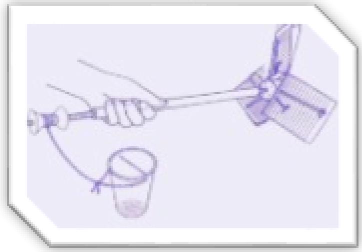
MacGyver Windmills Lesson Plan



Description: Students design, build, and test windmills using everyday materials to explore how energy is transferred from wind to mechanical motion. After testing and redesigning, they extend their learning by calculating the energy and power produced by their windmills, connecting their models to real-world wind turbines.

Grade Level: 9–12

Learning Objectives:
By the end of this lesson, students will be able to:

- Design and construct a functional windmill using common materials.
- Test and analyze how variations in blade design and friction influence windmill performance.
- Calculate the energy (joules) and power (watts) produced by their windmills.
- Explain the relationship between their windmill models and real-world renewable energy systems.

Subject Areas: Physics, Engineering, Environmental Science

NGSS:

Physical Science (PS3: Energy)

- **HS-PS3-3** – Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- **HS-PS3-5** – Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. *(applies if you extend to generator/electrical output)*

Engineering Design (ETS1: Engineering Design)

- **HS-ETS1-2** – Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- **HS-ETS1-3** – Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Earth & Human Activity (ESS3: Earth and Human Activity)

- **HS-ESS3-4** – Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

- **Disciplinary Core Ideas (DCI):**
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and Energy Transfer
  - PS3.C: Relationship Between Energy and Forces
  - ETS1.A: Defining and Delimiting Engineering Problems
  - ETS1.C: Optimizing the Design Solution
- **Science and Engineering Practices (SEP):**
  - Asking questions and defining problems
  - Planning and carrying out investigations
  - Analyzing and interpreting data
  - Using mathematics and computational thinking
  - Constructing explanations and designing solutions

- **Crosscutting Concepts (CCC):**
    - Cause and Effect
    - Systems and System Models
    - Energy and Matter

Time Length: 2 class periods (45–60 minutes each)

Materials Preparation:
- Gather simple building supplies: cardstock, index cards, cardboard, tape, glue, straws, skewers, paper clips, scissors, hot glue (if available), small fans, string, and small weights or cups (for lifting).
- Prepare measurement tools: stopwatch, ruler, protractor, scale (for measuring mass lifted), voltmeter/energy sensor (optional, if generating electricity).
- Set up a safe testing area with fans to provide consistent wind.
- Create example windmill models to show possible designs without revealing an "ideal" solution.

Safety Considerations:
- Ensure students use scissors, hot glue guns, or cutting tools under supervision.
- Keep loose clothing, hair, or jewelry away from fans and rotating blades.
- Use lightweight materials for blades to minimize hazards if they detach.

Classroom Setup:
- Organize students into small groups (3–4 works well).
- Arrange a central testing station with fans and weights for consistent testing conditions.
- Provide lab notebooks or worksheets for sketching designs, recording test data, and calculating energy/power.

Materials:

For each group (2–3 students):
- **Blades Options**
    - Index cards
    - Paper
    - Paper plates
    - Scrap cardboard
    - Cardstock
    - Plastic pieces
- **Hub Options**
    - Foam cylinder
    - cork
    - pool noodles cut in ¼ pieces
    - spools
- **Shaft Options**
    - Skewer
    - Dowel
    - Cardboard tube
    - Plastic straws *(best option-10 mm diameter and 8 1/2" height)*
- **Lifting Mechanism Options**
    - Small cup
    - Small bucket
    - Washers
    - Pennies

- Gram weights
- String

- **Other**
  - T-pins or push pins
  - Paper clips
  - Rubber bands
  - Tape
  - Hot glue (optional)
- **Shared materials:**
  - Box fan (20″ × 20″ recommended) bigger classes you may want more than one fan.
  - Rulers or measuring tape
  - Stopwatch/timer
  - Scissors
  - Pencils
  - Marker

Modifications:

Instructional Supports:

- Provide **step-by-step visual instructions** (diagrams, photos, or video clips) alongside verbal directions.
- Offer a **partially completed data table** or calculation template to reduce the load of setting up math work.
- Allow use of **calculators or digital tools** for energy and power calculations.
- Give **sentence starters or graphic organizers** to help with written explanations and reflections.

Task Adjustments:

- Allow students to **choose simpler materials/designs** (e.g., pre-cut blades, pre-drilled hubs) to reduce fine motor demands.
- Provide **extra time** for building and testing.
- Reduce the number of redesign cycles required (e.g., at least one instead of multiple).
- Permit students to focus on **one variable at a time** (e.g., blade angle only, rather than blade size, shape, and number).

Collaboration Supports:

- Pair IEP students with supportive peers in small groups, ensuring roles are **clear and accessible** (e.g., “data recorder,” “timer,” “tester”).
- Encourage peer tutoring for math-heavy portions.
- Provide opportunities for oral explanations instead of written responses if that better demonstrates understanding.

The Problem: (Driving Question)

- *How can we design a windmill that uses wind energy to lift a weight, and how much energy and power can it produce?*

Procedure:

Engage: (5 min)

- Show images of wind turbines.
  - Ask: *How do engineers maximize energy from wind?*
- Introduce challenge: Build a windmill to lift weight using wind energy.

Explore: (20–25 min)

- Students design/build their windmill.

- Test lifting ability (mass lifted OR height lifted).
- Record results.

Explain: (10 min)

- Teacher reviews key terms: **kinetic energy, mechanical energy, torque, friction, blade pitch, angle of attack**.
- Discuss how real turbines maximize energy capture.

Elaborate: (20–25 min)

- Students redesign based on first trial.
- Test again and compare results.
- **Extension (Quantitative Analysis):**
    - Use formula to calculate: **Energy**:

$$E(J) = m(kg) \times g(9.8m/s^2) \times h(m)$$

    - Measure time (s) to lift load.
    - Calculate **Power**:

$$P(W) = \frac{E(J)}{t(s)}$$

    - Standardize height (≈ 0.5 m).

Evaluate: (10–15 min)

- Students complete analysis questions, redraw design, write conclusion, and connect to real-world turbines.

Teacher Notes:

- Choose one test type (weight lifted OR height lifted). Keep fan speed, distance, and lift height constant.
- Remind students the straw acts as a bearing to reduce friction.
- Emphasize safety (scissors, skewers, glue).
- Encourage multiple redesigns—engineering is iterative.

Assessment:

- Student worksheet (sketches, trial data, energy/power calculations).
- Analysis questions: friction, blade design, pitch, attachment.
- Reflection on performance and real-world connections.
- Teacher observation during group work.

Background Information:

Wind turbines capture the kinetic energy of moving air and convert it into mechanical or electrical energy. Historically, windmills were used for pumping water and grinding grain, demonstrating how humans have long harnessed wind for useful work. Today, wind turbines play a vital role in renewable energy production, helping reduce dependence on fossil fuels.

The design of the blades—such as their shape, pitch (angle), number, and material—significantly affects turbine performance. Students can observe how these factors influence efficiency through hands-on building, testing, and redesigning of windmills. Concepts of force, torque, energy transfer, and power output are explored directly in this activity, making it a strong connection to both physics and engineering practices.

By calculating energy and power from their windmill trials, students connect classroom experiments to real-world applications of renewable energy and the science of sustainability.

- American Wind Energy Association (AWEA). *How Do Wind Turbines Work?* U.S. Department of Energy, 2021. https://www.energy.gov/eere/wind/how-do-wind-turbines-work
- KidWind. *MacGyver Windmills Activity.* KidWind Project, 2025. https://kidwind.org/activity/macgyver-windmills
- U.S. Department of Energy. *History of U.S. Wind Energy.* Office of Energy Efficiency & Renewable Energy, 2020. https://www.energy.gov/eere/wind/history-us-wind-energy
- Wind Energy Technologies Office. *Wind Energy Basics.* U.S. Department of Energy, 2022. https://www.energy.gov/eere/wind/wind-energy-basic

Glossary:

- **Kinetic Energy** – The energy of motion. Moving air (wind) has kinetic energy that can be captured by wind turbines.
- **Mechanical Energy** – The energy associated with motion and position of an object. A windmill converts wind's kinetic energy into mechanical energy in the spinning blades and shaft.
- **Torque** – A measure of the turning force on an object, such as the twisting force that makes the windmill shaft spin.
- **Friction** – A force that resists motion when two surfaces are in contact. In a windmill, friction in the shaft or bearings can slow the blades down.
- **Blade Pitch** – The angle at which a blade is tilted compared to the direction of the wind. Adjusting blade pitch changes how much energy the blades capture.
- **Angle of Attack** – The angle between the incoming wind and the surface of the blade. The angle of attack affects lift and drag, influencing how efficiently the blades spin.

Answer Key:

This teacher guide provides sample calculations, suggested answers, and tips to support high school students as they complete the MacGyver Windmill activity. It aligns with the provided student worksheet.

Sample Trial Data:

Trial #	Mass (kg)	Height (m)	Time (s)	Notes
1	0.5	0.50	6.0	Blades angled too steep
2	0.5	0.50	4.2	Improved blade angle
3	0.5	0.50	3.8	Reduced friction at axle

Sample Calculations:

Energy *(J)* = ***Mass*** *(kg)* × ***Acceleration of Gravity*** *(9.8 m/s²)* × ***Height*** *(m)*

Power *(W)* = ***Energy*** *(J)* ÷ ***Time*** *(s)*

Example using Trial 2 data:

Mass = 0.5 kg, Height = 0.50 m, Time = 4.2 s

Energy = 0.5 × 9.8 × 0.50 = **2.45 J**

Power = 2.45 ÷ 4.2 = **0.58 W**

Analysis Question Guidance:

- What is holding it back/preventing spin?
  Possible answer: friction at axle, poor blade angle, uneven blades.
- What parts were most difficult to design and make functional?
  Possible answer: Students may say cutting and attaching blades.
- How did you attach your blades?
  Possible answer: Tape, glue, hot glue, push pins, etc.
- Where is there friction in your design?
  Possible answer: Axle, blade connections, string.
- How did you reduce friction in your windmill?
  Possible answer: Using smoother axle, washers, lubrication, reducing blade wobble.
- How did you pitch or angle the blades?
  Possible answer: Students should describe angles (10°–45° typical).
- Were your blades changing pitch frequently?
  Possible answer: If yes, may show instability.
- Did the fan work better from the front of the blades or the side?
  Possible answers: Typically front, where blades catch airflow directly.

Reflection & Conclusion:

- Students should summarize whether their design worked effectively to lift the washers. Encourage them to support answers with data (time, energy, and power).
- Real-world connection: Wind turbine engineers face the same challenges — optimizing blade angle, reducing friction, and ensuring consistent power output.

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