Forces and Motion

Secondary: (ages 11 – 14)	Science (physics)

This 10-lesson unit engages students in investigations to understand Newton's second law of motion. Students start the unit by discussing vehicle collisions, and continue by performing activities to explore the driving question 'How can I design a car which is safer for passengers during a collision?' The content focus of this unit is on understanding the relations between the net force on an object, its mass, and its acceleration. The unit includes several opportunities for students to construct, test, revise and share their models to explain the investigated phenomena, while performing experiments and using computer simulations.

Time allocation	10 lesson periods
Subject content	Develop inquiry and modelling skills for scientific explanations and analyse data to assess the explanations Gain an understanding of Newton's second law of motion Identify relationship between acceleration, mass, and force
Creativity and critical thinking	This unit has a **creativity** and **critical thinking** focus: • Design, evaluate, and refine a personally novel solution (device) to a scientific problem • Generate unusual ideas to propose and model scientific solutions
Other skills	Communication, Collaboration, Persistence/Perseverance
Key words	force; mass; acceleration; motion; Newton; collision; cars; velocity

Products and processes to assess

The unit provides opportunities for students to develop their collaborative, creative, and critical thinking skills in the context of generating scientific explanation. Students analyse patterns in data to explain and model relationships between mass, change in velocity and the force of a collision. At the highest levels of achievement, the student actively tests both the internal and external consistency of information and is able to check the accuracy of two or more assumptions or implications/predictions that he/she has been able to identify him/herself.

Authors: Cameron Cochran, Steve Barry Israel Touitou and Joseph Krajcik. This unit was developed by support from the National Science Foundation for the PIRE project: Crafting Optimal Learning in Science Environments (award #: OISE-1545684. Principal investigators: Barbara Schneider and Joseph Krajcik). These materials were developed by the authors and do not represent the views and positions of NSF. This work was modified for the OECD for the CERI project *Fostering and assessing creativity and critical thinking skills*.

Teaching and Learning plan

This plan suggests potential steps for implementing the activity. Teachers can introduce as many modifications as they see fit to adapt the activity to their teaching context.

Step	Duration	Teacher and student roles	Subject content	Creativity and critical thinking
1	Lesson period 1	In this introductory session, students are first engaged in the phenomena of collisions through videos and exploration with toy cars. Students then generate a series of questions in order to work out the driving question (How can I design a car which is safer for passengers during a collision?) They then construct an initial model of a two-body collision Note: The driving question will be revisited in lessons throughout the unit. The models built from exploring collisions with the toy cars will also be revised throughout the unit and the teacher may decide to make toy cars available at other times to help students understand the concepts more clearly. As appropriate, the teacher may also decide at any point to review Newton's laws of motion or other related concepts with the class as a whole in order to support students' ability to create their models and collect and interpret data. Students should be asked to document their ideas, thoughts, and results throughout so their thinking is visible through each step of the unit.	Exploring different variables in collisions	Generating ideas and questions about a physical phenomenon (collision) and linking this to the driving research question
2	Lesson period 2	Students are asked to use what they learned in the previous lesson about collisions to design an investigation of the relationship between force, mass, and acceleration. Though the concept of force may not be defined at this point, students may begin making the connection between some aspects of this lesson's investigation and force. Students work in groups or individually to plan investigations, develop a prediction, generate hypotheses, and collect data regarding force, mass, and acceleration	Investigating the relationship between force, mass, and acceleration	Proposing how to solve a scientific problem in a personally novel way
3	Lesson period 3	Students are supported to use mathematical thinking to analyse data and to create graphical representations of the relationship between force, mass, and speed over time (acceleration). Students add to their existing models of vehicle collisions based on their observations and data from the previous lesson's investigation. Students use patterns in data from the experiment to develop a model that describes cause and effect relationships among the key variables. Students use the model they generate to make predictions, and use these predictions to evaluate their model, by comparing the predictions with their empirical data.	Analysing data and creating graphs Investigating cause and effect in relation to force, mass, time, speed, and acceleration Generating predictions and hypothesis	Revising scientific explanations using relevant observations and data Evaluating and explaining the strengths and limitations of their proposed solutions
4	Lesson period 4	Students create a computer model to explain the relationship between the force of vehicle collisions and the mass or the speed/acceleration of the objects in the collision.	Explaining the relationship between the variables.	Envisioning and producing a computer model
5	Lesson period 5	Students investigate the relationship between the force of a collision and the speed/acceleration of the objects colliding by tossing water balloons. Students examine	Experimenting with the application of force and changes in	Making connections between scientific explanations and their

		the role that minimizing force by maximizing the time that force is applied on an object has on keeping that object safe or intact. They collect data, generate hypotheses, and share their models with their classmates.	speed/acceleration to investigate the relationship between the variables	own physical actions
6	Lesson period 6	Students revise their models to explain the relationship between the force of balloon collisions and the stopping speed or deceleration of the balloon in the collision.	Adding new components to models (change in velocity /time of impact)	Reflecting on steps taken and results in order to improve a scientific model's explanatory power
7	Lesson period 7	Students plan and carry out an investigation to determine the effect that placing different materials on a cart has on the force of the collision. Students plan and carry out their investigation, generate hypotheses and collect data regarding their suggested experiment.	Investigating the variables that affect the force of collisions	Generating ideas for a scientific experiment
8	Lesson period 8	Students rely on their models and previous investigations (lab data) to create a design sketch and final design for a device that minimizes the damage to a vehicle during collision. Students work in groups, use previous knowledge and engineering ideas to design a device. Once the design is complete, it must be approved by the teacher.	Applying knowledge gained to design a device	Generating and playing with unusual ideas in order to propose how to solve a scientific problem in a personally novel way.
9	Lesson period 9	Students use evidence from data to revise their designs for safety apparatus to minimize the damage on a vehicle during a collision. The teacher may need to engage in group discussion to help generate ideas for how designs could be modified. Students continue the refinement process of their design, building on previous data and group discussion.		Reflecting on the chosen approach relative to others, considering alternative perspectives, and taking steps to revise and improve where relevant
10	Lesson period 10	Students finalize their device and construct explanations of the relationship between force, motion and speed over time and vehicle safety. Students share their device with the rest of class. Students and teacher revisit the driving question and connect it to the steps taken, as well as to the final project and reflect on what they have learned.	Connecting the activities undertaken back to the driving question of improving car safety	Reflecting on the steps taken and connecting knowledge gained to real-life applications

Resources and examples for inspiration

Web and print

- The Concord Consortium's Building Models STEM Resource Finder and SageModeler (https://learn.concord.org/building-models)
- Student packet

Other

- Toy cars, water balloons
- Computers for creating computer models

Opportunities to adapt, extend, and enrich

- This unit is the first in a sequence of three high school Physics units. The other units focus on magnetic fields and electric motors.
- This could be extended by giving examples that explore Newton's laws of motion in cricket or other sports. See, for example, this video on American Football https://www.youtube.com/watch?v=qu_P4lbmV_I

Creativity and critical thinking rubric for science

- Mapping of the different steps of the lesson plan against the OECD rubric to identify the creative and/or critical thinking skills the different parts of the lesson aim to develop

	CREATIVITY Coming up with new ideas and solutions	Steps	CRITICAL THINKING Questioning and evaluating ideas and solutions	Steps
INQUIRING	Make connections to other scientific concepts or conceptual ideas in other disciplines	1,5	Identify and question assumptions and generally accepted ideas of a scientific explanation or approach to a problem	1
IMAGINING	Generate and play with unusual and radical ideas when approaching or solving a scientific problem	1,2,7,8	Consider several perspectives on a scientific problem	9
DOING	Pose and propose how to solve a scientific problem in a personally novel way	2,4,8	Explain both strengths and limitations of a scientific solution based on logical and possibly other criteria (practical, ethical, etc.)	3
REFLECTING	Reflect on steps taken to pose and solve a scientific problem	6,9,10	Reflect on the chosen scientific approach or solution relative to possible alternatives	9,10