NEXT ENGINEERS

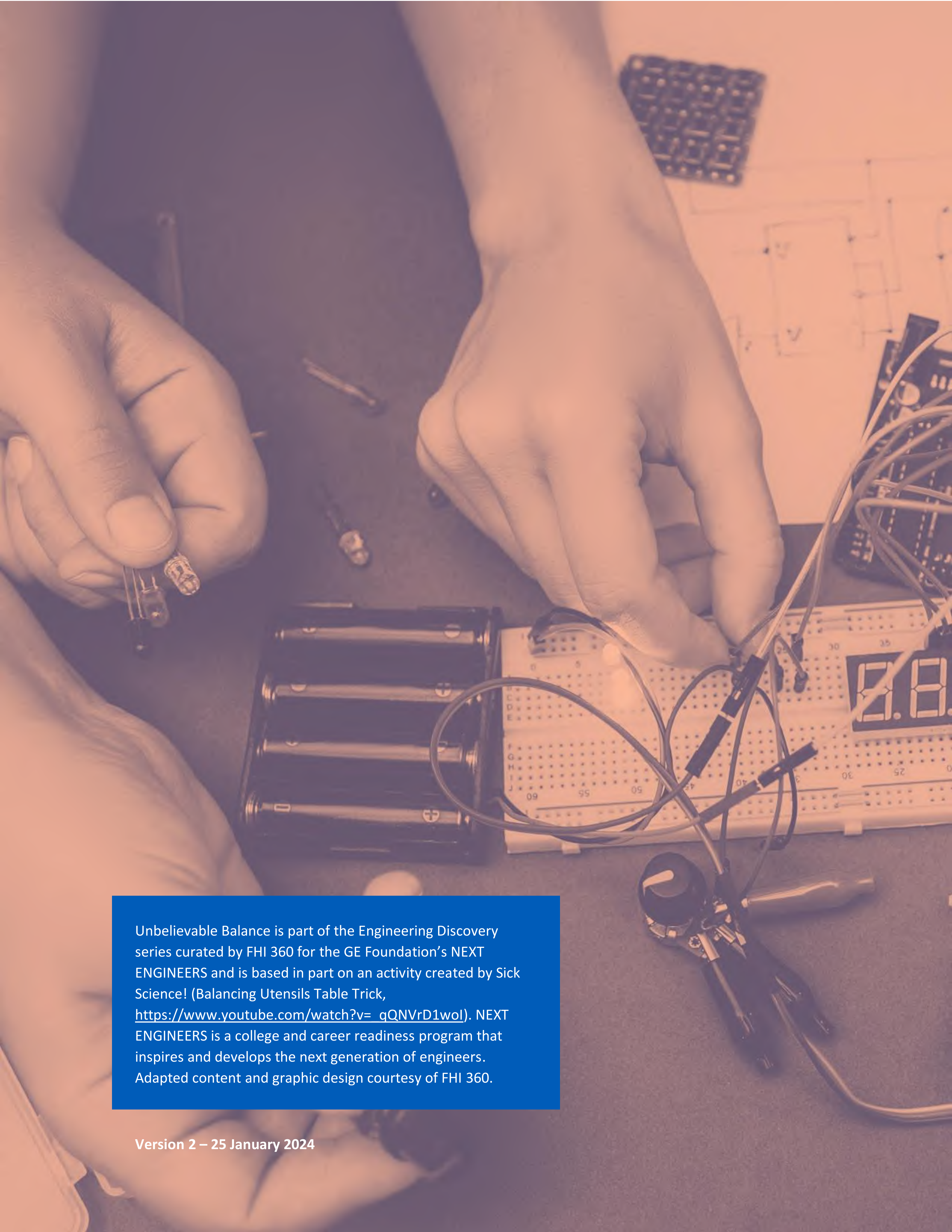
ENGINEERING DISCOVERY

Unbelievable Balance

Balance

Center of Gravity

GE Foundation



Unbelievable Balance is part of the Engineering Discovery series curated by FHI 360 for the GE Foundation’s NEXT ENGINEERS and is based in part on an activity created by Sick Science! (Balancing Utensils Table Trick, https://www.youtube.com/watch?v=_qQNVrD1woI). NEXT ENGINEERS is a college and career readiness program that inspires and develops the next generation of engineers. Adapted content and graphic design courtesy of FHI 360.

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Unbelievable Balance

DEMONSTRATION

Time	Ages	Cost	Activity Type
40 minutes	12 - 14	Low	Demonstration
Concepts Covered			
• Balance	• Center of gravity		

Demonstration Overview

This very simple, classic, but "unbelievable" demonstration of the center of gravity will amaze students. To begin with, you balance a fork and spoon over the edge of a glass with nothing more than a toothpick, and then you burn the toothpick!

KEY WORDS

- Balance
- Center of gravity
- Gravity

Materials

- A metal fork
- A metal spoon
- A tall glass, cup, or vase
- 2 toothpicks
- Matches or a lighter
- Single hole punch
- Short piece of string with a mass tied to the end to use as a plumb line
- Various pieces of cardboard (120 g/m^2, 32 bond or greater) cut into unusual shapes about the size of a side plate (15-20 cm, 6-8 in across). You will need one piece per two to three students in the group.

Demonstration Principles

Working with Youth: Facilitation Tips
(https://www.nextengineers.org/resource/working-youth-facilitation-tips) is a handy summary of the key facilitation principles that volunteers need to keep in mind when demonstrating any activity with students.

Facilitator Preparation

1. Read the step-by-step instructions.
2. Collect the materials.
3. Practice doing the demonstration. You definitely want to get the hang of finding the center of gravity of the fork and spoon and positioning them and the toothpick on the edge of the glass. The better prepared you are, the more of a show you can put on.

4. Plan when and how you will share your story and career journey in a relevant and personal way. Try to integrate your story into the demonstration as much as possible. You can find the following volunteer resources for how to tell your story on the Next Engineers website:
   a. ***I'm an Engineer! Storytelling Worksheet*** (https://www.nextengineers.org/resource/im-engineer-storytelling-worksheet)
   b. ***I Work with Great Engineers! Storytelling Worksheet*** (https://www.nextengineers.org/resource/i-work-great-engineers-storytelling-worksheet)
5. Practice asking and answering questions students may ask. See ***Frequently Asked Student Questions*** (https://www.nextengineers.org/resource/frequently-asked-student-questions).

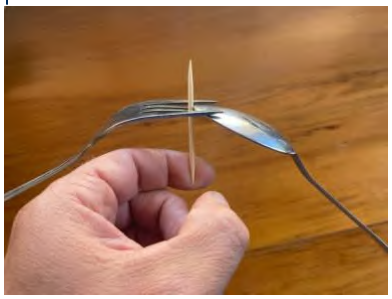
Step-by-Step Instructions

Time	Instructions	Materials
3 min	**Welcome & Introductions** • Welcome students to the demonstration and introduce yourself. • Tell the group a little about the kind of engineering you do and why you enjoy it. • Describe briefly how you became an engineer and when you realized that this was the career for you. • Show the group the fork, spoon, and toothpick. Ask them if they think you can balance the fork and spoon over the edge of a glass with the toothpick.	
12 min	**Demonstration Part 1** Perform the demonstration as follows. 1. Push the middle two tines of the fork down slightly and then thread the spoon between these tines and the other tines so that the spoon is over the middle tines but under the outer tines. 	Fork Spoon Glass Toothpick Matches

DEMONSTRATION TIP

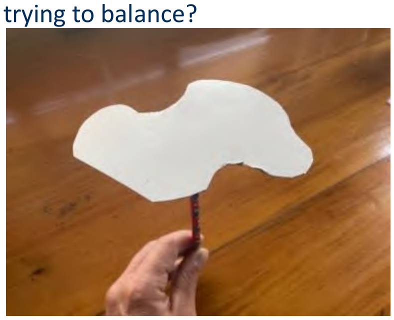
Make sure you have practiced your balancing act before the demonstration.

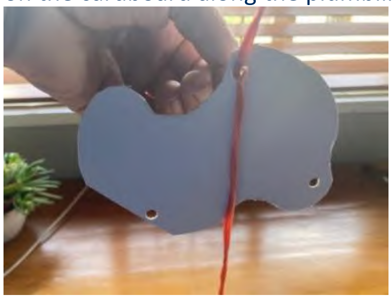
2. Balance the connected utensils on your finger to find the center of gravity and push the toothpick between the tines of the fork at this point. You should be able to balance the toothpick and utensils on your finger at this point.



3. Position the toothpick on the edge of the glass such that it is horizontal and with the handles of the utensils curving down and around the sides of the glass.

4. Ask the group to explain what they think is happening. How is it possible that the cutlery can balance like this seemingly in mid-air? Why do the handles of the utensils curve down and around the side of the glass?
5. Now ask the group what they think will happen if you light both ends of the toothpick. Will the cutlery come crashing down?
6. Light both ends of the toothpick. The ends will stop burning as the flame reaches the rim of the glass and the cutlery, respectively. The glass and cutlery both absorb the heat of the flame, extinguishing it.

	7. Ask the group to explain how the utensils remain balanced over the side of the glass. What do they think will happen if you bend the handles of the utensils into different positions? 8. Leave the balanced cutlery to refer to in the Review and Closing.	
15 min	**Demonstration Part 2** 1. Hand out the unusually shaped pieces of cardboard to pairs of students and ask them to balance these on the tip of a pen or pencil. They can pierce the cardboard slightly (but not all the way through) to help the cardboard balance. Tell students to number each position on the cardboard where they try to balance it. As they do so, ask them to think about how they go about the exercise. What sort of adjustments do they make to find the point where the cardboard is balanced? How do they know what adjustments to make? What are they really trying to balance?  2. Once they have managed to balance the cardboard, ask them to mark the final point where the cardboard is balanced on the top of the pen/pencil. 3. Ask students if this point is at the center of the piece of cardboard. What kind of center is this? Is this point unique? 4. Explain that the point they found where their cardboard was balanced is called the center of gravity. This is the point where the total weight of an object is evenly distributed on all sides, and, therefore, the object is balanced around that point. Ask the group if they can think of another way of finding the center of gravity of their pieces of cardboard. Demonstrate the plumbline process as follows.	Unusually shaped pieces of cardboard

	1. Use the single-hole punch to make three equally spaced holes in one of the unusually shaped pieces of cardboard near the edge. 2. Tie the plumbline to a toothpick and pass it through each hole in turn, allowing the cardboard to come to rest before drawing a line on the cardboard along the plumbline.  3. Where the three lines intersect is the center of gravity.  4. Refer students back to the balancing cutlery and ask them where they think the center of gravity of this system is. Point out that the center of gravity, in this case, is actually an imaginary point in space by pointing out how the system is balanced along all three axes.	
10 min	**Review and Closing** • Ask the group for examples of situations where they use or experience the center of gravity every day. Some simple examples include the balancing people do when they walk, run, dance, or play sports, play on a seesaw, or ride a bicycle. • Note that engineers use the concept of a center of gravity for objects in space orbiting large bodies like planets, moons, and stars. • Show the group the picture of the Lagrange point (L2) (see the Demonstration Background) at which the newly launched James Webb Space Telescope has been positioned, explaining how, at this point (one of five), the effects of gravity of the Sun and the Earth are perfectly balanced. It is like a center of gravity in space.	

TOP TIP

To save time, have all the punched pieces of cardboard and plumbline ready for this part of the demonstration.

Extension

One way to extend this demonstration is by experimenting with different locations for the center of gravity. An easy way to do this is to use a toothpick and two forks pushed into a cork or small potato. Show how it is impossible to balance the potato on the end of the toothpick alone but that this becomes far easier when two forks are pushed reasonably symmetrically into the potato as well. If you move either of the forks or the toothpick, you risk altering the center of gravity of the whole system.

Balance point of a ruler by IngridScience is used under fair use https://www.ingridscience.ca/sites/default/files/images/activities/img_6667.jpg

Key Words

- **Balance:** An object (or system of connected objects) is in balance when all the forces acting on it cancel each other out because they are equal but opposite. In other words, an object is balanced when there is no net force acting on the object, causing it to move or rotate. In many cases, we consider balanced objects as only acted on by gravity.
- **Center of gravity:** A (usually imaginary) point in an object or system of connected objects where the total weight of the object or system may be thought to act. In other words, it is the point in the object or system where the object or system is balanced. The weight of the object is evenly dispersed around the center of gravity.
- **Gravity:** The natural phenomenon whereby all matter (things with mass and/or energy) are attracted to each other. The greater the mass of an object, the greater the attraction other matter will experience towards it. The closer two objects are, the greater the attraction will be. Gravity is what gives weight to mass.

Demonstration Background

While this demonstration can seem like a silly party trick, especially the part where the ends of the toothpick are burned, it does illustrate some very important principles about gravity and balanced forces.

Eagle balancing toy is used under fair use https://www.quora.com/What-is-the-principle-behind-balancing-birds

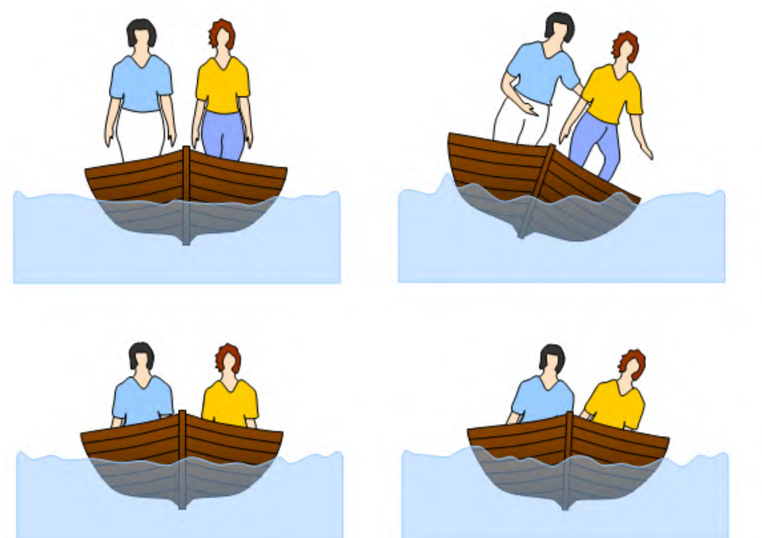
When an object (or system of connected objects) is balanced, this simply means that the net force acting on the object is zero. In other words, every force acting on the object is balanced by an equally sized but opposite force. A simple illustration of a system in balance is a glass sitting on a table. The force resulting from the acceleration due to gravity pulling the glass towards the earth is exactly the same size but acts in the opposite direction to the force of the table pushing up on the glass. The forces "cancel each other out," and the system is in balance.

The same thing happens when you balance an object, like a ruler, on your finger. Your finger acts as a pivot. The force of gravity acting at any point of the ruler to the left of the pivot is exactly matched by the force of gravity acting at some other point to the right of the pivot. The sum of all the forces pulling the ruler down on the left is exactly matched by all the forces pulling the ruler down on the right, and all these downward forces are exactly matched by the force of your finger pushing up against the ruler.

The position where you need to place your finger is the ruler's center of gravity and can be thought of as the point where the ruler's total weight is concentrated or the single point where gravity acts on the ruler. If you add a mass to either side of the ruler, you will change the weight distribution of the whole system, causing the center of gravity of the system to shift. Watch the video called Balancing a Ruler (5:33) - https://www.youtube.com/watch?v=djmec-Bweeg for a wonderful demonstration of how to easily and automatically find the center of gravity of such a system and an explanation of why it works.

Estimating where the center of gravity is for flat, basically 2D objects is reasonably straightforward. This is not always true for 3D objects, especially ones with non-regular shapes (like forks and spoons stuck together). In many cases, the center of gravity is actually outside the object and is a point in empty space.

We all make intuitive use of the center of gravity whenever we walk, run, or dance to stay balanced. Objects with centers of gravity closer to the ground also tend to be more stable. Therefore, tall, thin objects are easier to topple over than short, squat ones. In fact, toppling a tall, thin object over has the effect of lowering its center of gravity. This explains why you are much less stable when standing in a boat than when sitting.



Standing vs sitting in a boat by School Physics is used under fair use *https://www.schoolphysics.co.uk/age11-14/Mechanics/Statics/text/Stability_/index.html*

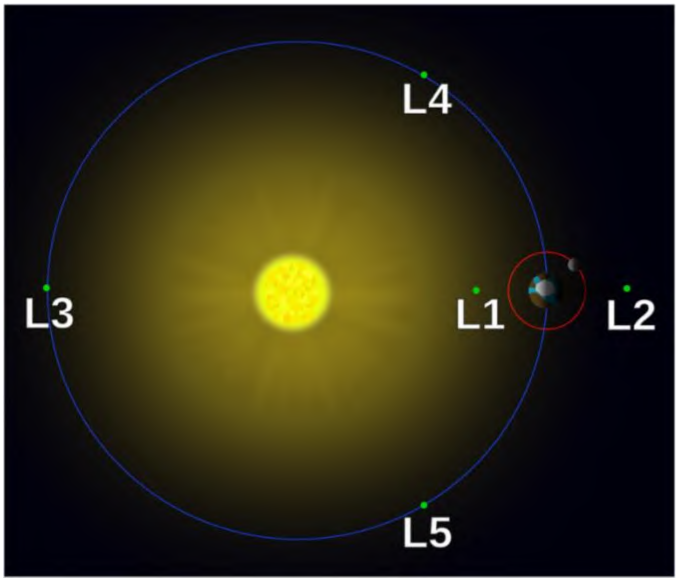
Have a look at the following additional resources for more on the center of gravity and, in particular, how this relates to the human body.

- ***Centre Of Gravity – Definition, Examples, Experiment*** (2:26) https://www.youtube.com/watch?v=R8wKV0UQtlo
- ***Centre of Gravity (of the human body)*** https://www.physio-pedia.com/Centre_of_Gravity

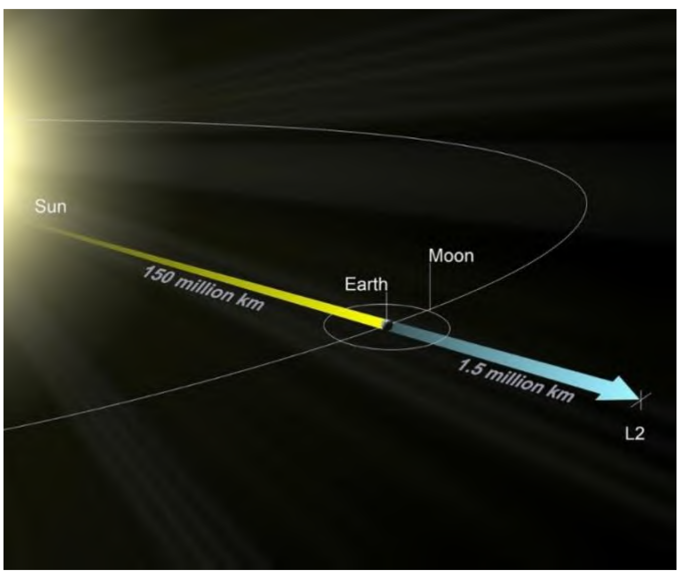
Lagrange points extend the idea of centers of gravity. These are points in space where the effects due to gravity of two massive orbiting bodies (like planets, moons, and stars) are in equilibrium, meaning that any small object at these points experiences the gravitational forces of the two massive bodies equally.

Objects at these positions can be thought of as being balanced between the two massive bodies.

In any two-body system, there are always five Lagrange points. These points are excellent positions for satellites and space-based telescopes (like the James Webb Space Telescope) because relatively little energy is required to correct their orbits over time and maintain a constant position in space relative to the massive bodies.



Lagrange points by Xander89 is released under a CC-BY 3.0 license
https://commons.wikimedia.org/wiki/File:Lagrange_points_simple.svg



The Lagrangian L2 point for the Sun-Earth system by NASA/ESA is in the public domain
https://commons.wikimedia.org/wiki/File:L2_rendering.jpg

References

This demonstration is based in part on a demonstration contained in the video **Balancing Utensils Table Trick** by **Sick Science** and available at https://www.youtube.com/watch?v=_qQNVrD1woI.