Instructor Guide: Force and momentum in collisions

What is this ACORN Physics Tutorial designed to do?

This worksheet is designed to **elicit common conceptual resources** for thinking about forces & momentum, including:

- **Momentum is conserved and/or transferred.** This resource uses conservation and/or transfer of momentum as a fundamental constraint that explains and/or predicts the motion of objects after a collision.
- ***Momentum is directional.*** This resource foregrounds that momentum is the kind of quantity that has a direction and the importance of directionality for momentum calculations. This resource is consistent with the canonical definition of momentum as a vector. This resource may be active when students describe momentum as being positive or negative or use momentum vectors to map out the interactions of objects in a collision.
- **The kind of collision (e.g., elastic or inelastic) matters.** Students using the collision resource imply that the type of collision that an object undergoes (e.g., elastic or inelastic) affects its final momentum; in using this resource, students formally or informally apply a constraint to their analysis of the system.
- **Properties of the material matter.** Students use this resource when they suggest that the properties of an object (e.g., whether it is hard, soft, bouncy, heavy, light, fast, etc.) matter for how it interacts with other objects in a collision and for the resulting momentum of the objects. Students may use these two resources to explain why a bouncy ball has a different impact on an open drawer than a piece of clay.
- **Forces cause objects to speed up or slow down.** Students use this resource to connect the force on an object to changes in its motion. In the context of momentum questions, students may use this resource in addition to or as an alternative to the above resources as they explain changes in motion that occur during collisions.
- **For every action there is an equal and opposite reaction.** This resource is a nascent or colloquial form of Newton's third law, and in the context of collision questions it is often used to explain why objects change direction or begin moving as the result of a collision. This resource may be used as an alternative or addition to the momentum resources listed above.

This worksheet includes questions that elicit, refine, test, and/or build upon these ideas while at the same time leaving space for less-common ideas about collisions, momentum, and force. In particular, this worksheet was designed to support students to connect force and momentum resources to construct a comprehensive model for collisions.

What content learning goals might this worksheet support?

ACORN Physics Tutorials are designed to support students in constructing their own models for physics concepts. This worksheet guides students to construct a qualitative model for the relationship between forces and momentum in collisions. This worksheet supports learning goals related to both scientific practices and disciplinary content.

Students will be able to:

- generate rules (about changes in momentum) based on experimental observations and apply those rules to predict/explain the behavior (relative speed and direction) of (colliding) objects.
- choose an experiment to test a rule (about changes in momentum). They may generate the experiment themselves or select it from an instructor-provided list.
- explain and predict relative speed and direction of colliding objects in terms of conservation of momentum.
- explain changes in momentum in terms of forces and Newton's second and third laws: e.g., for specific collisions, "forces transfer momentum" or "the change in momentum is equal to the impulse."

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An example model that the worksheet has supported students in constructing is:

"Force and momentum are both connected to velocity and acceleration. The force of an object is equal to the mass of the object multiplied by the acceleration of the object. The momentum of a physical object is equal to the mass of the object multiplied by the velocity of the object. From our observation with the experiment with the clay being thrown at a drawer and the rubber bouncy ball being thrown at the other drawer shows that an object with a higher elasticity will exert a greater force meaning there is a greater rate of change in momentum.Since the clay ball is inelastic it will not bounce off but stick to the object it is hitting and move with it and have the same final velocity as the object it sticks to. This can also be explained using Newton's third law, which states every force occurs as one member of an action/reaction pair of forces. To have an action/reaction pair of forces is made up of two objects that interact by exerting a force on each other that are equal in magnitude but opposite in direction."

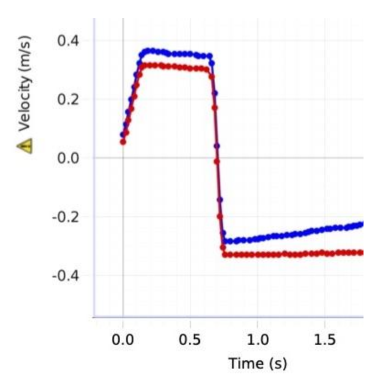
An example of a more advanced, quantitative model might look like:

"Like an object's velocity changing while a force is applied, the momentum of an object will change as long as a force is applied. This is evident in the equation for force, $F_{net} = ma$. *The acceleration of an object, a, is given as the change in velocity over time. Therefore, the equation for force can be rewritten as* $F_{net} = \Delta v/\Delta t$. *Because momentum is given as p = mv, force can be reduced to include momentum as* $F_{net} = \Delta p/\Delta t$. *By manipulating this equation to* $F_{net}\Delta t = \Delta p$, *it is even more evident that the longer a force is applied (or more specifically, the larger* Δt *is) the larger the change in momentum will be. There is clearly a direct relation between the change in momentum and the amount of force, along with the time of exertion. Furthermore, the momentum of a system is conserved and will remain the same unless there is an external force enacted on the system. While the elasticity of a collision will not affect whether the momentum is conserved, it does affect the force experienced between colliding objects. During an elastic collision, there is a more dramatic change in the momentum of each object. Looking at the previous equations, it is evident that a greater change in momentum in a constant amount of time would yield a greater force. Therefore, objects will experience a greater amount of force during an elastic collision, and a lower amount of force in an inelastic collision."*

What questions can assess student progress toward these learning goals?

A red cart with mass 1.25 kg is moving at 0.3 m/s when it collides with an identical blue cart moving at speed -0.3 m/s. A velocity vs. time graph for the cart before, during, and after the collision is shown at right.

1. Use this information to determine the change in momentum of the red cart during the collision.
2. Explain how you determined your answer above: what information did you use, and how did you use it?
3. Draw a force vs time graph for the red cart in this collision.
4. Explain why you drew the force vs. time graph as you did.



What resources, equipment, or experiments activities are good supplements to this worksheet?

Section II of this worksheet guides students to examine several -dimensional collision experiments. The **Supplement** to this worksheet includes descriptions and accompanying data for a variety of collision experiments for students to refer to. Videos of collisions can be found in this folder.

What are specific strategies to help students with this worksheet?

- Keep track of questions that students express and suggest ways they can test their questions using equipment or simulations.
- Suggest thought experiments to clarify what a student is thinking or to resolve inconsistencies in their ideas.

What research has been done to develop and/or test this worksheet?

Learn more about the research involved in this worksheet here:
https://www.physport.org/curricula/ACORN/research#forces