



## **Force to Energy: Increased efficiency through intelligent design**

Curriculum Unit 24.04.08, published September 2024  
by Donovan Spatz

### **Content Objectives**

---

Since we will be studying the physical manifestation of energy in this unit, we will be approaching energy conservation from a somewhat different perspective. The most recent Boston Dynamic-type robots and the James Webb space telescope are examples of technological advancements of ancient technologies that have been in use for more than two millennia and continue to increase the energy efficiency of operations.<sup>1</sup> All physical forces are just manifestations of energy at work, and in this section, we will investigate in detail how efficient a system is in conveying energy from one side to the other using both equations and practical experiments. We shall be expanding in many respects upon the work of Josiah Willard Gibbs, who in 1863 received the first engineering doctorate in the United States from Yale University. In order to better understand the various interacting geometrical or key mechanical precision that need to be taken into account to decrease wear and boost efficiency, Gibbs studied the interaction between the surfaces of the wheel's teeth in his PhD thesis on the form of the key of wheels in spur gearing.<sup>2</sup> My eighth-grade physical science students in Oklahoma learn about the application of force through a system of interactions and how that energy output varies in this unit.

For a system to be efficient, all its components must be monitored to ensure efficiency and minimize loss. Energy is defined as "a fundamental entity of nature that is transferred between parts of a system in the production of physical change within the system and usually regarded as the capacity for doing work."<sup>3</sup> Many of the advancements in energy efficiency and green energy are readily apparent to our pupils, such as the widespread use of solar farms and wind turbines/windmills that provide renewable energy. We also teach students about how to use energy created by smart grid transmission and optimization for end users such as lights, heating, and electronics. But frequently, our students fail to understand the inner workings of those systems that boost efficiency, particularly in mechanical devices where gearing is used. Energy at work takes the form of physical forces. In this section, we will investigate the efficiency and inefficiency of a system while transferring energy from one side to the other using both equations and practical experiments. Over time, there have been notable developments in mechanical drive systems that have resulted in increased efficiency across a range of industrial and commercial applications. The need for increased productivity and performance, combined with technological developments and a deeper comprehension of mechanical principles, has led to the growth of gear drive systems.

## Demographics

---

As the science lead at Carver Middle School, I collaborate with all science instructors on lessons for grades sixth through eighth, and I have eighth grade classes that this material is designed for to get them ready for high school at Booker T. Washington. Since many of our students come from low-income families, exposing them to interesting experimentation is essential to creating a wonder-filled environment in science. Students today live in a culture of instant gratification and believe that all it takes to obtain the answers is a quick internet search. Even the most disinterested kids can and frequently will become curious when given something to handle, as their peers' reactions to the stimulation of wonder do.

With 33,211 kids enrolled, Tulsa Public Schools is the largest school system in Oklahoma. Of these, 37.2% are Hispanic, 22.7% are Black, 22.2% are White, 4.8% are American Indian, 1.5% are Asian, and 1.1% are Native Hawaiian. With 656 students enrolled in grades 6 through 8, Carver Middle School is a magnet school located in the Greenwood district of north Tulsa, Oklahoma. Of these students, 29.1% are White, 28.1% are Black, 25.8% are Hispanic, 10.7% are two or more race, 4.4% are Native American, and 1.5% are Asian. The only school where students can start their participation in the International Baccalaureate program is Carver Middle School that they will continue through at Booker T. Washington High School. Most curricula do a great job of illustrating how we generate power, exposing students to the plethora of methods that include fossil fuels, solar, wind, geothermal, and a host of other possibilities. We have a great opportunity to teach force and physics when it comes to the application of generated or harvested power.

By introducing this level of comprehension into our lessons, students will be able to go above the foundational requirements established by regulatory authorities and get a grasp of how force is applied, rather than just memorizing Newton's equations of motion. Students will get a genuine understanding of Newton's Laws of motion and how they relate to practical experiments in this lesson. The mechanical components of motion and how force is delivered via a system and converted into something useful will be covered in this curriculum. Students will be instructed how advances in scientific understanding have led to the improvement of similar energy harvesting systems across time. Examples of these technologies include improved windmill airfoils and gearboxes that control and increase the efficiency of captured energy.<sup>4</sup> Modern hydroelectric facilities are the result of the innovation that made it possible to harness the power of moving water, starting with a basic water wheel. Since the generation of energy is essential to many aspects of Oklahoman life and contemporary culture, it is critical that we prepare our students to be responsible environmental stewards. Examining every option to boost productivity is a great way to encourage scientific methods like experimentation and design cycles and critical thinking abilities.

Students' engineering knowledge equips them with the knowledge and abilities needed to assure community growth, it plays a significant role in reshaping communities. Students in these communities are given the technical knowledge and engineering expertise that grows to support everyone. The appropriate use of force is crucial in the subject of robotics, particularly when it comes to keeping a unit's position. Engineers understand that increasing power alone is not always the same as applying it correctly. Whether it's more force or speed, this may be accomplished in a variety of ways by utilizing gear ratios and a large range of gear choices.

Additionally, students will develop creative answers to problems like failing to recognize electricity transmission infrastructure flaws. The critical thinking, problem-solving, and analytical abilities that

engineering education promotes are also crucial for advancing social justice and economic growth in low-income communities.

When we consider our lesson from a global perspective, we find that engineering studies have a big influence on low-income communities by generating jobs. People who are proficient in engineering fields can acquire higher-paying employment and enhance their overall quality of life by increasing their competitiveness in the job market. This promotes general economic growth in addition to lessening poverty in these places. By bridging the wealth gap between richer and poorer areas, this economic expansion advances social justice and inclusivity.

Additionally, engineering education makes it possible for people to launch their own companies, encouraging self-sufficiency and entrepreneurship in the neighborhood and bringing about beneficial changes. A more just and wealthy society is the result of engineering education's positive effects on low-income communities, which open doors for socioeconomic growth, female emancipation, and general quality of life enhancement.

## Force to Energy

---

### Newton's laws

As students begin examining Isaac Newton's three laws of motion, we will examine the fundamental concepts that govern how objects act when they are in motion. These laws will provide a framework for comprehending the flow of energy and forces within a system.

Newton's first law of motion states that if there is not an external force acting on an item, it will remain at rest. The concept of inertia and the tendency of an item to resist changes in motion until energy is applied is illustrated by this law.

An object's acceleration is directly correlated with the net force acting on it and inversely proportionate to its mass, according to Newton's second law of motion. This law can be expressed mathematically as  $F = ma$ , where "m" is the mass of the object, and "a" is the acceleration, and "F" is the net force. This law shows the link between force, mass, and acceleration all of which must be expressed in SI units and demonstrates how an external force can cause an object to accelerate or decelerate.

Every action has an equal and opposite reaction, according to Newton's third law of motion. This law will demonstrate how, in response to an application of force by one object on another, the second will apply an equal and opposite force to the first. This theory describes how the energy exchanges among the objects in a system result in balanced forces and motion.

By understanding Newton's laws of motion, students may assess and predict the behavior of components in a system using mathematical equations. In this unit, students will start with a trebuchet (Figure 1) throwing a lead weight. This experiment will provide a foundation for understanding force interactions and energy manifested in motion in a variety of settings. The designing and building of systems that rely on the concepts boosting lifting capacity also benefit from Newton's laws.

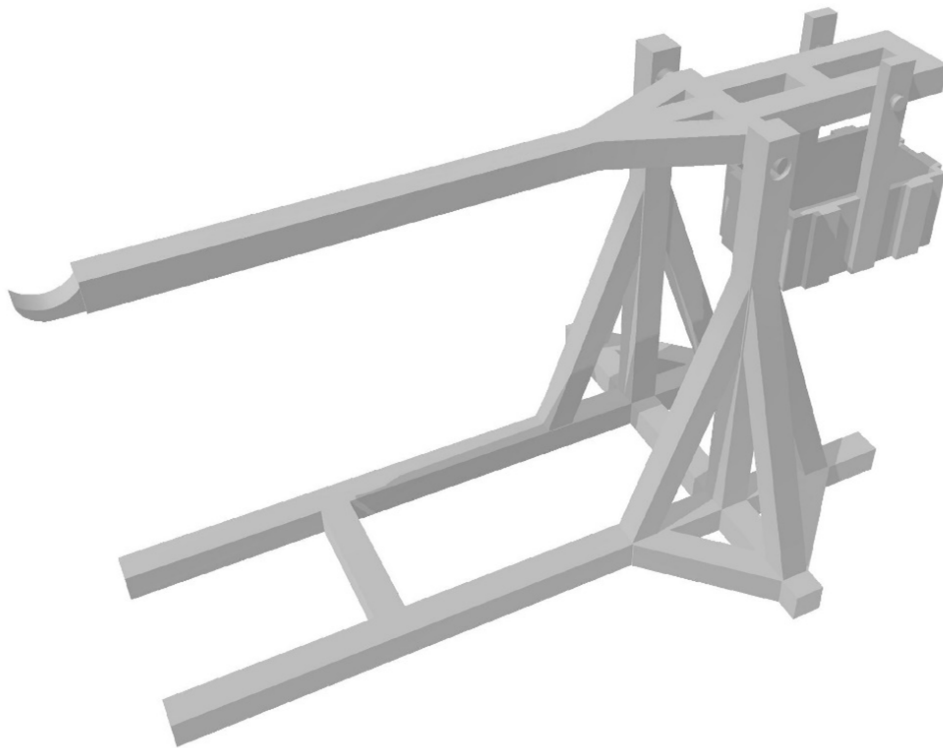


Figure 1. Trebuchet.

This course explores the inner system of energy using Newton's equations of motion. Students will also learn how to effectively apply mechanics and engineering to solve force and motion-related problems. These guidelines are used, for example, by engineers to optimize the operation of machines and automobiles and to build earthquake-resistant and wind-resistant structures.<sup>5</sup> By applying Newton's laws, scientists can understand complicated systems and anticipate their behavior with remarkable accuracy.

All things considered, a solid basis for understanding how objects move and interact with one another within a system is provided by Newton's laws of motion. By employing these guidelines to evaluate and predict the behavior of objects in various situations, we can design and construct systems that depend on the ideas of motion and force. The fundamental ideas of Newton's laws form the basis of physics research and greatly influence our perception of the natural world.

## Gears as Levers

---

With better gearing, alternative energy sources can operate more efficiently. Recent years have seen a significant focus on developing alternative energy sources due to concerns about climate change and the depletion of natural resources. One of the key components to increasing the efficiency of alternative energy sources is the development of new mechanisms that permit more predictable and efficient energy generation.

To increase sustainability and efficiency overall, these creative gears are crucial for harvesting energy from renewable energy sources including geothermal, wind, and hydroelectric power.<sup>6</sup>

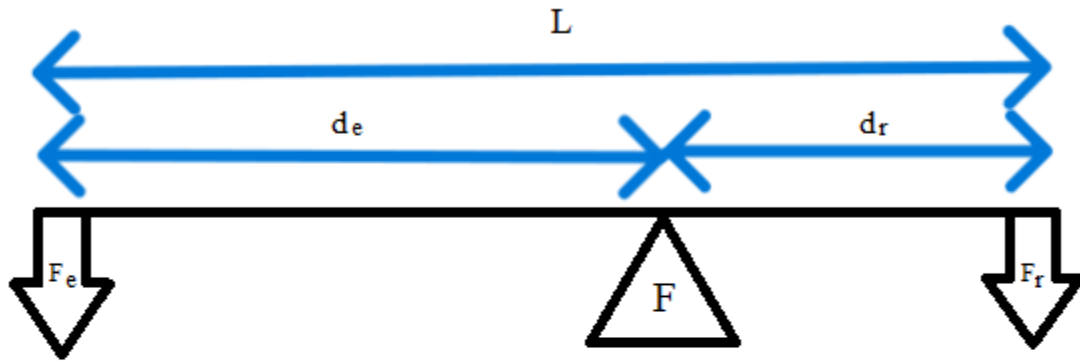
As the world strives to address challenges like climate change and the depletion of natural resources, the necessity to develop alternative energy sources has increased. One of the biggest barriers to employing alternative energy sources has been the inefficiency of the technologies used to capture and convert them into forms that are useful. These include wind and hydroelectric, as examples. However, recent advancements in gear technology have increased the practicality and cost of alternative energy sources by allowing for a large boost in efficiency.<sup>7</sup> Because of the new gears' decreased wear and friction, which lowers energy losses, a higher percentage of the energy produced by hydropower plants or wind turbines may be converted into useful power. Because they can operate more efficiently and provide more power with less input energy, alternative energy systems are becoming more competitive with traditional fossil fuel-based energy sources.

As I teach students about high-efficiency gearboxes and materials science, I stress the importance of both and how they have contributed significantly to increasing the efficiency of alternative energy sources. Thanks to the introduction of novel materials like carbon fiber and advanced polymers, gears are now being produced that are stronger, lighter, and more resilient than before. This helps to reduce energy losses from wear and friction and makes alternative energy systems more dependable and effective over long periods of time. Another important development in gear technology that has raised the efficiency of alternative energy sources is the use of variable-speed transmissions. Variable-speed transmissions allow wind turbines and devices powered by electricity from solar panels to adjust their operating speeds in response to environmental changes, which can maximize energy capture and conversion efficiency. Because of this, alternative energy systems are now able to adapt to changes in the quantity of wind or water, ensuring that they are always operating at their peak efficiency.<sup>8</sup>

## **Gear Technology Advancements Improving Society**

---

Engineering has a lengthy history of creation and advancement, with each new finding built on the knowledge and skills acquired before. Born in the third century BC, the Greek mathematician, physicist, and engineer Archimedes was one of the first engineers. Archimedes was also considered the father of mathematics and many of the equations we use are based on his observations and understanding of the real world. Understanding basic mathematical principles allows us to develop more complex techniques over time such as the formula for mechanical advantage (Figure 2).



$$MA = \frac{F_r}{F_e} = \frac{d_e}{d_r}$$

Figure 2. Formula for mechanical advantage (MA).

His invention of the Archimedes screw, a device for lifting water from a lower to a higher elevation, is just one of his many noteworthy contributions to engineering. This invention revolutionized irrigation and provided a template for other water-lifting devices such as screw pumps.

In several fields, including mechanical engineering, new discoveries have been made as engineering has advanced throughout the years. One of the most significant advancements in mechanical engineering in recent years is the invention of strain wave gear technology (Figure 3). Strain wave gears are a type of gear system that has a high torque capacity, small size, and accurate, backlash-free motion control. This is achieved through a complex system of three interlocking gears working together to always achieve a roughly 30% interface between the gear surfaces. As an inner elliptical wave generator gear turns it interacts with the flex spline which can transfer its torsional force to the outer circular spline gear. These gears are widely used in robotics, aerospace, and other industries where precise motion control is crucial. The development of strain wave gear technology has significantly advanced mechanical engineering by providing designers and engineers with additional tools to utilize in the creation of innovative and efficient systems. One of the main features of strain wave gears is their high torque capacity, which allows for precise control over large loads. For applications where precise motion control is essential, such as robotic arms and satellite positioning systems, this makes them ideal.

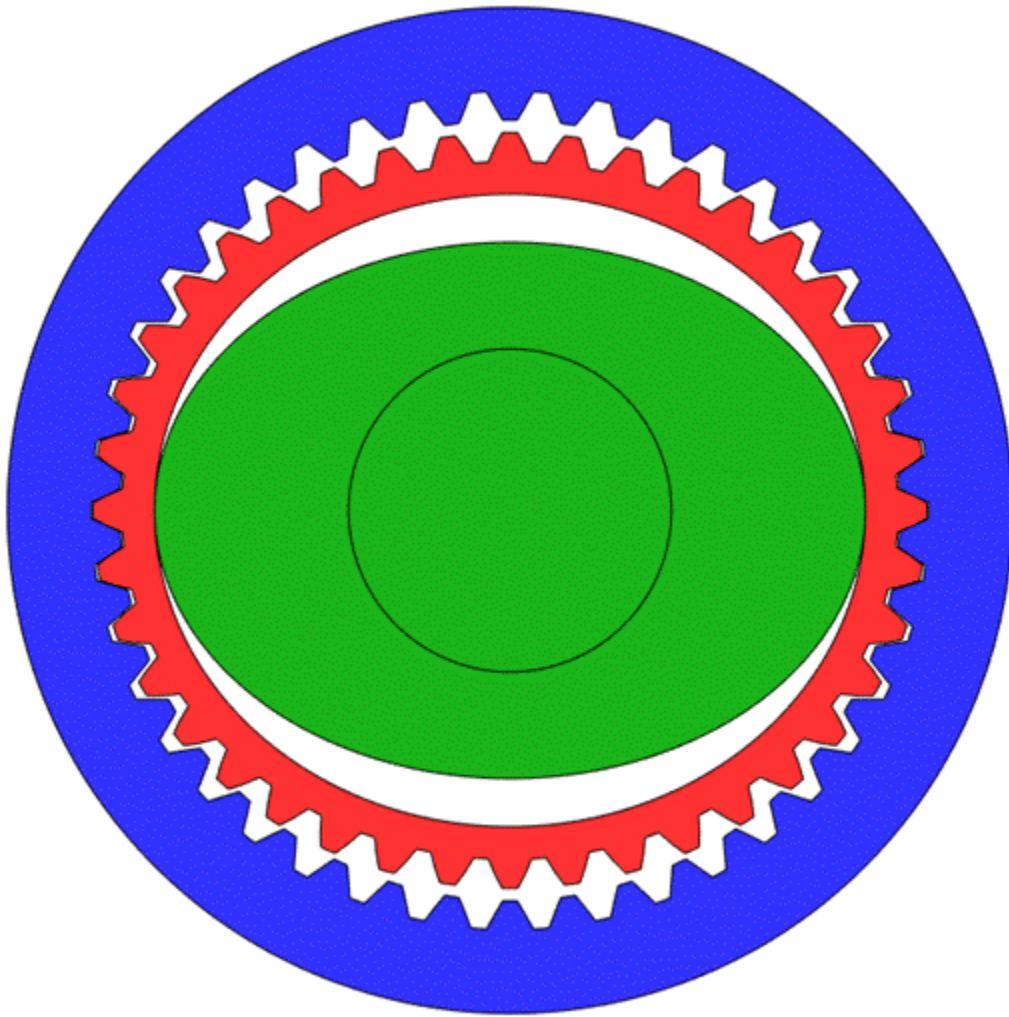


Figure 3. Strain wave gear (“Strain Wave Gearing” 2024).

Another advantage of strain wave gears is their compact size, which increases their space efficiency in a range of applications. Strain wave gears are a great and versatile solution for a variety of engineering difficulties due to their high torque capacity and compact size. Moreover, strain wave gears ensure accurate and consistent performance in demanding applications by offering backlash-free motion control.

The development of strain wave gear technology has ushered in a new era of mechanical engineering innovation, with engineers and designers continuously pushing the boundaries of what is practical. As the demand for more precise and effective motion control systems increases, strain wave gears are anticipated to play an increasingly important role in a range of sectors.

From Archimedes' early discoveries to the most recent advancements in strain wave gear technology, engineering has always been a subject of development and advancement. The development of strain wave gears has significantly advanced mechanical engineering by providing engineers with new tools and knowledge to create innovative and efficient systems. Strain wave gears' high torque capacity, small size, and backlash-free motion control provide the potential to completely revolutionize several sectors and pave the way for even greater advances in engineering.

With this unit my students will deepen their comprehension of the concepts and learn how they can



manipulate energy as force and the subsequent generation of power through work by controlling the power that surrounds them, from the most modern strain wave gearing which is used to gear servo drive motors for motion control in robots to an Archimedes screw which is still in use today. It is the wonder we instill by manipulating devices that will carry forward and develop a level of retention with knowledge beyond the simple textbook.

## Mechanical Drive Systems

---

Notable advancements in mechanical drive systems over time have led to higher levels of efficiency in a variety of commercial and industrial applications. The desire for greater productivity and performance, combined with technological advancements and a deeper understanding of mechanical principles, have all influenced the history of drive systems. This unit looks at how mechanical drive systems have evolved to become more effective and efficient. One of the primary driving causes behind the development of mechanical drive systems is the ongoing advancement of technology. Advances in computer-aided design tools, manufacturing processes, and materials have allowed engineers to develop more dependable and efficient drive systems than in the past. For example, using lightweight materials like carbon fiber composites to reduce overall weight and friction in gearboxes and drive shafts increases efficiency and decreases energy consumption.<sup>9</sup>

Mechanical drive systems can operate more efficiently when mechanical concepts are better understood, and the system design is optimized. As our students move into today's sophisticated modeling and simulation tools, it will enable them to accurately predict energy input and the performance of a drive system and identify potential improvement areas. By optimizing gear ratios, bearing designs, and other critical components, they learn how engineers may significantly increase energy efficiency while lowering maintenance costs and downtime. Moreover, the requirement for higher performance and productivity has driven the development of mechanical drive systems. Drive systems with more power, speed, and accuracy are always required in the automotive, aerospace, and robotics industries. Engineers are thus constantly creating new technologies, such as hybrid drive systems and regenerative braking systems, to satisfy these demands and raise overall system efficiency.

When my students are exposed to the major advancement in mechanical drive systems, they will start being able to make that connection to smart technology, including sensors, actuators, and control systems. Students working in groups studying drive systems can learn how to optimize their efficiency and adapt in real-time to changing forces.<sup>10</sup>

So as our students are learning of the evolution of mechanical drive systems and how they have been impacted by advances in technology, they will gain an increasing awareness of sustainability and energy efficiency. It will be made clear through practical experimentation how drive systems with low energy and environmental impact are becoming more and more necessary as global efforts to cut carbon emissions and save resources gain momentum. By incorporating energy recovery components like flywheel storage and regenerative braking, mechanical drive systems may capture and repurpose wasted energy, which can lead to significant gains in overall efficiency.<sup>11</sup>

When everything is said and done, the evolution of mechanical drive systems has been characterized by a



constant search for improved reliability, efficiency, and performance. With the advent of new technologies, a deeper understanding of mechanical principles, and higher productivity standards, engineers can now design and build drive systems that are more efficient and sustainable than ever before. Because mechanical drive systems integrate smart technologies, optimize system design, and prioritize energy conservation, they have the potential to play a significant role in the development of a more technologically advanced and sustainable future. Notable advancements in mechanical drive systems over time have led to higher levels of efficiency in a variety of commercial and industrial applications. The desire for greater productivity and performance, combined with technological advancements and a deeper understanding of mechanical principles, have all influenced the history of drive systems. This essay looks at how mechanical drive systems have evolved to become more effective and efficient.

One of the primary driving causes behind the development of mechanical drive systems is the ongoing advancement of technology. Thanks to developments in computer-aided design tools, manufacturing processes, and new materials, engineers can now design and build drive systems that are more dependable and efficient. "Arthur C. Clarke's famous dictum comes to mind: the more advanced the technology, the more it seems like magic. Ironically, in modern techno culture, most people are at a loss to explain how the appliances of their daily life, from smartphones and laptops to automobiles, work, not to mention nuclear submarines or rockets."<sup>12</sup>

Mechanical drive systems can operate more efficiently when mechanical concepts are better understood, and the system design is optimized. Today's sophisticated modeling and simulation tools enable engineers to accurately predict the performance of a drive system and identify potential improvement areas. By optimizing gear ratios, bearing designs, and other critical components, engineers may significantly increase drive system efficiency while lowering maintenance costs and downtime.<sup>13</sup>

Students will gain an understanding of how the need for high efficiency energy systems and the need to develop higher performance and productivity has driven the development of mechanical drive systems. Drive systems with more power, speed, and accuracy are always required in the automotive, aerospace, and robotics industries. Engineers are thus constantly creating new technologies, such as hybrid drive systems and regenerative braking systems, to satisfy these demands and raise overall system efficiency.

A good strategy as students begin to better incorporate their knowledge of mechanical drive systems is smart technology, including sensors, actuators, and control systems, utilizing the accuracy of modern wave gears. Examine how these gears are critical elements for precision movement as well as reducing temperature and vibration as the improved system more effectively converts energy to power.<sup>14</sup>

The evolution of mechanical drive systems has been impacted by advances in technology as well as an increasing awareness of sustainability and energy efficiency. Drive systems with low energy and environmental impact are becoming more and more necessary as global efforts to cut carbon emissions and save resources gain momentum. By incorporating energy recovery components like flywheel storage and regenerative braking, mechanical drive systems may capture and repurpose wasted energy, which can lead to significant gains in overall efficiency.

When everything is said and done, the evolution of mechanical drive systems has been characterized by a constant search for improved reliability, efficiency, and performance. With the advent of new technologies, a deeper understanding of mechanical principles, and higher productivity standards, engineers can now design and build drive systems that are more efficient and sustainable than ever before. Because mechanical drive

systems integrate smart technologies, optimize system design, and prioritize energy conservation, they have the potential to play a significant role in the development of a more technologically advanced and sustainable future.

## Power Source

---

Windmills and dams are two of the most popular renewable energy sources in the world. These structures are required to generate energy from the components of wind and water, respectively. Significant progress has been made in windmill and dam technology in recent years, particularly around high input gearing. The benefits of high input gearing technologies, how windmills and dams use them, and how these developments can impact renewable energy in the future will all be covered in this essay.

One of the main ways windmills and dams manage high input gearing improvements is through the introduction of complex gear systems. These gear systems are designed to efficiently convert the raw energy generated by the wind or water into useful energy. By adopting high input gearing advancements, windmills and dams can boost their energy output while preventing equipment wear and tear. Ultimately, this leads to higher production efficiency and dependability for renewable energy.

Modern technology plays a major role in how windmills and dams react to developments in high input gearing. Using advanced control systems to adjust the pitch and rotation speed of the blades is one way to optimize the energy output from windmills. On the other hand, by utilizing innovative turbine designs and state-of-the-art generators, dams may optimize the energy extracted from flowing water. Students familiar with the technologies of windmills and hydroelectric dams often miss the very important gearing operation required.

High input gearing improvements enable windmills and dams to better handle changes in wind and water flow. By optimizing their gear systems and technologies, these buildings can keep up a steady source of renewable energy and adjust to changes in the surrounding environment. Operating windmills and dams will find renewable energy to be a more enticing alternative for development and investment due to the possibility for significant cost reductions.

When high input gearing advancements are used in windmills and dams, they may also have a significant effect on renewable energy in the future. As technology advances, windmills and dams will need to continue advancing their technologies if they wish to be competitive in the global energy market. This would reduce reliance on fossil fuels and mitigate the consequences of climate change by promoting the use of renewable energy sources more extensively. Improvements to high input gearing can allow windmills and dams to play a major role in the future energy transition to cleaner, more sustainable sources.

Increasing the efficiency of alternative energy sources has been made possible by advancements in computer modeling and simulation software. By accurately predicting how different gear configurations and materials will perform under various operating conditions, engineers can now design gears to maximize efficiency and dependability. Consequently, gear systems that could only achieve modest efficiency in the past have evolved to achieve up to near perfect efficiency.

All things considered, we are getting closer to a day when only all these renewable and sustainable energy sources will be used, thanks to advancements in gear technology that have made alternative energy systems

run more smoothly. Because they reduce energy loss, boost power production, and enhance system stability, these new gadgets have made alternative energy sources more appealing and competitive as potential sources of energy to meet our needs. It is reasonable to assume that gear technology will continue to progress and bring the effectiveness and efficiency of alternative energy systems to unprecedented levels if research and development in this area is supported.

Improvements in high input gearing are essential for maximizing the dependability and efficiency of windmills and dams, which are essential components of the environment for renewable energy. By leveraging cutting-edge gear systems and technology, windmills and dams can effectively harness the power of wind and water to generate clean, sustainable electricity. In addition to improving the efficiency of windmills and dams, these advancements may also reduce maintenance costs, increase flexibility, and influence the future of renewable energy. As the world gets closer to a future powered by more sustainable energy, the significance of high input gearing advancements in windmills and dams cannot be overstated.

Students can gain an understanding of the importance of a well-planned design—including how energy is converted into power and used by the system to accomplish tasks—through robotics. To complete an energy cycle and increase our capacity to create and use future technologies, this research will partially examine robots and how they primarily depend on advancements in physical mechanical systems to convert mechanical energy stored in motion into electrical energy. Thanks to advances in science and technology, our children are never short of new stuff to keep them engaged. The formulaic approach of applying scientific phenomena from textbooks to the fast-growing technical field in which we compete daily is not enough for a scientific curriculum. This holistic method to teaching forces has practical applications because it thoroughly develops a grasp of forces and how they are transferred in a way that maintains as much of the harvested or created power as feasible. "Torque on the shaft - the higher the speed the less the torque and the less the torque the smaller the shaft required since smaller shafts mean savings in weight and cost the shaft is usually operated at the highest speed which the conditions of the application will permit."<sup>15</sup>

## Robotics

---

Gears are crucial components in robotics that enable the transfer and modulation of the force generated by motors. In the realm of robotics, efficiency is essential to achieving optimal performance and functioning. Gears allow robotics to transfer force more efficiently since they can accurately control movement, alter rotational speed, and increase or decrease torque. One major advantage of using gears in robots is that they can boost torque. This suggests that a small input force can be converted into a larger output force using gear ratios. Robotic systems can use gears with different sizes and numbers of teeth to achieve the necessary degree of force to perform tasks that would be impossible with simply a motor. It is essential to have this torque amplification for heavy lifts and load transfers.<sup>16</sup>

Reducing torque is another advantage of gears, and this is also important for robots. Robotic systems that use gears with different tooth counts and sizes can produce more torque while reducing rotation speed. This is useful for applications where precise control over movement is required, such as robotic arms and legs. By adjusting the gear ratios, robotic systems can achieve the force and accuracy needed to do challenging tasks.

In robotics, gears are crucial for controlling rotational speed as well as for amplifying and reducing torque. This

is particularly important for applications requiring a constant pace, such as robotic vehicles and conveyor belts. Gears provide an accurate speed control mechanism that makes robotic systems operate smoothly. Another key benefit of using gears in robotics is its capacity to transfer force and motion across several axes. Robotic systems use gears to mesh and to provide power and movement between components without physical contact. This opens the door to building complex systems that can perform a variety of tasks, such as robotic manipulators or grippers. Robotic systems can carry out a wide range of tasks and navigate a wide range of environments due to the efficient transfer of force in multiple directions made possible by gears.

Furthermore, gears are necessary in robotics to minimize energy loss and improve overall performance. Robotic systems that use highly precise and low-friction gears can provide effective power transfer from the motor to the end effector and prevent loss of energy. As a result, the robotic system performs better and endures longer. Gears reduce the amount of energy required to accomplish tasks and ensure that robotic systems operate as efficiently as possible by maximizing force transfer.

In conclusion, gears are essential components of robotics that enable more efficient force transfer and motion control. Precision movement control, torque amplification, gear ratios, and speed reduction are all key components of robotic systems that work well. Gears provide the mechanism that distributes force and motion along several axes, minimizes energy loss, and boosts efficiency. All things considered, gears are necessary to increase the capabilities of robotic systems and enable them to carry out a range of duties precisely and accurately.

## Strategies

---

### Overview

Students will begin the process of examining how energy is not only generated but transmitted through systems. As their knowledge advances, each team will be responsible for deciding what type of power is best for the local area and the best way to create efficiency within the system. By examining current technologies as well as gear systems, we will be focusing on physical production of electricity through mechanical means. The only less ideal option for this solution would be solar energy production as the absence of moving parts would require outside of the box thinking for students to come up with a mechanical advantage, they could implement with the only real option being a mechanical tracking system to move the solar panels.

### Gallery Walks

#### Energy production

Energy production is a vital part of our daily lives, providing us with the power we need in our homes, businesses, and transportation. There are several types of energy production, each requiring different inputs and producing different outputs. In this gallery walk, students will explore some of the most common types of energy production in poster format that each group has created and discuss in their groups' required inputs, outputs and the system that brings them together.

One of the most common types of energy production is fossil fuel energy production. Fossil fuels, such as coal, oil, and natural gas, are burned to produce heat that creates steam to turn a turbine which is then used to

generate electricity. The input for fossil fuel energy production is the fossil fuels themselves, which must be mined and extracted from the earth. The output of this process is electricity, which can be used to power everything from light bulbs to computers.

Nuclear power plants use nuclear reactions to generate heat that creates steam to turn a turbine which is then used to generate electricity. The input for nuclear energy production is uranium, a radioactive element that is mined from the earth. The output of this process is also electricity, which can be distributed to homes and businesses through power lines. Discharging waters from nuclear reactors can be detrimental to local environments as they have higher than normal temperatures. Nuclear reactors also have spent nuclear rods and other components which will remain nuclear radioactive for decades and need treatment.

Hydropower has been utilized for a long time in many different ways from water wheels to modern hydropower dams. By utilizing the potential energy of water running downhill mechanical energy is harvested through water wheels and turbines that are used to generate electricity. Though the byproduct of large dam construction can also be detrimental to the local environment and ecosystems.

Geothermal power plants are regionally specific requiring access to geothermal heating created from the earth itself. These plants pass water underground to have it heated and return to the surface as steam where it turns a turbine which is then used to generate electricity.

Solar energy collected through photovoltaic cells can collect photons and convert them directly into electricity for use. Solar farms can generate electricity immediately but not always when the electricity is needed therefore like many environmentally based electricity production methods it requires a storage system to be effective.

Wind technology is another ancient technology that has grown as society has grown. From primitive windmills used to turn mechanical devices into two modern wind turbines designed to convert wind power to electrical energy, they use mechanical devices to turn the end product which is a generator to produce electricity. Like solar wind has tremendous potential if an adequate storage system can be created to store the electricity for when it is needed as opposed to trying to use it when it is generated.

Biomass energy is generated from organic materials, such as wood chips, crop residues, and animal waste. These materials can be burned to produce heat that creates steam to turn a turbine which is then used to generate electricity. The input for biomass energy production is the organic materials themselves, while the output is heat and or electricity. As building a fire is one of the most primitive forms of energy production, we can see how far we've come.

Water splitting is a chemical reaction that uses an external energy source to break down water into hydrogen and oxygen. This has the advantage of creating a storable energy source that can be truly carbon neutral depending on its input energy. If solar energy is used in the water splitting, then there is a zero-carbon footprint. The current negative of this technology is not the process but the high-cost materials required to build the apparatus.

In conclusion, energy production is a complex process that involves a variety of inputs and outputs. Fossil fuel energy production requires mining and extracting fossil fuels, while nuclear energy production requires uranium. Renewable energy production relies on sources such as wind, solar, and hydro power, while biomass energy production uses organic materials. Emerging technologies like geothermal and water splitting are also being explored as alternatives to traditional energy sources. By understanding the inputs and outputs of

different types of energy production, students will be able to identify where physical force is being exerted and where we could have possible improvements to the physical design.

### **Types of Gearing**

During a gallery walk, students will examine replicas of various gears and have the opportunity to manipulate the models to observe how they work. Students will be able to observe not only how the various gearing systems work and create a free body diagram of how force is transferred through them, as well as the benefits and drawbacks of each system, through hands-on investigation. The groups will next decide which gearing scheme will maximize the overall efficiency of the energy production they have chosen.

Parallel shafts are used by spur gears to transfer power. The shaft axis and the spur gears' teeth are parallel. Because spur gears only have one line of contact between teeth, they are typically noisier than helical gears.

In contrast to spur gears, which are aligned parallel to the shaft, helical gears contain teeth that are arranged at an angle. As a result, during operation, several teeth come into contact, and helical gears can support a higher weight than spur gears.

A gap separates the two helical sides of a herringbone gear, which makes them extremely similar to double helical gears. Herringbone gears are perfect for heavy shock and vibration applications since they are usually smaller than equivalent double helical gears.

The most typical application for bevel gears is power transmission between shafts that cross at a 90-degree angle. They are employed in situations when a gear drive with a correct angle is necessary. In general, bevel gears are more expensive and have a lower torque transmission capacity per size than parallel shaft arrangements.

Worm gears transfer power via non-intersecting shafts at right angles. Worm gears are excellent for applications requiring strong shock loads and produce thrust force, but their efficiency is significantly lower than that of other gears.

When combined with external gears, internal gears feature teeth carved into the inside of cylinders or cones. Planetary gear drives and gear-type shaft couplings are the principal applications for internal gears.

One kind of linear actuator is a rack and pinion, which consists of a linear gear (the rack) engaging a circular gear (the pinion). When combined, they create linear motion from circular motion. The rack is driven in a line when the pinion is rotated.

Screw gears consist of two helical gears on the same hand that have a 45° twist angle and are mounted on non-intersecting, non-parallel shafts. Their load-carrying capacity is minimal, and they are not appropriate for large power transmission since the tooth contact is a point.



## Activities

---

### Trebuchet

Our students will have a hands-on science lab where they get to engage with a trebuchet creating a unique and exciting opportunity for students to apply what they have learned through the reading and discussion in class. A trebuchet is a type of medieval siege weapon that uses a counterweight to launch projectiles, and by building and experimenting with one, students can gain a deeper understanding of concepts like force, momentum, and projectile motion. Instead of just reading about these principles in a textbook, students can see them in action and manipulate the variables to see how they affect the trebuchet's performance.

As students work on constructing their trebuchet, they will use a model frame and beam assembly printed in advance. They will then load their calculated counterweight and attach a weight at the end of a string that is of a length they have also calculated, giving them the opportunity to test their accuracy at hitting the target. Students are not only learning about physics but also gaining valuable hands-on experience with engineering and design. They must consider factors like the weight of the counterweight, the length of the throwing arm, and the angle of release in order to optimize the trebuchet's performance. This process of trial and error encourages critical thinking and problem-solving skills, as students must analyze their results, make any needed adjustments, and test again to achieve the desired outcome.

Engaging teamwork with a trebuchet in a hands-on science lab also fosters collaboration among students. Building and testing a trebuchet requires communication, cooperation, and a willingness to share ideas and listen to others. Students must work together to troubleshoot problems, brainstorm solutions, and coordinate their efforts to achieve a common goal. This collaborative environment not only strengthens students' interpersonal skills but also teaches them the importance of working together to achieve success.

By utilizing a 3D printer, students are able to manipulate their designs as a team and come up with their best option. This hands-on science lab utilizing a trebuchet provides students with a fun and interactive way to explore and apply principles of physics, engineering, and teamwork. By building, experimenting, and analyzing the performance of their trebuchet, students gain a deeper understanding of how Newton's Laws of motion work in real-world applications. This hands-on approach not only enhances students' learning experience but also reinforces key skills like problem-solving, critical thinking, and collaboration that will benefit them in their future academic and professional endeavors.

### Gearbox Applications

As the students advance to this point, their comprehension as to how force is transmitted through a system to create energy should have significant depth to apply the knowledge of how to increase mechanical advantage for the task required. Crucial components in many machines and devices are subjected to varying forces that need to be taken into account for power efficiently. By using different types and sized gears, machines can increase or decrease the speed or force of movement, allowing for precise control over lifting loads or spinning generators. Students will be required to attempt to assemble their gearbox using the formulas they have learned in a manner that achieves the individual task at each station in this lab. At these stations, students will utilize a preassembled gearbox that they have constructed from preprinted gears. By using gears that operate at different ratios stacked within the assembly, force can be manipulated. The students will first be required to mathematically calculate how much force is required to achieve the task at the station. In this



crucial assembly step, students will discern if stepping up will be required to generate more speed or stepping down will be required to create more power. It is this force manipulation that is at the center of the experiment and the place where our true eureka moment will occur.

At some stations students will be lifting loads of varying mass with varying lengths of travel where gearing can be used to increase the force applied. This is done by using gears with different sizes, such as a small gear connected to a larger gear. As the small gear turns, it transfers its rotational force to the larger gear, increasing the force applied to the load. This allows for heavier loads to be lifted with less effort, making the process more efficient and less strenuous. The students will also be able to use spring scales to calculate the load on the handle and determine the mechanical advantage of their system. The students' goal is efficiency and how quickly can you move the load over the required distance with the least amount of force.

Other stations will have students spinning generators demonstrating that gearing can be used to increase the speed at which the generator spins. By using gears with different sizes, the rotational speed of the input can be increased, which in turn speeds up the rotation of the generator. This allows for more electricity to be generated in a shorter amount of time, making the process more efficient and cost-effective. In this activity, the students will be looking to count the number of revolutions per minute and monitor a voltmeter to see the output of electricity they are generating. This is especially important in renewable energy sources such as wind turbines, where the efficiency of the generator directly impacts the amount of electricity produced.

Overall, my students are learning that gearing plays a crucial role in lifting heavy loads and generating power efficiently. By using different sized gears to control speed and force, machines can optimize their performance and reduce energy consumption. This allows for more efficient operations in various industries, from construction to renewable energy. Understanding how gearing works and how to apply it effectively is key to achieving maximum efficiency in lifting loads and spinning generators.

## **Essay**

At the end, my students will write an essay conveying their understanding of how force is efficiently transferred through a mechanical system. A key concept they will grasp is when it comes to the efficiency of force in a mechanical system is the idea of mechanical advantage. Mechanical advantage is the measure of how much a machine multiplies force or distance. In simpler terms, it is the ratio of the force applied to the machine to the force exerted by the machine. The greater the mechanical advantage, the more efficiently force is transferred through the system. And this key is how efficiency can be increased in many of our modern systems. At the root of all of this is Newton's laws of motion and how that motion and force is applied is relevant to so many things in the modern world. There are many other auxiliary points to look for that convey their understanding of force such as considering friction, which is a force that resists the motion of objects in contact with each other. Friction can have a significant impact on the efficiency of force in a mechanical system, as it can cause energy loss and decrease the overall effectiveness of the system. In addition to friction, another factor that can affect the efficiency of force in a mechanical system is the presence of mechanical losses. Mechanical losses refer to the energy that is lost due to factors such as vibration, heat, and sound. These losses can reduce the overall efficiency of a system and must be accounted for in the design process.

In order to maximize the efficiency of force in a mechanical system, engineers often utilize different types of mechanisms and components to help transfer force more effectively. One common example is the use of specific gears which are designed to change the direction of force and provide a mechanical advantage. By incorporating them into a system, engineers can reduce the amount of force needed to achieve a desired

outcome.

Students will produce an essay that demonstrates their understanding of the required efficiency of force through a mechanical system is essential for engineers and designers to create machines that perform optimally. By considering factors such as mechanical advantage, friction, and mechanical losses, engineers can ensure that force is transferred efficiently and effectively. By utilizing mechanisms such as pulleys, gears, and levers, engineers can design systems that are able to overcome resistance and achieve desired outcomes with minimal energy loss. With careful consideration and planning, it is possible to create mechanical systems that are not only efficient but also reliable and durable.

## Reading list

---

Gibbs, Josiah Willard. "On the Form of the Teeth of Wheels in Spur Gearing." Essay. In *The Early Work of Willard Gibbs in Applied Mechanics, Comprising the Text of His Hitherto Unpublished Ph. D. Thesis and Accounts of His Mechanical Inventions*, 1st ed., 7–39. New York, New York: Henry Schuman, 1947.

This is a rather interesting read as these 32 pages are a transcript of one of the first doctorates granted in the United States at Yale University. Gibbs' interest in mathematics and engineering led him to study how the gears interacted and the geometry that best suited their performance in many ways making him one of the first STEM teachers.

Greenwood, Douglas C. *Mechanical power transmission; component selection and application*. New York: McGraw-Hill, 1962.

Like so many of the books on this list mechanical power transmission goes in depth into not only how mechanical gearing works but the interaction of materials and seals within mechanical systems.

Langston, Lee. "Gears Drive the World." *American Scientist* 110, no. 2 (2022): 80.  
<https://doi.org/10.1511/2022.110.2.80>.

*American Scientist* is a publication that has been around since 1918 with many articles covering science. This specific article looks at how ancient technologies have been modernized through the centuries and continue to be utilized to this day.

Lemire, Jacques. "Gear Backlash in Robotics Applications." *Gear Technology Magazine RSS*, April 9, 2024.  
<https://www.geartechnology.com/articles/30637-gear-backlash-in-robotics-applications>.

*Gear Technology Magazine* is an excellent resource for modern gear and drivetrain innovation and, in this article, it examines how by using wave gear technology backlash which is the unwanted back and forth movement of gears can be eliminated from modern robotics.

Mayor, Adrienne. *Gods and robots: Myths, machines, and ancient dreams of Technology*. Princeton: Princeton University Press, 2020.

This may be one of the funniest background reads in my list. It provides a history of automatons and how

gearing and automation has advanced through the EIN's not only centuries but eons. From primitive innovations to modern solutions this might be the first book to read to inspire you for this curriculum

Radzevich, S. P., and Darle W. Dudley. Dudley's Handbook of Practical Gear Design and manufacture. Boca Raton: CRC Press, 2021.

This particular book is less of a read and more of a reference material to help design and organize experiments so that the correct verbiage is used throughout. Words have meaning and if you are looking for a big book of terminology this definitely has everything in it for gears.

## Appendix of Standards Implemented

---

### Oklahoma Academic Standards for Science

8.PS2.1 Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects in a system

Students demonstrate scientific principles through the design of objects, tool, process, and system.

Students observe the interaction between the first object and the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).

Models are used to represent systems and their interactions with input, processes, and output and energy, and power flowing within the systems.

8.PS2.2 Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law); frame of reference; and specification of units. An increase in force can be caused by increasing the mass, the acceleration, or both the mass and acceleration of an object. An example of evidence could include reasoning from mathematical expressions ( $F=ma$ ).

Plan an investigation individually and collaboratively; identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to support a claim.

The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero its motion will change.

The greater the mass of the object, the greater the force needed to achieve the same change in motion.

For any given object, a larger force causes a larger change in motion.

Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.

## Next Generation Science Standards (NGSS)

MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

## Citations

---

“Energy Definition & Meaning.” Merriam-Webster. Accessed July 13, 2024.

<https://www.merriam-webster.com/dictionary/energy#:~:text=%3A%20a%20fundamental%20entity%20of%20nature,the%20capacity%20for%20doing%20work>.

Gibbs, Josiah Willard. “On the Form of the Teeth of Wheels in Spur Gearing.” Essay. In *The Early Work of Willard Gibbs in Applied Mechanics, Comprising the Text of His Hither to Unpublished PH. D. Thesis and Accounts of His Mechanical Inventions*, 1st ed., 7–39. New York, New York: Henry Schuman, 1947.

Greenwood, Douglas C. *Mechanical power transmission; component selection and application*. New York: McGraw-Hill, 1962.

Langston, Lee. “Gears Drive the World.” *American Scientist* 110, no. 2 (2022): 80.

<https://doi.org/10.1511/2022.110.2.80>.

Lemire, Jacques. “Gear Backlash in Robotics Applications.” *Gear Technology Magazine RSS*, April 9, 2024.

<https://www.geartechnology.com/articles/30637-gear-backlash-in-robotics-applications>.

Mayor, Adrienne. *Gods and robots: Myths, machines, and ancient dreams of Technology*. Princeton: Princeton University Press, 2020.

Radzevich, S. P., and Darle W. Dudley. *Dudley’s Handbook of Practical Gear Design and manufacture*. Boca Raton: CRC Press, 2021.

“Strain Wave Gearing.” 2024. Wikipedia. February 18, 2024.

[https://en.wikipedia.org/wiki/Strain\\_wave\\_gearing#/media/File:HarmonicDriveAni.gif](https://en.wikipedia.org/wiki/Strain_wave_gearing#/media/File:HarmonicDriveAni.gif).

## Notes

---

<sup>1</sup> Langston

<sup>2</sup> Gibbs

3 Merriam-Webster

4 Lemire

5 Greenwood

6 Langston

7 Radzevich

8 Radzevich

9 Radzevich

10 Langston

11 Langston

12 Mayor

13 Greenwood

14 Lemire

15 Greenwood

16 Lemire

---

<https://teachers.yale.edu>

©2024 by the Yale-New Haven Teachers Institute, Yale University, All Rights Reserved. Yale National Initiative®, Yale-New Haven Teachers Institute®, On Common Ground®, and League of Teachers Institutes® are registered trademarks of Yale University.

For terms of use visit [https://teachers.yale.edu/terms\\_of\\_use](https://teachers.yale.edu/terms_of_use)