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Robot Soccer Lab: Head-On, Momentum Before and After a Collision

Grades 9-12 · 45 minutes

Physical science



Slides, rubric and answer key | Print and go | No student accounts | Chromebook friendly

What's included

- A one-page overview: objectives, essential question, vocabulary, standards and assessment
- A 45-minute lesson sequence: warm-up, direct instruction, guided practice, independent practice, closure
- Slides for the board: a PowerPoint file that also opens in Google Slides
- A student worksheet with a QR code and a data table for three collisions
- A 3-question exit ticket, two to a page, with an answer key
- A rubric: 3 criteria, 4 levels, scored out of 12
- Differentiation for English learners, students with IEPs or 504 plans, and students who need more support or more challenge
- Cross-curricular extensions, and notes for teaching it in middle school and in AP Physics
- Standards: NGSS

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Level 12 of Robot Soccer Lab is a straight-line collision test. The robot drives straight into a resting ball three times: two speeds with the golf-size ball, then the big ball. For each hit a table gives the robot's speed before and after, the ball's speed after, and the momentum, mass times velocity, before and after. Students change the program to run two speeds, then calculate the momentum themselves from the masses and speeds, and show it is the same before and after every hit. The big ball, about three times as heavy, slows the robot about three times as much. Then they predict a new collision before running it.

At a glance

ESSENTIAL QUESTION

When a robot hits a ball, what stays the same?

OBJECTIVES

Students will be able to:

- calculate momentum from mass and velocity
- add the momentum of two objects before and after a collision
- use data to support the claim that total momentum is conserved
- explain why a heavier ball slows the robot more
- predict a speed after a collision from momentum and check it

VOCABULARY

Momentum, System, Conserved, Collision, Head-on, Mass

STANDARDS

HS-PS2-2

TIME AND MATERIALS

45 minutes, grades 9-12.

- One computer or Chromebook per student
- A projector
- The worksheet and exit ticket, one copy each per student
- The rubric, one copy per student if you grade the work
- A calculator

PREP

Make copies of the worksheet and exit ticket. Before class, open mytekdev.com/try/robotsoccerlab?lesson=head-on-momentum-before-and-after-a-collision&ref=tpt-robotsoccerlab-4 once on a student computer, which checks that your school's filter allows the app, and follow the short guide yourself: about ten minutes.

ASSESSMENT

- Formative: the questions under What to look for, asked while students work, and the exit ticket (answer key included).
- Summative: the worksheet, scored with the rubric.

TECHNOLOGY AND PRIVACY

Runs in any browser, Chromebooks included, with nothing to install. Students need no account and no email: the link works signed out, and nothing they do is stored on our server unless they choose to save.

Lesson sequence

MINUTES	STAGE	WHAT YOU DO	WHAT STUDENTS DO
0 to 5	**Warm-up** Hook	Show the title, essential question and Today I can slides (about 1 minute). Then the warm-up: the bowling ball and the two balls.	Answer the warm-up on the worksheet.
5 to 13	**Direct instruction (I do)** Model it	Project Level 12. The field is in the middle: green carpet, white lines, the yellow goal (the robot's own) and the blue goal it attacks. The red robot is round, with an arrow on top for its front, and the orange ball glows so the robot can find it. The box on the field says the level's goal and, after each run, what happened and why. The readings beside it show the ball clock, the heading, the speed and how far away the ball is. Define momentum, p = m v, and the system, robot plus ball. Show the round 1 slides and work the momentum before (1.387 x 0.40) and after (1.387 x 0.38 + 0.046 x 0.58) together. **It's working when:** The table rounds to two decimals, so hand calculations land within 0.01 of it. 1.387 x 0.381 + 0.046 x 0.581 is 0.555; 1.387 x 0.40 is 0.555.	Fill in the vocabulary, and work round 1 on the worksheet.
13 to 20	**Guided practice (We do)** Run it	Students open the link or scan the QR code. A short guide runs the starter, which drives at 40 in both rounds: the referee says the same speed twice. They change the second 40 to 80 and play: three hits and the full table. **Watch for:** Students who change the first 40. Either works, as long as the two speeds differ by 20 or more.	Follow the guide. Copy the table onto the worksheet.
20 to 37	**Independent practice (You do)** Calculate and predict	Students calculate the momentum before and after for all three rounds from the masses and speeds, and the robot's slowing in rounds 2 and 3. Then they choose a new pair of speeds, such as 30 and 60, predict the robot's momentum before each hit (mass x speed / 100), and run it to check. Each level starts in real time. Speed up and Slower, under the field, change the speed; the round play button starts the level again from the beginning, with the program as it is now. Walk the room with the What to look for questions. **If they ask:** "The big ball is about three times as heavy. How many times as much did it slow the robot?" The big ball **Watch for:** Students who expect the ball to leave at the robot's speed. It leaves faster than the robot was going; the momentum still adds up.	Fill in the data table and the prediction, and answer the questions.
37 to 45	**Closure** What stays the same? And exit ticket	Show the closure slide and take answers. Make the claim with the class: in every hit, total momentum before equals total momentum after. Hand out the exit ticket.	Discuss, then answer the exit ticket.

Before you teach: a ten-minute walkthrough

Open mytekdev.com/try/robotsoccerlab?lesson=head-on-momentum-before-and-after-a-collision&ref=tpt-robotsoccerlab-4. A short guide opens over Level 12, Head-on, with the program in the Python tab.

1. **The rounds.** Three rounds of 3 seconds. Each puts the robot 35 cm (center to center) behind a resting ball and lets it drive. Rounds 1 and 2 use the golf-size ball, 0.046 kg; round 3 the big ball, about 0.14 kg. robot.time() says which round it is: under 3 seconds is round 1.
2. **The table.** In the box, one row a round: the robot's speed before and just after the hit, the ball's speed after, and the momentum before and after, in kg m/s. Under it, the robot's mass: 1.387 kg for the starter robot.
3. **The program.** If the time is under 3, move at angle 0 speed 40; else move at angle 0 speed 40. Speed 40 is 0.40 m/s. The referee wants rounds 1 and 2 at least 0.2 m/s apart, so the starter fails with "the same speed twice" and still shows the table.
4. **Speed.** Each level starts in real time. Speed up and Slower, under the field, change the speed; the round play button starts the level again from the beginning, with the program as it is now.
5. **Numbers to expect.** 40 then 80: round 1, 0.40 to 0.38, ball 0.58, momentum 0.55 and 0.55. Round 2, 0.80 to 0.76, ball 1.16, 1.11 and 1.11. Round 3, the big ball, 0.80 to 0.69, ball 1.09, 1.11 and 1.11. 30 then 60: 0.42, then 0.83 and 0.83. 50 then 100: 0.69, then 1.39 and 1.39. These do not change from run to run.

> The numbers depend on the robot's mass, which comes from its parts in Robot, Configurator. A robot with the kicker taken off weighs 1.227 kg (40 then 80: 0.49, 0.98, 0.98); with a dribbler added, 1.457 kg (0.58, 1.17, 1.17). Before and after still match. If one student's numbers differ from a neighbor's, check the mass under the table first. After each hit the robot keeps driving and may touch the ball again; only the first hit of each round goes in the table.

Background for the teacher

In a collision the two objects push on each other with equal and opposite forces for the same short time, so the momentum one loses the other gains. With no net force from outside the system, the total momentum is conserved. The robot's wheels push on the carpet too, but over the instant of the hit that push is tiny next to the collision, so robot plus ball is a system with no net force for that moment.

The collision is not elastic: in the app the ball leaves faster than the robot by half the robot's speed before the hit (a coefficient of restitution of 0.5, a classroom value, not a measurement). Momentum is conserved; kinetic energy is not. The golf-size ball's 46 g is the weight of a golf ball of its size; the big ball's 141 g, with its batteries, is our estimate.

Robot soccer has led to real companies: Raffaello D'Andrea, who coached Cornell's robot soccer team, went on to co-found Kiva Systems, whose warehouse robots Amazon bought in 2012. Robotics, mechanical, electrical and software engineers all work on robots like these.

What to look for

Ask these while students work. A student who has understood the lesson can answer them without help:

- Why is all the momentum before the hit the robot's?
- In round 2, how much momentum did the robot lose, and where did it go?
- Why did the big ball slow the robot more than the small one?
- Why are the robot's speeds the same in rounds 2 and 3 before the hit, but different after?
- If the robot were heavier, what would change in the table, and what would not?

> The second question is the one that matters. A student who says "1.387 x 0.04 is about 0.054, and the ball gained 0.046 x 1.16, about 0.053" has supported the claim with numbers. A student who says "they match" has the result but not the idea.

Cross-curricular extensions

- Math: graph the ball's speed after the hit against the robot's speed before, for four speeds. What is the slope?
- Engineering: why do real teams keep their robots under the 1.5 kg limit, and what would a heavier robot gain in a push?
- Sports: find how a golf club's mass and speed affect the ball's speed off the tee.
- Careers: look up crash testing for cars, where engineers measure momentum and forces in collisions.

Vocabulary

Momentum	Mass times velocity, in kilogram meters per second (kg m/s).
System	The objects you count together: here, the robot and the ball.
Conserved	The same before and after: the total momentum of the system does not change in the collision.
Collision	Two objects pushing on each other for a very short time.
Head-on	Moving straight along the line between the two objects, so everything happens in one dimension.
Mass	How much matter an object has, in kilograms: the robot 1.387 kg, the golf-size ball 0.046 kg.

Differentiation

ENGLISH LEARNERS

- Keep the vocabulary slide up, and point at the robot, the ball or the box on the field as you say each word: the picture carries the meaning.
- Give a sentence frame on a card: Before the hit the momentum was ____; after, the robot had ____ and

STUDENTS WITH IEPS OR 504 PLANS

- Pair students, one at the keyboard and one calculating.
- Give the data table with the masses filled in.
- Allow a calculator. Where the IEP allows a modified assignment, score the first two rubric rows only.

the ball ____, a total of ____.

- Act it out with two rolling balls on a desk, one heavy, one light, naming before and after.

STUDENTS WHO NEED MORE SUPPORT

- Work round 1 together, every number on the board.
- Read the momentum columns in the app's table first, then calculate one row to see where they come from.
- The box on the field says what went wrong if a run fails: missed, not head-on, or the same speed twice.

STUDENTS READY FOR MORE

- Open Robot, Configurator and take the kicker off (the robot becomes 1.227 kg). Predict the momentum before the 80 hit, then run it.
- Calculate the kinetic energy (half m v squared) before and after round 2. Is it conserved? What does that say about this collision?
- The ball always leaves faster than the robot by half the robot's speed before the hit. Use that and momentum to predict both speeds after a hit at 60.

Adapting for other grades

Younger students: In middle school, use the app's momentum columns rather than calculating, and focus on the pattern: the robot loses what the ball gains, and the heavier ball takes more. MS-PS2-1 (Newton's third law in a collision of two objects) fits this version. Score the first two rubric rows, total 8, and 6 meets the objectives.

Older students: In AP Physics, add the coefficient of restitution: the ball leaves at 0.5 of the closing speed faster than the robot. With momentum, derive both speeds after the hit for any mass, and compare with the table.

Student worksheet

Name: _____ Date: _____

Open the app: scan the QR code, or go to mytekdev.com/try/robotsoccerlab?lesson=head-on-momentum-before-and-after-a-collision

Essential question: When a robot hits a ball, what stays the same?

Warm-up: A bowling ball hits a ping-pong ball, then a soccer ball. Which slows it more?

_____

1. **Vocabulary.** Momentum, system, conserved, collision, head-on, mass: write each in your own words.

2. **Masses.** Robot: _____ kg. Golf-size ball: 0.046 kg. Big ball: about 0.14 kg (an estimate).
3. **Data.** Round 1: robot before ____ after ____, ball after ____. Round 2: ____ ____ ____. Round 3 (big ball): ____ ____ ____.

4. **My calculations.** Momentum before and after, in kg m/s. Round 1: _____ and _____. Round 2: _____ and _____. Round 3: _____ and _____. The robot slowed by _____ in round 2 and _____ in round 3.

5. **My prediction.** New speeds ____ and ____. Predicted momentum before each hit: _____ and _____. The table said: _____ and _____.

1. What stayed the same in every hit, and how do your numbers show it?

2. Why did the big ball slow the robot about three times as much?

Exit ticket

Name: _____

1. A 2 kg cart moving at 0.5 m/s has a momentum of: (A) 0.25 kg m/s (B) 1 kg m/s (C) 2.5 kg m/s

2. Before a hit the robot has 1.11 kg m/s and the ball is at rest. After the hit the total momentum is: (A) 0 (B) 1.11 kg m/s (C) more than 1.11

3. A friend says the robot lost momentum in the hit, so momentum was not conserved. Use what you learned today to answer.

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Answer key: exit ticket

QUESTION	ANSWER	WHY
1	B	2 x 0.5 = 1 kg m/s.
2	B	With no net force on the robot and the ball, the total is the same before and after.
3	Open answer	The robot lost momentum, but the ball gained exactly that much: the total for the system is the same, 1.11 before and after.

Worksheet: what students should find

BLANK	WHAT THE APP SHOWS
Masses	Robot 1.387 kg (the starter robot; another build shows its own mass under the table).
Data	Round 1: 0.40, 0.38, 0.58. Round 2: 0.80, 0.76, 1.16. Round 3: 0.80, 0.69, 1.09 (with 40 then 80).
My calculations	Round 1: 0.55 and 0.55. Round 2: 1.11 and 1.11. Round 3: 1.11 and 1.11. The robot slowed by 0.04 in round 2 and 0.11 in round 3.
My prediction	For 30 and 60: 0.42 and 0.83; the table agrees.
Question 2	The big ball has about three times the mass, so it takes about three times the momentum from the robot.

> These numbers do not change from run to run. They do change with the robot's mass: a student who changed the robot in Robot, Configurator gets different speeds and momentum, and before and after still match.

Rubric

Score each row from 1 to 4.

Name: _____

CRITERIA	4 EXCEEDS	3 MEETS	2 APPROACHING	1 BEGINNING
Calculating momentum	Calculates momentum before and after for all three rounds, with units, matching the table within 0.01.	Calculates all three rounds.	Calculates one round.	No calculation.
Supporting the claim	States the claim and supports it with all three rounds and the big ball's larger slowing, with numbers.	States the claim with data from two rounds.	States the claim with no data.	No claim.
Predicting	Predicts a new collision, runs it, and explains any difference.	Predicts and runs it.	Runs it without a prediction.	Does not try.

Total: ____ / 12. A score of 9 or more meets the objectives.

Standards

The lesson is built for HS-PS2-2: students use mass times velocity, measured for two objects moving in one dimension, to support the claim that total momentum is conserved in a collision. For a middle school version, MS-PS2-1 (Newton's third law in a collision of two objects) fits; see the grade notes.

FRAMEWORK	CODE	GRADES	STANDARD	HOW THE LESSON MEETS IT
NGSS	**HS-PS2-2**	9-12	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.	Students calculate the momentum of the robot and the ball before and after three head-on collisions, and use the totals to support the claim that momentum is conserved.

Checked November 2026 against: NGSS HS-PS2-2, Motion and Stability: Forces and Interactions.

Optional: save student work in a free class

The whole lesson runs at the link on the worksheet, with no accounts and no sign-up.

To keep students' work, and see it all in one place, make a free class. It takes about ten minutes, once, and covers every lesson in this series: mytekdev.com/tools/class-setup

Students in a class open mytekdev.com/tools/robot-soccer-lab/lessons/head-on-momentum-before-and-after-a-collision/start instead of the worksheet link. Each one gets their own copy of the starter, and the same link reopens it next time.

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