ask an Expert: Answers to Your Science Questions (http://www.sciencebuddies.org/science-fair-projects/ask-an-expert-intro) forums.

Q: Only one of my robot's wheels is spinning. What is wrong?
A: Your robot's circuit consists of two identical halves that drive the two motors. If only one wheel is spinning, chances are you just have something placed incorrectly on the breadboard in one half of the circuit. Very carefully double-check all of your writing on the side of the motor that is not working. It only takes *one* misplaced component or jumper wire to prevent the motor from spinning! Whether the motors spin properly also depends heavily on the distance between the IR sensors and the ground. If a sensor is touching the ground so its face is totally blocked, or if it is too far away from the ground, then it will not detect any reflected IR light and the wheel on that side will not spin. Try adjusting the distance between your sensors and the ground.

Q: My robot is going backwards! What should I do?
A: If your robot is going backwards, you just need to switch the red and black leads for each motor. This will cause the motors to spin in the opposite direction. These connections are shown in Figure 15.

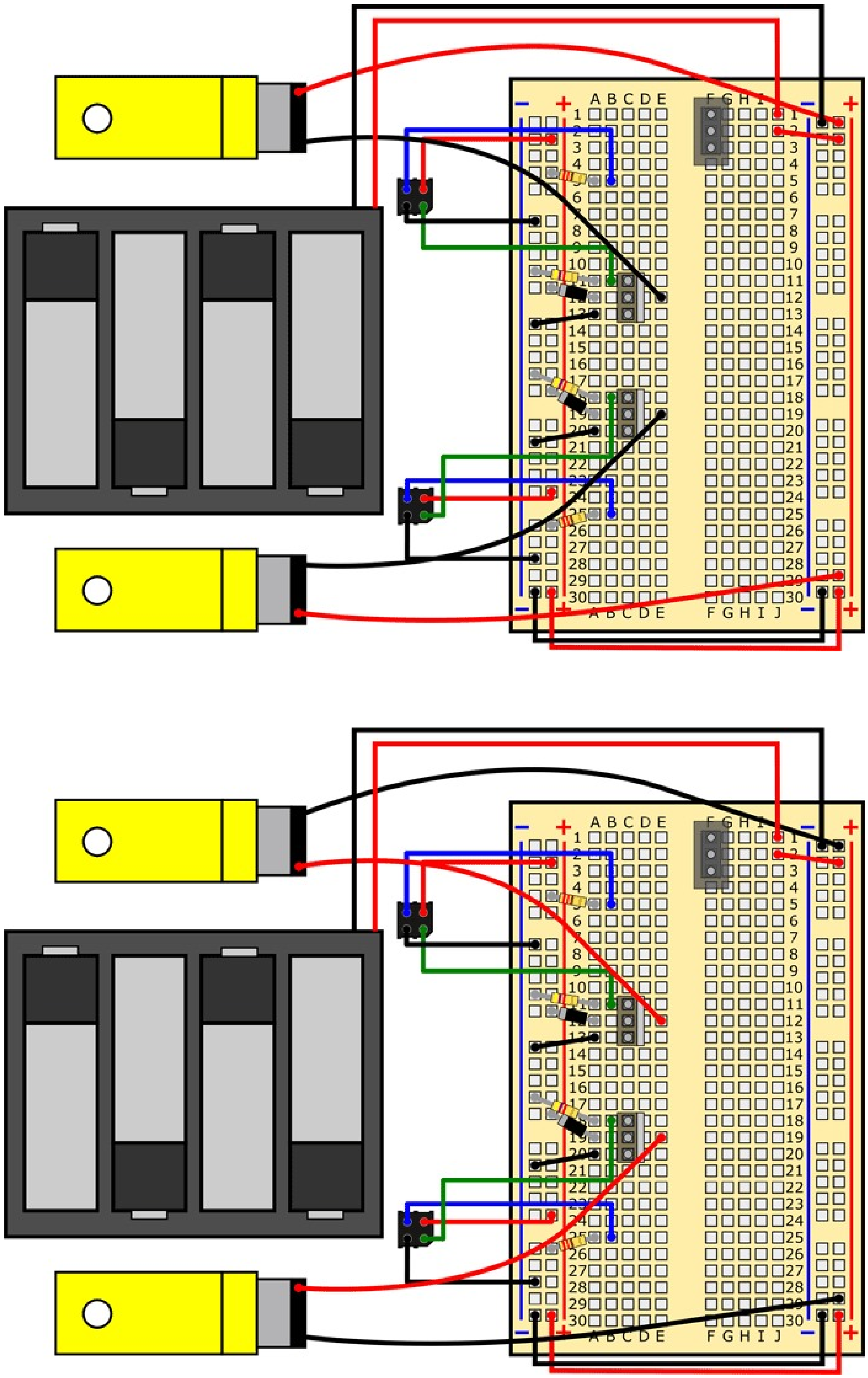


Figure 15. In the top image, the motors' red leads are connected to the power bus, and the black leads are connected to the MOSFETs' drain pins (holes E12 and E19). If this configuration causes your robot to go backwards, just switch the red and black wires for each motor, as shown in the bottom image. Connect the black wires to the power bus, and the red wires to holes E12 and E19. Do not worry about violating the color-coding convention for positive and negative; all this does is reverse the direction in which the motors spin.

Q: I have double-checked everything and my robot still does not work. How can I check if something is broken?

A: If you are having trouble figuring out why your robot will not work, you can try asking a question in our Ask an Expert: Answers to Your Science Questions (http://www.sciencebuddies.org/science-fair-projects/ask-an-expert-intro) forums. If you have access to a multimeter, you can also use that to help troubleshoot your circuit. See the Science Buddies reference How to Use a Multimeter (http://www.sciencebuddies.org/science-fair-projects/references/how-to-use-a-multimeter) if you need help using a multimeter. There are several steps you can take to check individual parts of your circuit (depending on your multimeter's probes, you may need alligator clips and additional jumper wires to take these measurements).

- Try plugging your motor's leads directly into the buses on your breadboard (for each motor, one lead to the power bus, one lead to the ground bus). If the motors turn on, then you know that they are working, and the problem is elsewhere in your circuit. If the motors do not turn on, that does not necessarily mean they are broken. There might be a problem with your power supply (see next point).
- Check your breadboard's power supply.
    - Set your multimeter to measure DC volts. Four fresh AA batteries should provide just over 6 V.
    - Turn your power switch on and measure the voltage between the breadboard's buses. If you do not read a voltage, there may a problem with your power switch (see the first question in this FAQ), but you should also double check that your power switch and the red jumper wire from hole J2 to the power bus are in the right place.
    - Unplug the red and black battery pack leads and measure the voltage of the battery pack directly. If you get a reading, then you know your battery pack is working, and the problem is with your breadboard connections or the power switch. If you do not get a reading, make sure all the batteries are in the correct orientation in your battery pack, and that none of the metal clips and springs that hold the batteries in place are loose.
- Make sure the IR LEDs in the IR sensors are working.
    - Connect your multimeter in *series* with the IR LED (meaning, between pin 4 of the IR sensor and ground, or between the 220 Ω resistor and pin 3 of the sensor), and measure current when the robot is switched on. You should measure about 20 mA. If no current is flowing at all, the LED may be burned out, or it might not be receiving power (see above).
    - If your multimeter has a diode test function, you could also use that to test the LEDs.
- Test the output of the phototransistors.
    - Measure the voltage between pin 2 of an IR sensor and ground (make sure the robot is turned on). When the sensor is aimed at a dark surface, or is very far away from a light surface, this voltage should be close to zero. When the sensor is held close to a white surface, the voltage should increase (to almost the battery pack voltage, but not quite). If this voltage does not change, the phototransistor may not be properly receiving power.
- If the motors work when you plug their leads directly into the buses, and the output voltage of the IR sensors increases when they are held close to a white surface, then the problem is elsewhere in your circuit. You know the individual components work so nothing is "broken." Double and triple-check your wiring. Remember that just one misplaced wire can prevent the entire circuit from working.

Q: How can I get my robot to slow down so it can follow lines more easily?
A: See the Troubleshooting (#troubleshooting) section in the Procedure.

Q: How does the IR sensor work?
A: The IR sensor consists of an infrared LED and an infrared phototransistor. A regular transistor has three pins: the **base**, **collector**, and **emitter**, as shown in Figure 16 (note: technically this is a **bipolar transistor**, which is slightly different from a **field-effect transistor**; see the next bullet point). Normally, when a small current is applied to the base pin, this causes a larger current to flow between the collector and emitter pins. The ratio between these two currents is called the **gain** (note: the transistor must be connected to a power supply; current will not just flow on its own). A *photo*transistor is activated when the base pin is exposed to light instead of current. So, when light from the IR LED is reflected back toward the sensor, it hits the base of the phototransistor, causing a larger current to flow. This triggers the gate pin of the MOSFET, activating the motors. You can read more about the IR sensor on its datasheet (http://www.avantlink.com/click.php?tt=cl&mi=10609&pw=182414&ctc=line-following-robot&url=http%3a%2f%2fwww.jameco.com%2fJameco%2fProducts%2fProdDS%2f1872628.pdf).

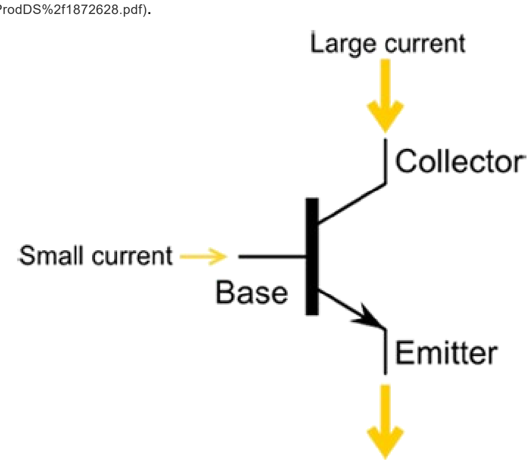


Figure 16. Diagram of a bipolar transistor. It has three pins: the base, collector, and emitter. Normally, a small current applied at the base causes a larger current to flow between the collector and emitter. A phototransistor is activated by light instead of electrical current.

Q: How does a MOSFET work?
A: MOSFET stands for *metal-oxide-semiconductor field-effect transistor* (so you can see why it is a lot easier just to say "MOSFET"). The three pins of a field-effect transistor are called the **gate**, **drain**, and **source**. Unlike a *bipolar* transistor, which is controlled by a small current applied to the base pin, a *field-effect* transistor is controlled by a voltage applied to the gate pin, but the gate does not actually draw any current. A voltage applied to the gate causes current to flow between the drain and source pins. Figure 17 shows a simplified explanation of how a MOSFET works. A voltage is applied to the gate pin in order to control the flow of current between the drain and source pins. When the voltage between the gate and source pins (V_{GS}) is below a certain limit, called the **threshold voltage** (V_{th}), no current flows. When V_{GS} exceeds V_{th}, the MOSFET begins to conduct, allowing current to pass through. This is what allows you to use the gate voltage of a MOSFET to turn a DC motor on and off. For this robot, the MOSFET's gate voltage is controlled by the IR sensor.

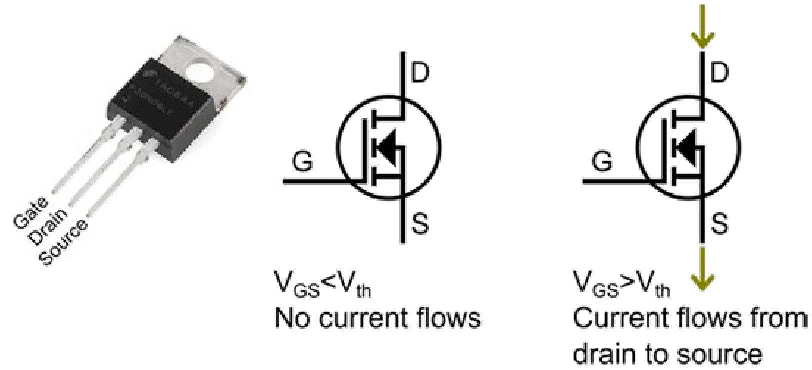


Figure 17. Simplified explanation of a MOSFET's operation.

The exact description of how a MOSFET works is more complicated than this. As V_{GS} increases past V_{th}, the current through the MOSFET will continue to increase. Eventually the MOSFET will reach **saturation**, where no additional current can flow, even if V_{GS} continues to increase. The MOSFET's behavior will also depend on the type of **load** to which it is attached. The MOSFET used in this project is an **N-channel MOSFET**, which requires a positive gate voltage to turn on. A **P-channel MOSFET** requires a negative gate voltage to turn on. Advanced users can refer to the Bibliography (#bibliography) for more information on MOSFETs.

Q: How does the circuit work? What is the circuit diagram?
A: Figure 18 shows the complete circuit diagram for the robot. More detailed explanations for some of these individual components are given in the questions above. Refer to Table 5 for a list of the individual circuit diagram symbols, if necessary.

Since the circuit consists of two identical halves—one to control each motor—we can just explain how one half of the circuit works. The same explanation applies to the other side.

- The batteries supply a voltage, V_{batt} to the circuit. When the switch is closed, $V_1 = V_{batt}$. When the switch is open, V_1 is "floating", so the circuit does not receive any power.
- The 220 Ω resistor acts as a **current-limiting resistor** for the IR LED. It prevents too much current from flowing through the LED and burning it out.
- The IR LED emits infrared light. If enough light is reflected back to the sensor, it triggers the base of the phototransistor, allowing current to flow from the collector to the emitter.
- The 4.7 kΩ resistor acts as a **pull-down resistor**. When the phototransistor is not conducting, it "pulls down" the MOSFET's gate voltage (labeled V_2 in Figure 18) to ground. When the phototransistor conducts, V_2 will increase, approaching, but not quite reaching, V_{batt}.
- When V_2 is below the MOSFET's threshold voltage V_{th}, no current flows through the motor. When V_2 exceeds the threshold voltage, the MOSFET allows current to flow, turning the motor on.
- The end result is that when the IR sensor "sees" white, it triggers the MOSFET and turns the motor on. When it "sees" black, it turns the motor off.
- Finally, each motor has a diode connected across its terminals. Motors can create large voltage spikes when they abruptly come to a stop (this has to do with the relationship between electrical current and magnetic fields, if you want to do more research on the explanation). The diodes help prevent damage to the MOSFET by safely discharging the current generated by the voltage spike.

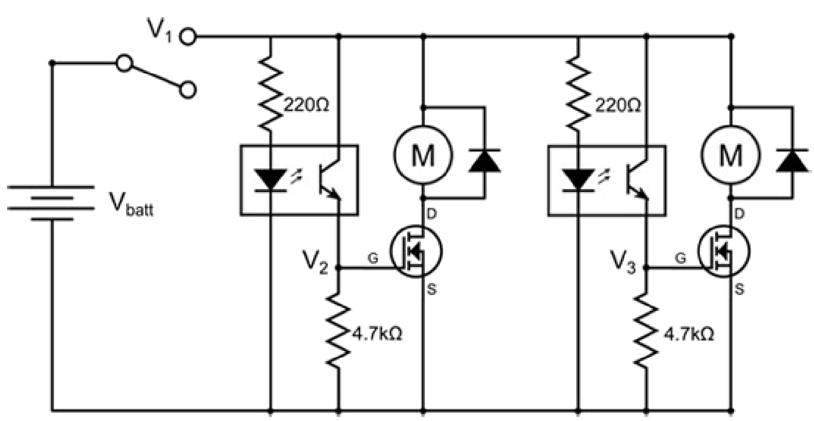
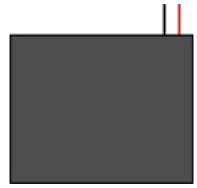
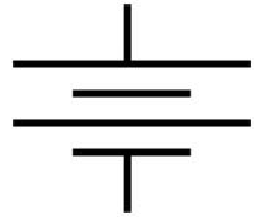
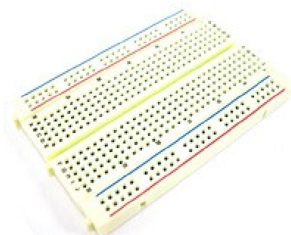
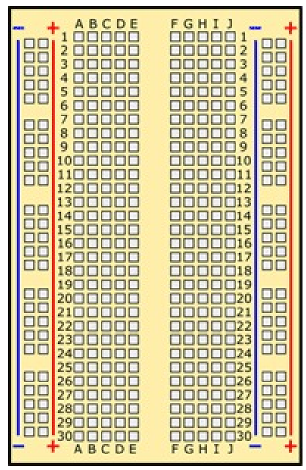
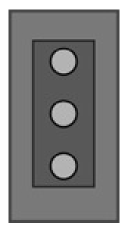
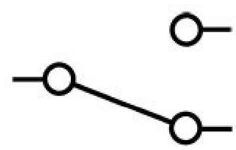
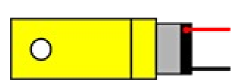
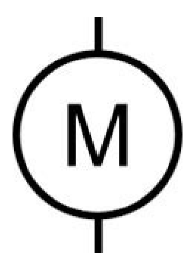


Figure 18. A complete circuit diagram for the line-following robot.

Q: What are the circuit diagram symbols for the components in this project?
A: Table 5 shows a picture, breadboard diagram symbol, and circuit diagram symbol (when applicable) for each component in the project.

Item Name	Picture	Breadboard Diagram Symbol	Circuit Diagram Symbol

Item Name	Picture	Breadboard Diagram Symbol	Circuit Diagram Symbol
Battery pack			
Breadboard			N/A
Switch			
Jumper wire			
DC Motor			

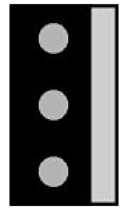
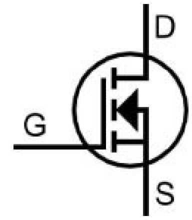
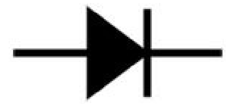
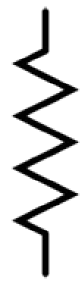
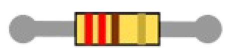
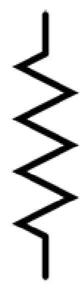
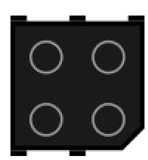
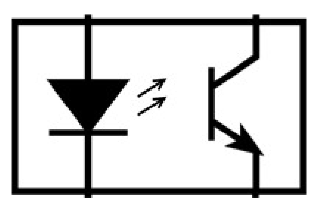
Item Name	Picture	Breadboard Diagram Symbol	Circuit Diagram Symbol
MOSFET			
Diode			
4.7k Ω resistor			
220 Ω resistor			
IR Sensor			

Table 5. A picture, a breadboard diagram symbol, and a circuit diagram symbol for each of the components used in this project.

Q: How did you make the breadboard diagrams for this project?
A: The breadboard diagrams for this project were created using Inkscape (http://inkscape.org/en/), a free vector graphics program. You can find free scalable vector graphic (SVG) files for many circuit components on Wikimedia Commons (http://commons.wikimedia.org/wiki/Main_Page). There are other free programs specifically for making breadboard diagrams, such as Fritzing (http://fritzing.org/home/).

Ask an Expert

The Ask an Expert Forum is intended to be a place where students can go to find answers to science questions that they have been unable to find using other resources.