

Module 1 Overview

Levers and Mechanical Equilibrium

The Hardware Store Science program’s curriculum is appropriate for an introductory high school Integrated Chemistry and Physics (ICP) course or introduction to Career Technology Education (CTE) courses. The merging of the inquiry-based Science experiments and the engineering design process leads to an integrated STEM course that prepares students for careers in STEM related professions. Throughout the program, students will engage with content from science, technology, engineering and math through the context of engaging problems solving activities and competitions. In the process, students learn technology, engineering and math concepts directly related to the theme of conservation of energy, as it applies to the motion of objects, chemical interactions, and electricity.



The hands-on projects, basic making skills and activities, and integration of all components of STEM (Science, Technology, Engineering, Math) provide an authentic means of encouraging student engagement. In addition, the one-year Hardware Store Science program addresses all state and national academic standards associated with an Integrated Chemistry Physics (ICP) course.



One of the major concepts that runs through physical science are the **Conservation Laws**. These laws state that when looking at an isolated system, certain properties of the system cannot change. These are often referred to as constants. These constants are said to be conserved when any system is in equilibrium. Understanding equilibrium will help students relate the gain/loss of energy to a specific type of motion. They will (i) learn how motion causes work, (ii) learn the application of the work-energy theorem when only conservative forces are involved (leading us to the

conservation of energy principle) and (iii) investigate mechanical equilibrium – a concept that is transferable to other major physical processes throughout this course. An understanding of balanced and unbalanced forces will be used in subsequent modules studying object motion and its causes.

The engineering process, combined with fundamental technology, will be used during the learning of science principles and content. Understanding how engineers apply the design process steps to create, prototype, and manufacture items will greatly enhance student learning and retention of concepts that are otherwise abstract in nature. Applying scientific knowledge to solve everyday problems is one of the fundamental aspects of an engineering career, while inquiring into scientific phenomena in action will solidify the learning process.

Prototyping, building, testing, and producing usable products is a major job description of engineers and technicians today. The Engineering Design lessons provide students with first-hand experience with not only the career tasks of an engineer, but the use of such technology as modeling software, 3D printing, and rapid prototyping. Each lesson will focus on one particular aspect of the engineer career field, culminating in the development of a usable model for conducting scientific investigations throughout the remainder of the Hardware Store Science program. This thinking process will continue to be developed as students encounter more complex questions and scenarios.



The Program Introduction Module has the following components.

1. Objective and Lesson Plan. Statement of educational purpose of the module, learning objectives and sample lesson plan for the topic.
2. Investigations and karting Activities. Investigations include a description of (i) the experimental apparatus, (ii) the various steps needed for construction, (ii) detail instruction on one experiment, and (iv) inquiry questions. Karting activities include materials that have students using the go kart to learn related content within the context of motorsports and go-kart racing.
3. Background and Context. Material that describes the working knowledge behind phenomena that is being studied as well as how that phenomena connects to practical applications.
4. Practice Problems. End of lesson practice problems and that can be completed as Homework or an in-class activity. Each question is a review of a question found within the background materials and linked to specific questions found in the end of lesson quizzes.
5. Additional Lesson Resources (only available to the teacher). Includes (i) standard lesson components such as graphic organizers, bell assignments, slideshows etc., (ii) Practice Problems, (iii) answer keys with worked problems and (iv) links to helpful online resources.
6. Assessment Tools (only available to the teacher). Includes such things as (i) exit tickets, (ii) quizzes, (iii) unit assessments, and (iv) answer keys. . Each of these questions are linked to the background materials and practice problems.

Learning Objectives

Students will learn Newton’s 1st law of motion and the influence of Aristotle and Galileo on its development. An investigate into balanced and unbalanced forces will lead students to develop free-body diagrams as a means of visualizing the forces acting on an object. Next, students will use their knowledge of balanced and unbalanced forces as a means of connecting with the concept of a lever. Three classes of levers will be explored using the position of the fulcrum, an applied input force, and the resulting output force. Students will learn about mechanical advantage and how to determine the mechanical advantage of a lever. Students will then investigate lever action in a manner that will allow them to determine the equilibrium rule for a simple lever with a centrally located fulcrum. Group members will utilize hand tools for assembling their fulcrum and beam. After collecting data to calculate the force distance ratio required on one side of a balanced board to lift an object of greater mass on the other side of the balanced board, students will determine the mathematical rule for equilibrium.

Guiding Questions

How does the action of a lever demonstrate mechanical equilibrium?

Learning Objectives (SWBAT)

- Identify and explain the difference between balanced and unbalanced forces.
- Demonstrate an understanding of Newton’s 3rd law by identifying action and reaction pairs.
- Utilize hand tools to construct a fulcrum for investigating equilibrium and mechanical advantage of a lever.
- Investigate lever action and use collected data to support the equilibrium rule.



- Demonstrate an understanding of levers and the equilibrium rule by obtaining a minimum score of 70% on the Levers Practice Quiz.

Key Concepts

- Action
- Balanced Force
- Caliper Use
- Engineering Design Process
- Equilibrium
- Force
- Inertia
- Interaction
- Mass
- Measurements and dimensions
- Mechanical Advantage
- Prototyping/Modeling
- Rapid Prototyping
- Reaction
- Work
- Tolerance within product dimensions
- Unbalanced Force
- 3D Printing

Unit Timeframe and Lesson Components

Traditional Classroom – 11 Days (45-55 minutes); Day 4 Lesson Plan is dedicated to allowing student groups to rapid prototype a model “car”. Days 7 students use Tinkercad modeling software and 8 begin printing their 3D models. Days 5 and 10 students utilize checklists for evaluating prototypes and models.

Lesson 1 – Understanding Mechanical Equilibrium	Connected Resources	STEM Content
<p>Engage – Students will learn about the causes of motion during a discussion of Newton’s 1st law of motion. During this discussion students will learn about the influence of Aristotle and Galileo on the development of Newton’s laws of motion. Students will investigate balanced and unbalanced forces as they relate to Newton’s development of his motion laws. Students will be asked to develop free-body diagrams as a means of visualizing the forces acting on an object. The accurate depiction of free-body diagrams will be the first step in determining whether all forces acting on an object are balanced or unbalanced. Students will apply their understanding of forces involved in motion by completing a series of open-ended questions. <i>(ICP.3.2)</i></p> <p>Explore – Students will use their knowledge of balanced and unbalanced forces as a means of connecting with the concept of a lever. Three classes of levers will be explored, from the position of the fulcrum, an applied input force, and the resulting output force. Students will learn about mechanical advantage and how to determine the mechanical advantage of a lever. Students will demonstrate their understanding of levers and mechanical advantage by determining the mechanical advantage from an input and output force, and/or resolve a mechanical advantage into its input and output forces. <i>(ICP.4.4; POE-3.3, 6.1)</i></p>	<p><i>STEM Content Document</i></p> <p>Expanded Lesson Plan, 1.1a</p> <p><i>MSTEM-Lesson Log</i></p> <p><i>Cause of Motion PPT Slideshow, 1.3a</i></p> <p><i>Balanced and Unbalanced Forces, 1.3b</i></p> <p><i>Levers and Equilibrium PPT Slideshow, 1.3c</i></p> <p><i>Action Reaction Pairs, 1.3d</i></p> <p><i>Levers Experimental Investigation Data Sheet, 1.2a</i></p> <p><i>MSTEM-Investigation Scoring Rubric</i></p> <p><i>Work PPT Slideshow, 1.3e</i></p>	<p><i>Action-Reaction Pairs</i></p> <p><i>Balanced and Unbalanced Forces</i></p> <p><i>Collaboration</i></p> <p><i>Engineering Design Process</i></p> <p><i>Equilibrium</i></p> <p><i>Force</i></p> <p><i>Mathematical Reasoning</i></p> <p><i>Mechanical Advantage</i></p> <p><i>Problem Solving</i></p> <p><i>Scientific Inquiry</i></p> <p><i>Technological Literacy</i></p>

<p>Engineer – Students are organized into lab groups of 3 to 4 individuals and tasked with the creation of a fulcrum for investigating lever action in a manner that will allow them to determine the equilibrium rule for a simple lever with a fulcrum located in the center of the lever. Group members will utilize a common wood saw for cutting 2x4 material to length, a hack saw for cutting ½ inch aluminum the length, and a cordless drill/driver for assembling their fulcrum with screws. Groups will also design a board that can be used to easily measure the distance an object is placed from the fulcrum. Students will receive instruction on use of hand saws, cordless drill/drivers, and a standard retractable tape measure. <i>(ICP.3.5, 3.7; IED-0.1, 2.6, 6.10; POE-3.2, 3.4, 3.7, 6.1, 6.6)</i></p> <p>Explain – After collecting data during an investigation into how a simple lever can demonstrate mechanical equilibrium, groups share their findings. Data will be collected from placing weights, of different mass, at various locations on a balanced board (i.e. a seesaw). Using weight and placement measurements, students will calculate the force distance ratio required on one side of a balanced board to lift an object of greater mass on the other side of the balanced board. Students will also determine the mathematical rule for equilibrium. Students will share their findings with their peers and evaluate the success of each group’s investigation based on how accurately a group determines similar equilibrium rules. <i>(ICP.3.2, 4.4; POE-3.2, 6.1, 6.4)</i></p> <p>Evaluate – Students will participate in a review discussion on causes of motion, balanced and unbalanced forces, action reaction pairs, the equilibrium rule and mechanical advantage. They will be introduced to the concept of work as a prelude to future investigations and be assessed on the module learning objectives and activities. The practice quiz assessment will cover balanced and unbalanced forces, lever equilibrium, and action reaction pairs. <i>(ICP.3.2, 4.4; POE-3.2, 6.1, 6.4)</i></p> <p>Deliverables</p> <ul style="list-style-type: none"> ● Balanced and Unbalanced Forces ● Action Reaction Pairs ● Levers Investigation Data and Analysis ● Levers, Work and Mechanical Advantage Practice Problems ● Mechanical Equilibrium Practice Quiz 	<p><i>Levers Work and Mechanical Advantage, 1.4a</i></p> <p><i>What is Horsepower MUTT Article, 1.5b</i></p> <p><i>MSTEM-ABC Vocabulary Reading Strategy</i></p> <p><i>Mechanical Equilibrium Practice Quiz, 1.6a</i></p> <p><i>U1L1 Warm-ups and Exit Tickets PPT Slideshow, 1.5d</i></p> <p><i>Educator Activity Answer Key, 1.5a</i></p> <p><i>MSTEM-Maker Skills</i></p>	
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Materials and Equipment Needed

- Chalkboard or Overhead Projector
- Computers with Internet access
- 1x3 MDF board (8 foot, \$3.69 @ Menards)
- 2x4 (8-foot framing lumber, \$2.49 @ Menards)
- Screw (1-pound box of #7 x 2" Construction Screws, \$3.79 @ Menards)
- 1/8-inch flat aluminum (1/8 x 2 x 36 Hillman solid flat aluminum, \$10.65 @ Menards)
- Hex Nuts (Midwest Fastener® 3/4" - 10 Zinc Grade 2 Coarse Thread Hex Nut – 87 Count, \$23.61 @ Menards)
- Hand Saw with Miter Box base (MasterForce® 14" Hand Back Saw with Miter Box, \$7.98 @ Menards)
- Metal cutting saw (Hacksaw) (Tool Shop® 12" Plastic Dipped Steel Handle Adjustable Hacksaw Frame, \$4.82 @ Menards)
- Electric drill/driver (Black & Decker® 20 V Max Lithium-Ion Cordless 3/8" Drill/Driver Kit, \$39.99 @ Menards)
- Screw driver (6-in-1 Screw Driver, \$2.97 @ Menards)
- Drill bits (7/64") (Tool Shop® Titanium Twist Drill Bit Set - 21 Piece, \$9.99 @ Menards)
- Tape measure (Performax 12 foot, \$4.99 @ Menards)
- Scale (Mainstays Slim Digital Scale, \$14.86 @ Walmart)

Optional Materials

- [3-D Printed M-STEM Accel Car Body](#) (STL file found at hardwarestore.science.org This file will open using Ultimaker Cura software, a free software download. The File can also be found at Tinkercad.com by searching M-STEM Accel Car Body)
- [3-D Printed M-STEM Wheels](#) (STL file found at hardwarestore.science.org This file will open using Ultimaker Cura software, a free software download. The File can also be found at Tinkercad.com by searching M-STEM Wheels)
- Wire Clothes hanger (10 pack, \$1.44 @ Walmart)
- #20 O-Ring (1-3/16" O.D. x 1" I.D., \$0.79 @ Menards) (Qty – 4)

Assessment

- [Lever Investigation](#) to assess student understanding of how a simple lever can demonstrate mechanical equilibrium, calculate the mass and distance required to balanced board, and determine the equilibrium rule for a lever.
- [Levers Work and Mechanical Advantage Practice Problems](#) to assess student learning and understanding of Newton's laws.
- [Mechanical Equilibrium Practice Quiz](#) to assess student understanding of balanced versus unbalanced forces, calculating force, work and mechanical advantage, and Newton's third law.
- [Engineering Design Process](#), to assess student learning and understanding of tolerance, dimensions, and the 5 phases of the engineering design process.
- [MSTEM Accel Car Model](#), to assess student learning and understanding of the design process through the development, design, and 3D Printing of their MSTEM Accel Car that will be utilized during the Seed Velocity Acceleration Module.

Career Connections

Throughout this unit students will learn critical skills related to human-centered approaches to engineering design and competencies in a repeating design process; design, prototype, test, redesign.

These skills will benefit students within all STEM career fields, especially technology and engineering. Broader career pathways include occupational pathways such as; manufacturing, Electrical Engineering, Mechanical Engineering, user experience (UX) design, and computer science.

Students will be introduced to the use of common hand tools and measuring devices as they relate to fabrication and assembly of products and components. These skills will benefit students within STEM career fields, especially construction, building trades, craftsman, and technicians. Broader career pathways include occupational pathways such as; commercial and residential contracting, machine shop technician/tradesman, and advanced manufacturing.

Students will become familiar with project management as it pertains to time management, managing resources and supplies, and developing project goals and outlines. These skills will benefit students within STEM career fields, especially science, technology, and engineering. Broader career pathways include management and administration activities in occupational pathways such as; Advanced Manufacturing, Engineering, user experience (UX) design, computer science, commercial and residential contracting, machine shop technician/tradesman, and advanced manufacturing.

Indiana based employers with career opportunities utilizing the skills taught in this lesson include: AES Corporation, Delta Faucet Company, Nidec Motor Corporation, Subaru of Indiana Automotive, Adidas, Kort Builders, J.R. Kell Company, Ely Lily and Company, and Wabash National Corporation.

Indiana Academic Standards

- [Science and Engineering Process Standards:](#)
 - SEPS.2 Developing and using models and tools
 - SEPS.3 Constructing and performing investigations
 - SEPS.5 Using mathematics and computational thinking
- [Literacy in Science/Technical Subjects: Grades 9-10:](#)
 - LST.1 Read and Comprehend science and technical texts independently and proficiently and write effectively for a variety of discipline-specific tasks, purposes, and audiences
 - LST.3 Build understanding of science and technical texts, using knowledge of structural organization and author’s purpose and message.
 - LST.4 Build understanding of science and technical texts by synthesizing and connecting ideas and evaluating specific claims.
- [Integrated Chemistry and Physics \(ICP\)](#)
 - ICP.3.2 Construct force diagrams and combine forces to determine the equivalent single net force acting on the object when more than one force is acting on the object.
 - ICP.3.5 Qualitatively describe and quantitatively determine the magnitude and direction of forces from observing the motion of an object of known mass.
 - ICP.3.7 Develop pictorial and graphical representations which show that when two objects interact, the forces occur in pairs according to Newton’s third law and that the change in motion of each object is dependent on the mass of each object.
 - ICP.4.4 Qualitatively and quantitatively analyze various scenarios to describe how energy may be transferred into or out of a system by doing work through an external force or adding or removing heat.
- [Math Process Standards](#)
 - PS.1 Make sense of problems and persevere in solving them.
 - PS.3 Construct viable arguments and critique the reasoning of others.
 - PS.4 Model with mathematics.
 - PS.5 Use appropriate tools strategically.

- PS.6 Attend to precision – Communicate precisely, use terms and symbols appropriately, specify units of measure, and calculate accurately and efficiently
- PS.7 Look for and make use of structure - Explain patterns and structures, know and explain properties that apply (*cumulative, for example*)
- PS.8 Look for and express regularity and repeated reasoning - Look for repetition in problems, explore and find short cuts, take repetitions and generalize into new situations using newfound shortcuts, check answers for reasonableness
- [Introduction to Engineering Design Standards](#)
 - IED-1.5 Students perform the steps of the design process to develop and analyse products and systems – Describe the steps in the design process, apply the steps of the design process as they are used to solve the problem, describe the iterative nature of the design loop, assess and refine original design solutions based upon reflection, critique, practice, and research.
 - IED-6.10 Students create designs using a variety of modeling techniques to communicate information – Formulate methods of communicating designs using various forms of modeling such as conceptual, graphical, mathematical, physical, or computer modeling.
- [Principles of Engineering non-PLTW Standards](#)
 - POE-5.3 Students apply the laws of motion as they apply to principles of engineering – Explain how gravity impacts motion.
- **Technology Standards related to STEM Careers**
 - **STEM-T.2** Students use a variety of technologies within a design process to identify and solve problems by creating new, useful or imaginative solutions.
 - **STEM-T.5** Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.

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