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What Makes Things Move? Levers in the Human Body

Curriculum Unit 14.04.04
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Objective

The human body is beautifully complicated machinery composed by a number of physical systems. The main purpose of this unit is to bring a new approach to teaching Physics, focusing on simple machines from the perspective of the human body. Additionally this unit emphasizes how understanding the basic Physics concepts is essential in real life and applied in building good mechanical models that further improve our understanding of the structure and function of the human body and enhance our life style.

After a general background on simple machines and identification of some examples within the human body students will be involved in a hands on activity that will require them to build a prosthetic arm able to lift a certain amount of weight. This will be an inquiry based activity where students have the liberty to choose how far from the hand the fulcrum (elbow) should be, what material to use for the arm and how far from the fulcrum the "muscle" that pulls the arm up should be.

At the end of the activity students should be able to discuss the importance of:
1. prosthetic arm material (strong but light)
2. the length of the arm (the longer, the better, but should take into account the regular size of the human body)
3. the length of the lever formed by the fulcrum and the muscle that takes the load (taking into account the physics of the lever and the anatomy of the body)

Introduction

Wilbur Cross High School is a comprehensive public school with a very diverse student population. With the support of the families and friends of our students we strive to provide our students an education focused on academic excellence and social responsibility in a safe environment. Our goal is to challenge our students every day to become life long learners and well-rounded citizens. For this we hold them responsible to high standards and academic responsibility through rigorous instruction. Given the diverse socio-economic background of our students, effective differentiation and engaging classes are a necessary part of the instruction. I plan to reorganize the content of the curriculum such that include more hands-on activities presented in an engaging manner and connected to everyday life. The goal is that the students will be engaged and invested in their learning such their retention of the content will increase.

Teaching Physics in New Haven I soon realized that sometimes the standard Physics curriculum falls short in engaging students to be active learners. I acknowledge that school is not the first priority for some of my students as they have other curricular, extra-curricular, job and family responsibilities. Using the standard Physics activities I can engage students for a short period of time but after a while students loose interest if they don't see how the activities relates to their day-to-day lives.

Historically the hands on activities in Mechanics, one of the main content units in Physics, involve some kind of mechanical machine or setup. For example, one can set up a lever system to measure how much force you put it and what is the force output and calculate the mechanical advantage of it. This method will account for engaging some of my students that do some kind of household work or hands on project around the house but fails short in engaging the rest of my students. While teaching AP Physics this year I noticed that some AP type problems piqued the interest of my students. The questions were related to using mechanical formulas to calculate force input or output in human body, such as "what is the maximum weight you can lift with one hand, if you know the strength of your muscle and the point of connection to the bone". Following this observation I decided to expand on this type of problem, especially as many teenagers are interested in the limits of their own body and exploring how far to push them.

For this curriculum is I plan to integrate traditional Physics problems with a fresh approach of Physics in the human body point of view. A quick literature search revealed endless options of connecting Physics to real life. This unit will focus on "Mechanics – Simple machines: Bones and Muscle as types of levers" with possible extension into the following units:

1. Vectors: Honey Bees navigation
2. Mechanics – Forces: Adhesive forces (gecko) and Tensile Forces (spider silk)
3. Fluids: Human Heart (Fluid flow and pumps)
4. Energy and Thermo: Eating/Drinking
5. Optics – Lens in the human eye

In the first stage of this module I plan to focus on identifying simple machines in the human body and connect them to fundamental learning in physics. I will develop fundamental physics problems that will connect to real life. I will then develop higher thinking problems that will address medical applications of this knowledge. For example, one can calculate how much force an arm or a leg bone withstands during normal human activity and what kind of properties a building material will need to meet in order to be used as prosthetic material. After teaching the fundamental physics behind the simple machine and connections to medical applications students will have a week to work in class on the Human Body project. An extension of this activity is finalizing this project and present their finding to the class.

Mechanics [1]

Physics is the study of matter and energy and the correlation between the two. Mechanics is a branch of Physics that deals with motion. Mechanics can be divided further into kinematics (describing motions) and dynamics (the causes of motion). In order to understand simple machines students need to have a basic understanding of describing motion and a basic understanding of energy and conservation of energy.

Force

In physics the force is considered a push or a pull that act on an object and it will cause a change in its movement, direction or shape. Net force is defined as the overall force acting on an object and it is the vector sum of all the forces acting on the object. A net force acting on an object that is considered a point particle will change its movement (start or stop moving, accelerate or decelerate) or will change its direction.

Torque

Torque is the rotational analogue of force. When a net force acts on a rigid body that is not considered a point particle it can cause the object to rotate about a rotation axis or a rotation point (called fulcrum or pivot). Mathematically, torque is defined as the cross vector of the force vector and distance vector (called lever-arm).

Equilibrium

An object is in equilibrium when the net force acting on is zero. An object is not in equilibrium when the net force acting on is different than zero. Static equilibrium, also called mechanical equilibrium, is the state in which the net force acting on an object is zero. Dynamic equilibrium, also called rotational equilibrium, is the state in which the net force acting on an object is zero and the net torque acting on an object is zero.

Kinematics

Kinematics is the branch of Mechanics that describe motion. Linear kinematics deals with motion in one direction, for example free fall, while two-dimensional kinematics deals with motion in two dimensions, for example projectile motion.

Dynamics

Dynamics is the branch of physics that studies the causes of motion and the effect of forces and torques on motion. Linear dynamics studies the motion of point particle objects under the action of a net force, while the rotational dynamics studies the motion and rotation of a rigid body under the action of a net force and/or net torque.

Simple machines

Simple machines are devices that make our life easier either by minimizing the force we need to put in to achieve a goal (levers, wedges, etc) or by changing the direction of the force we apply (pulley). There are six simple machines. All other machines are made of at least two simple machines and are called complex machines. The six types of simple machines are presented below. [2a, 3] They can be classified as "levers" (1-3) or "inclined planes" (4-6):

1. Lever is a stiff rod that rotates around a pivot point or fulcrum. When a downward force is applied at one end the result is an upward force at the other end. A lever can either multiply the applied force or the distance over which the force is applied. Depending on the relative position of fulcrum, input force and output force, there are three classes of levers (see next unit).
2. Pulley is a wheel with a cord wrapping around it (in a groove). The rotation of the wheel (pulley) results in a linear movement of the cord, either up or down.
3. Wheel and axle is a version of pulley in which the pulley, the wheel, is locked to its central axle. The long motion of the rotating wheel results in a stronger, shorter motion of the axle.
4. Inclined plane is a simple machine that helps lifting objects vertically by moving them across a distance. A common inclined plane is a ramp.
5. Wedge is a type of inclined plane that converts motion in one direction into a splitting motion that acts at right angles to the "blade" (wedge).
6. Screw is simple machine that converts rotational motion in linear motion (forwards or backwards). Screw is basically an inclined plane wrapped around a cylinder.

Levers

Lever is a stiff rod that can rotate around a pivot point, called fulcrum. By applying a downward force (input force or effort) at one end we achieve an upward motion (output force or load) at the other end. Depending on the positions of fulcrum, input force and applied force, one can define three types of levers: first class, second class and third class. The three different classes of levers and an example for each are presented in Figure 1.

In a first class lever, the fulcrum is located between the input force and output force; in a second class lever, the output force is between the fulcrum and the input force, while in a third class lever, the input force is between the fulcrum and the output force.

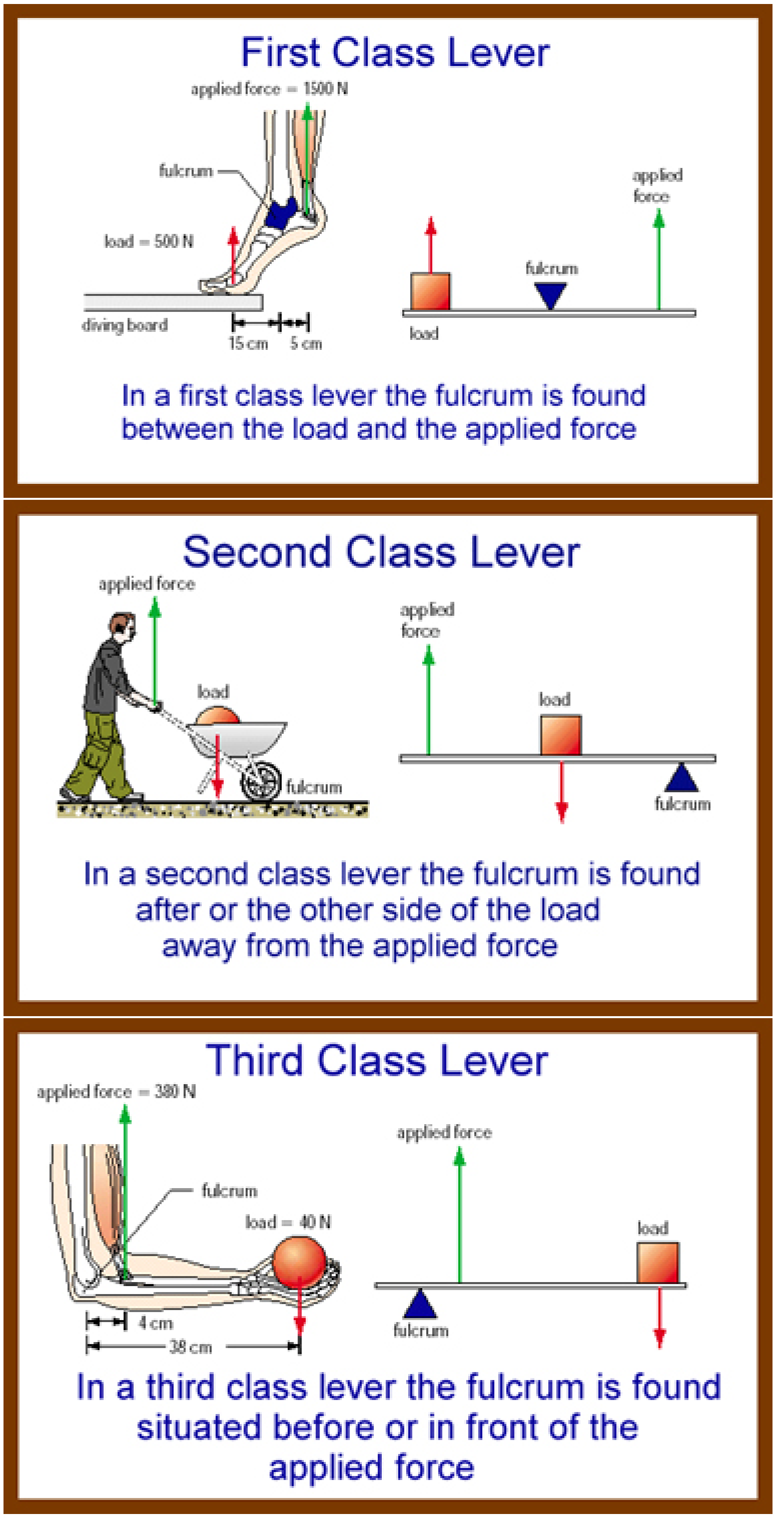

Figure 1: First, second and third class levers, definitions and examples (open source [4])

Levers in the human body

Ask students to identify levers in the human body. They should be able to come up with a list that includes at least the arms, the legs and the mandible. You can have a skeletal drawing of the human body such that students can directly identify these levers on the drawing.

Teaching Strategies

During this unit I will use a variety of teaching strategies in order to differentiate and reach different types of learners.

Inquiry

Students will identify the levers in the human body through inquiry as a group. After introducing simple machines pose the question: "What type of simple machines you can identify in the human body." Eventually students will come up with levers and wedges. Follow up with "Identify the levers in the human body". Distribute Post-Its to the students and ask them to put one of the levers on the Post-it note. Give them two minutes. At the end of the two minutes ask students to come to the board and put their Post-it note up. Get a volunteer to organize the post its and tally up the results.

Visual learning

Have a number of handouts and a big diagram of the skeletal system ready for class. Pair up students. Each pairs receive a drawing and they should label all the levers they can identify. Give students four minutes and have pairs exchange papers. Which pair identified more levers? Do you agree with the other pair? Why or why not? Ask students to come to the board and label on the big diagram one of the levers identified by THE OTHER pairs. Note that this technique includes student discourse and turn and share teaching strategies.

Teacher led

After a general intro of simple machine and then levers in the human body, the teacher will start focus on specific examples of how to calculate torques, forces, distances and mechanical advantages (see examples below, under "Classroom activities").

Cooperative learning

Students are given the choice to work in groups to complete this assignment. From my teaching experience many students benefit from group work, especially when the work is setup such that each member of the team as a function. For example one setup would be to have a Team leader, a Time Keeper, a Data Recorder and a Materials Manager. [5] Each member of the team is responsible for a certain aspect of the project (see Appendix: Collaborative learning job definitions) and the team manages itself. Students would work as a team to solve similar examples with the ones just learnt through "teacher led" strategy and then present them to their peers. Different teams would solve a different set of problems followed by "pair share" and "class share". (see "Classroom Activities' below for some relevant types of problems).

Pair share and class share

Pair share is a collaborative learning technique in which students work on a task first by themselves and then they turn to their partner and share. Generally "pair share" is followed by "classroom share" in which the pairs share they finding to the whole class.

Hands on (tactile) learning

The hands on teaching strategy would be the building of a prosthetic arm that will fulfill certain requirements (should be within certain lengths and able to lift a certain weight). This activity can be performed either as a discovery activity before the unit is taught or as an enrichment activity, at the end of the unit (see "Classroom Activities" below).

Choice of assessment

My former personal observations agree with the current literature [6, 7] that demonstrates students learn better if they are given the choice of the final product. They become emotionally invested in their learning and produce very creative and content-rich learning outcomes. In light of this teaching philosophy, I give students a choice of the media they use for their presentation: power point presentation, poster, model, science article, etc.

The most challenging part of this is having uniform grading across the media choice. In order to make sure all the students are kept to the same standards for this project, I use customized rubrics for grading as the one presented in the Appendix: Grading Rubric.

Classroom activities

Classroom activity – Classical problems

There are a number of classic problems that appear in the AP Physics B curriculum. Although the AP Physics curriculum is changing this year, a deep understanding of these classic problems is necessary to be successful in AP Physics 1. AP Physics students and Honors Physics students alike would benefit from developing problem solving skills and mastering this content. Although Physics for all focus is on the conceptual understanding and not on the algebraic manipulation, these problems can still be used for a conceptual level Physics class as a quick mathematical proof of the conceptual understanding.

Example 1: A weighted forearm [2b]

Calculate the force the biceps muscle must exert to hold the forearm and its load as shown in Figure 2a below, and compare this force with the weight of the forearm plus its load.

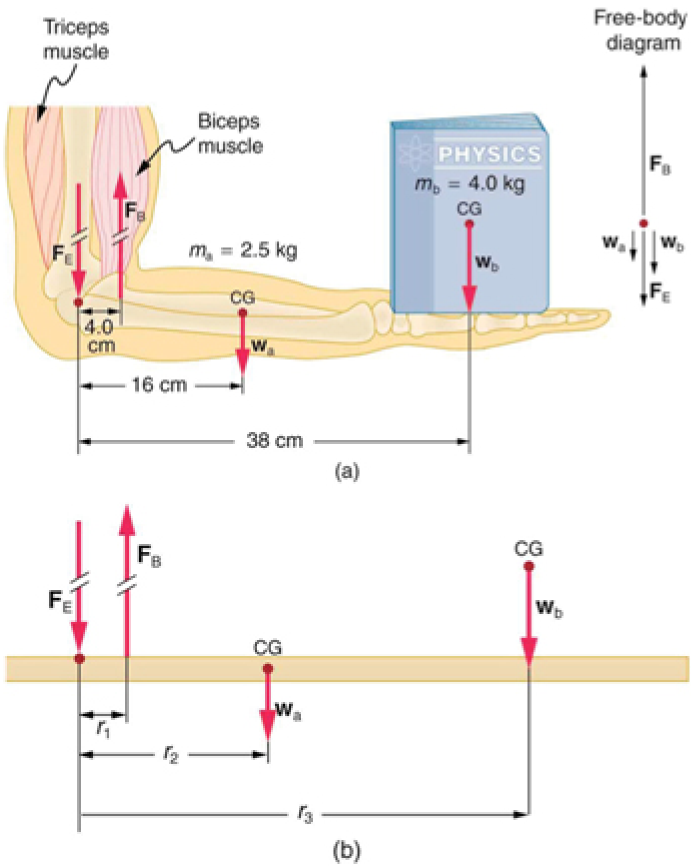

Figure 2: A weighted forearm type problem [2b]

Strategy - Step 1. Draw the free body diagram (shown in Figure 2b) that shows all forces acting on the forearm (drawn simplified as a bar). Since the weight "is held" the net force and the net torque is zero. Write the two equilibrium equations and solve for the unknown.

Strategy - Step 2. Apply the condition for torque equilibrium (zero net torque). Forces w_B and w_D rotate the lever clockwise, while force F_B rotate the lever counterclockwise. Force F_E does not rotate the lever since it is acting on the rotation point. Thus the torque condition for equilibrium can be written as $w_b \times r_2 + w_D \times r_3 = F_B \times r_1 + F_E \times 0$. We know w_B, r_2, w_D, r_3 and r_1 so we can solve for F_B, the upward force exerted by the biceps on the forearm, F_B = 470 N

Strategy - Step 3. Apply the condition for force equilibrium (zero net force): $w_B + w_D + F_E = F_B$. We know w_B, w_D, and F_B so we can solve for F_E, the force at the elbow joint, F_E = 63.7 N . The ratio F_B / F_E = 7.4. The biceps muscle exerts a force that is approximately seven times bigger than the weight it lifts.

A further extension of this problem would be to calculate the maximum weight you can attempt to lift for a given upward force F exerted by the biceps on the forearm. This variation also connects to the following classroom activity, Classroom activity – Prosthetic arm. Another extension of this problem is to calculate the strength of one's biceps – inquiry lab (see Classroom activity – How strong is your biceps?).

Example 2: Standing on tiptoe [2b]

A 75-kg man stands on his toes by exerting an upward force through the Achilles tendon. (a) What is the force in the Achilles tendon if he stands on one foot? (b) Calculate the force at the ankle joint. By following the procedure presented above and using the information given in Figure 8 from Reference [2b] we can solve for (a) $F_A = 2.21\times10^3$ N upward and (b) $F_B = 2.94\times10^3$ N downward. [2b]

Example 3: Masseter in the jaw [2b]

The masseter muscle in the jaw is attached away from the joint and enables large forces to be exerted by the back teeth. (a) Calculate the force exerted by the lower teeth on the bullet. (b) Calculate the force on the joint. By following the procedure presented above and using the information given in Figure 12 from Reference [2b] we can solve for (a) $F_1 = 1.2\times10^2$ N upward and (b) $F_2 = 84$ N downward. [2b]

Example 4: Head and neck lever system [2b]

Due to the fact that the center of mass of the head is not directly over the pivot point in the neck but shifted towards the front, the muscles at the back of the neck should exert a force to keep the head erect. Knowing the weight of the head to be 50 N, (a) Calculate the force exerted by these muscles. (b) What is the force exerted by the pivot on the head? . By following the procedure presented above and using the information given in Figure 9 from Reference [2b] we can solve for (a) the force exerted by the muscle at the back of the neck is 25 N downward and for (b) the force exerted by the pivot of the head is 75 N upward.

Classroom activity – Prosthetic arm

A hands-on classroom activity that can be performed either before the unit or after the unit is the design and construction of a prosthetic arm. This activity is adapted from prosthetic leg activity from Teaching Engineering website. [8] Students will work in groups to design a prosthetic arm with lengths between 35 and 65 cm that will be able to lift a 5 lb bag of rice (or flour, potatoes, sand, rocks, etc). They will have to measure the minimum force of the muscle has to put in to lift the bag. An extension of the activity is to calculate the maximum weight this particular prosthetic arm can lift if the muscle force is 500 N.

Students will use the resources found in the "Resource" part below to build their own prosthetic arm. The final goal is to optimize the arm to be able to lift a 5 lb bag of rice while putting in a force load of 500 N.

Resources

Materials needed for the prosthetic arm activity (adapted from Teaching Engineering [8]):

Each group: one meter stick, scissors, prosthetic arm structural materials (different for each group), a 10kN spring scale

Each student: Prosthetic Party Worksheet – adapted from Teach Engineering.

Entire class: 1 roll of duct tape, one or two 5lb rice bags

Suggestions for the structural material for the prosthetic arm:

For arm structure: 46 cm long plastic or metal pipes, unused toilet plungers, cardboard tube (from wrapping paper or paper towel roll), wooden "2 x 4"
For comfort: large sponges, scrap bubble wrap, scrap cardboard, etc
For lifelikeness: bath towels, shirt or T-shirt, gloves (use students')
For body attachment: String, rope, twine (about 30 ft [or 10 m])

Classroom activity – How strong is your biceps

This would be an extension activity of either the Prosthetic arm activity or of the Example 1 from the Classroom activity – Classical problems activity presented before. It is an inquiry-based activity in which students will have a choice to work alone, in pairs or in groups. Their task is to set up an experiment by which to measure how strong is their biceps muscle (in N or lb). Upon completion of this activity they will present their findings to the class. The class can challenge the presenters' findings using Physics content knowledge. There are a number of question that can be addressed at the conclusion of this activity. One question is if there is any correlation between the strength of the muscle and its circumference and between the strength of the muscle and the heaviest weight the student can lift. One should expect the strength of the muscle to increase with increasing the circumference of the muscle and the strength of the muscle to be about seven times bigger than the heaviest weight the student can lift?

Appendices:

Appendix: Prosthetic Arm Party

Leader/TK: _______Materials Manager_________ Data Collector ________ Date_____

Physics: Prosthetic Party

Objective : with the available materials, build a prosthetic arm able to lift a 5 lb rice bag.

Plan : What characteristics, qualities and features will your prosthetic arm have? How would you achieve this activity objective using the available materials?

Desired Quality	Construction Plan

Measure : How long is your prosthetic arm? ____________

Design : Draw a picture of how your prosthetic arm will look, using your plans from above. Label any measurement lengths or amount of materials to be used.

Evaluate use of materials (for your group) : After creating your final design, list the materials you used and how they contribute to the function of the prosthesis.

Material	Function

Evaluate use of materials (for other groups) : While watching the group presentations, list the best feature of each group's prosthesis and what material or technique accomplished this feature.

Group	Best Feature	Material / Technique

Reflection and improvements: From the group presentations, and reflection upon your own team's design, what improvements would you make to your prototype?

Appendix: Grading Rubric.

Performance Criteria	Excellent (10 points)	Good (5 points)	Poor (0 points)
Connection to the topic of choice	Project clearly demonstrates a connection to the topic. Equations and calculations are included.	Project demonstrates a moderate connection to the topic. Equations are included, but lack articulation and connection to the subject.	Areas of research are not connected to the topic. No equations or calculations are included.
Research Effort X 2	In-depth research effort is evident.	Student presented a fair level of research, but did not investigate all aspects of the topic.	Minimal research effort is evident.
Report Quality X 3	A neat, organized report was presented, which includes graphics and pictures to explain the research. Machine is well-constructed, consistently functions properly, and attention to aesthetics is clearly evident.	Report did not represent all aspects of the project, and/or included only a few graphics. Report was not neat. Machine does not consistently work and/or lacks aesthetic detail.	Report was poorly organized, messy, and/or did not include any graphics. Minimal information was provided in the report. Machine is poorly constructed/did not function.
Presentation X 3	Presentation was well-planned, rehearsed, and clearly explains all aspects of the chosen topic. All students presented a part of the research.	Presentation was not well-planned, and/or rehearsed. Presentation did not explain all areas of the research. Not all students presented.	No presentation was completed or not all students participated in the presentation. Student(s) were not prepared.
Class participation during other presentations	All members of the team took notes on all presentations and each asked at least one question	Some members of the team took notes on some presentations and asked some questions	Members of the team did not take notes and they did not ask any questions

Appendix: Collaborative learning job definitions.

Team leader

Team leader is the student that makes sure everyone participates in the discussion and that everyone is on task. The team leader is the person that will clarify group misunderstanding and confusions by asking the teacher.

Time Keeper

Time Keeper is the student that watches the clock and makes sure the group finishes on time. Best practice is to announce half way through the allocated time and five minutes before the time is up.

Data Collector/Recorder

Data Recorder is the student that records the data taken by the group or the main ideas during a group discussion. This student is the one that will write on the board for "class share"

Materials Manager

Materials Manager is the student in charge with collecting and returning all materials needed for the activity. This student is in charge to ask the teacher for additional supplies the group agreed on.

Appendix: Implementing District Standards

New Haven Public School Physics Curriculum for Unit 2: Mechanics covers the following Essential question: Should we use simple machines?

Performance Standards: After completing this unit the student will be able to:

Demonstrate knowledge of the way simple machines are useful.

Explain the use of machines to gain mechanical advantage and in assisting society.

At the end of this unit students will be able to list the six types of simple machines and provide their definition and an example of each. They should be able to identify advantages and disadvantages of using simple machines with focus on the advantages of using simple in real life.

They will be able to describe where in the human body once can find some of these simple machines, define the importance of having these simple machines as part of our bodies and describe how do they benefit us?

Students should also be able to correctly identify levers in the human body. They should be able to correctly engineer a prosthetic arm that will lift a certain weight proving the importance of understanding the physics of simple machines in improving our life style.

Students should be able to correctly apply the equilibrium conditions for force and equilibrium in a rotational system and correctly solve for the unknown(s)

Unit Extension

Physics is all around us. From astral bodies, to apples or other objects falling, to the energy transfer from the sun and finally to the machines humans created to help them in everyday life. Since Nature has everything perfected through evolution, humans use it as a source of inspiration for engineering new tools, machines and materials. Physics is involved in all stages of the process: from understanding how things work, to developing new machines and then assess their function.

This unit focused on understanding levers in the human body. An extension of the unit would be to focus on methods used in biomedical engineering in helping repair these body parts when needed (prosthetic limbs for amputees, bone implants etc).

Bibliography

[1] Serway, R.A., Faughn, J.A., Vuille, C., and Bennett, C.A.. "College Physics", 7th ed., edited by Thompson Educational Publishing (234-265). Toronto, Canada, 2006.

This is the book we use in our school for AP Physics B. Excellent for types of problems but needs teacher guidance.

[2a] OpenStax College. "Simple Machines." OpenStax-CNX. February 19, 2014. http://cnx.org/content/m42174/1.3

[2b] OpenStax College. "Forces and Torques in Muscles and Joints." OpenStax-CNX. February 20, 2014. http://cnx.org/content/m42175/1.6/.

This is an excellent open source Physics book.

[3] http://legacy.mos.org/sln/Leonardo/InventorsToolbox.html (accessed July 27, 2014)

Inventor's Toolbox, Boston's Museum of Science. Excellent website for science resources.

[4] http://www.oocities.org/rjwarren_stm/College_Physics/Mechanical_Systems.html (last modified September 2002, R. Warren).

Good review of simple machine and couple of standard problems.

[5] https://www.asdk12.org/MiddleLink/Inter/mosaic/Coop_Placards.pdf (accessed on July 28, 2014).

Excellent cooperative learning job cards for lab work and group work.

[6] Tomlinson, A. "How to Differentiate Instruction in Mixed-ability Classrooms". Association for Supervision and Curriculum Development, Alexandria, Virginia USA, 2012.

Good book on differentiation techniques in the classroom.

[7] Hall, T. "Differentiated Instruction. Effective Classroom Practices Report", National Center on Accessing the General Curriculum, June 2002.

Very good article that provides effective classroom differentiation practices including some evidence of the effectiveness.

[8] http://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_biomed/cub_biomed_lesson01_activity1.xml (last modified July 25, 2014)

Excellent website with a wide range of engineering worksheets that can be readily adapted to the classroom.