Co-funded by the
Erasmus+ Programme
of the European Union

Mechanics and Simulation

Purpose of the module: Introduce basic mechanic concepts and raise understanding of engineer's work from a technical evaluation perspective (calculations and simulations of products)

Tell about materials, their strengths and how forces interact with them.

Raise awareness and explain basic concepts of forces and stresses in engineering.

Give insight into mechanics and simulations in the design process.
Understand the need for product evaluation.

Show how computer simulation / virtual testing saves resources and allows faster product development with virtual product evaluation compared to real-life product testing.

Give an insight into topological modelling where the geometry is created depending on defined tasks.

Learn about the Factor of Safety as a part of engineering design.

Achievable results/ learning outcomes:

Materials and interactions with the surrounding world
The pupil have a basic understanding of what physical concepts are used in product evaluation.

Has a basic understanding of mass, force, the factor of safety and material properties like strength, density, and definition of evaluation of the task.

Virtual experiments
The pupil has an introductory understanding of how products are modelled and evaluated nowadays.
The pupil has seen examples of what happens when calculation or simulation is not done correctly.
The pupil knows what qualifications and knowledge are needed to be an engineer.

The pupil has an introductory level of understanding of material strength.
The pupil has seen demonstrations of simple and advanced Simulations and can talk at a basic level about seen.
The pupil has done some simple simulations on some software.
The pupil has introduction-level insight into topological geometry modelling and optioptimisation

practical experiments
The pupil gets a basic understanding of push and pull forces.
The pupil can talk about material strength.
The pupil gets experimenting experience.
Creating a model of a tower, bridge, chair etc. from different materials, making physical tests and simulations, comparing the results

Tasks

Materials and interactions with the surrounding world
Tell about mass, force and material properties like strength, density, the factor of safety and use of these parameters.
Explain the idea of product strength evaluation and its impact on product longevity and safety.
Sustainability differences in material use, metal ductility, and plastic recycling.

Virtual experiments
Explain what is meant by product evaluation in the design process.
Talk about history, how calculation possibilities and the overall knowledge of mankind have developed. (From hand calculations to calculators to computer simulation)
Raise awareness and explain basic concepts of forces and stresses in engineering and use simulation in the modern design process.

Explain form optimisation with the following demonstration and explanation of topological modelling that depends on defined constraints.

If possible, demonstrate the simulation process definition and calculation result *(content depends on if we will find some solution for demonstration).*

Give a task to find examples where the form or material optimisation could bring benefit and discuss it.
A demonstration or practical task:
(Example)

1. Make a simple bridge
2. Change material (choose at least 3 different) for the bridge and find out the strengths of the bridge (cardboard, spaghetti, formed paper sheet)
3. Choose one material and change the shape/form of the bridge or amount of the material, and evaluate the resulting increase or decrease of the strength

Example idea 2
Perform basic experiments about the strength of material and form (egg, paper cylinder with different thickness paper and loadings)

Show simple strength calculations, if possible, with the followed demonstration of computer simulations.

Practical experiments
Learning by doing, practical examples of materials strength, everyday and surrounding mechanics.

Length of module
1 lessons + 1 practical
*but needs to be tested

Name of learning subject in which module can be used:

Technology and design, Physics are available at this level (8th grade in LV), mathematics, computer sciences

Where to study after school
Basic concepts are taught in elementary school, but to have a deeper understanding of engineers work a good target would be to go study this topic in college and university.

The main professions in the market are Constructor (engineer), Technologist, Mechanical Engineering Specialist, and Mechanical Engineering Technician.
And you can learn these things in these schools:

- Rīgas Valsts tehnikums
- Ventspils tehnikums
- Rīgas Tehniskā koledža
- Olaines Mehānikas un tehnoloģijas koledža
- Latvijas Lauksaimniecības universitāte
- Rīgas Tehniskā universitāte un tās filiālēs

Mechanics and simulation

Materials and interactions with the rounding world – mechanics

This topic is intended to highlight a part of engineering design tasks and engineers everyday questions to have an insight into the use of physics and mathematics. Are you looking at some machine or building, or a bridge, or a plane, or space rocket - all these have in common that engineers have not only designed these products, but have done calculations of strength, forces, speed and, for example, how the compilation of previously mentioned parameters will affect the design. You can ride a bicycle or go in a vehicle or even fly in a plane, you can be sure that engineers have thought about the safety of a design.

Historically mankind has learned from trial and error, like somebody, built a house, but the house did collapse in the first windstorm, with that people concluded what was the weakest point and next time made it stronger. In a similar manner understanding about the surrounding world was collected and explained in the language of physics and mathematics and the end written down for common knowledge of humans. This common knowledge is taught in schools and then people who finish school in specific directions, like engineering, medical specialists, and scientists continue to use this mankind-accumulated knowledge and even add more to it every day.

By using everyday things from childhood, we intuitively learn about different properties of materials, some are stronger, some elastic, some can be used in food preparation, and some not. For example, some clothes last longer than others, and many times it depends on the properties of the material. In the same way, some shoes last longer than others and commonly there is a difference in material and quality of their production. The same goes with all other things that we see around us, most of them are produced. But of course, some things are created by mother nature and have their interesting properties. Like wood – different wood can have very different mechanical properties, some we build houses and furniture from some do not, but some can be used even in plane construction like balsa tree, which is not strong but is very lightweight, and some are very good for heating purposes, some not. These various properties we may times take into account intuitively, but designers need to go further and know exactly which material with its properties will be used, these properties can be evaluated, tested, and calculated.
The engineer's designers are specialists which have learned the knowledge and every day are at the core of creating something new or better, the process is called design. Some things are easy and are done with experience, but some tasks are demanding deeper understanding, like material behaviour, and loads that will be applied or even created by their design, and these things need to be understood and as much as possible made safe.

Before the computer age engineers did their calculations by hand, at the beginning even without calculators, but nowadays many things can be calculated on the computer and that is what is called *simulation. W*here it is possible to define real-life situations and describe mathematical and even model processes. Engineers in their everyday design work constantly need to think about how to create their product to satisfy set tasks that the product should solve, what material to use to satisfy needed strength and other parameters depending on the task, if something moves in the product – then it is called a mechanism and we can mathematically describe its movement. For example, to understand movement timing or to estimate loads in elements.

Let us briefly look at the main used construction materials:

- Still, the most common construction and product materials are **metals**

· Next to mention are various **plastic** (polymers etc.) materials

· **Wood** - interesting material with high strength in growing direction and lower properties in the perpendicular direction

· And if looked at from the perspective of amounts used, then **concrete** is used a lot and many times we can say that the end product with this material is composite

· **Composite materials** – like glass or carbon fibre in some resin, concrete and metal bars, and many other combinations of materials.

These properties need to be considered all the time during the design process and choose the best fit possible.

Additional information: *an interesting video about materials properties*

https://youtu.be/yRpY9Su4sKw

GROUP TASK: *Choose some everyday product, like a teapot or bicycle and write down what materials are used and try to explain why each of the materials has been chosen.*

Each type of material has its specific properties which differ from one to another. The main parameters of engineering interest are:

· Density – in simple words determine the mass or how heavy the design will be,

· Strength – describes what loads the material can withstand, or good it resists applied load

· Stiffness – how the material resists deformation (like when you apply the same load to rubber and metal you will get different deformation)

· And other specific parameters like an electrical (insulation or conductivity), thermal properties, wear & tear and at the end availability and costs.

For a better visible understanding of basic strength properties, we have created video material in the mechanical testing laboratory. We did a test on a wood plank, and a strip of steel and aluminium alloy samples and received their strength in the tension direction. In the tensile test, a constant force is applied to the material along the longitudinal axis, which deforms it until the material collapses. See videos for visual understanding:

- 2x Tensile tests on a plank of wood
- Tensile test on a steel plate
- Tensile test on an aluminium alloy workpiece

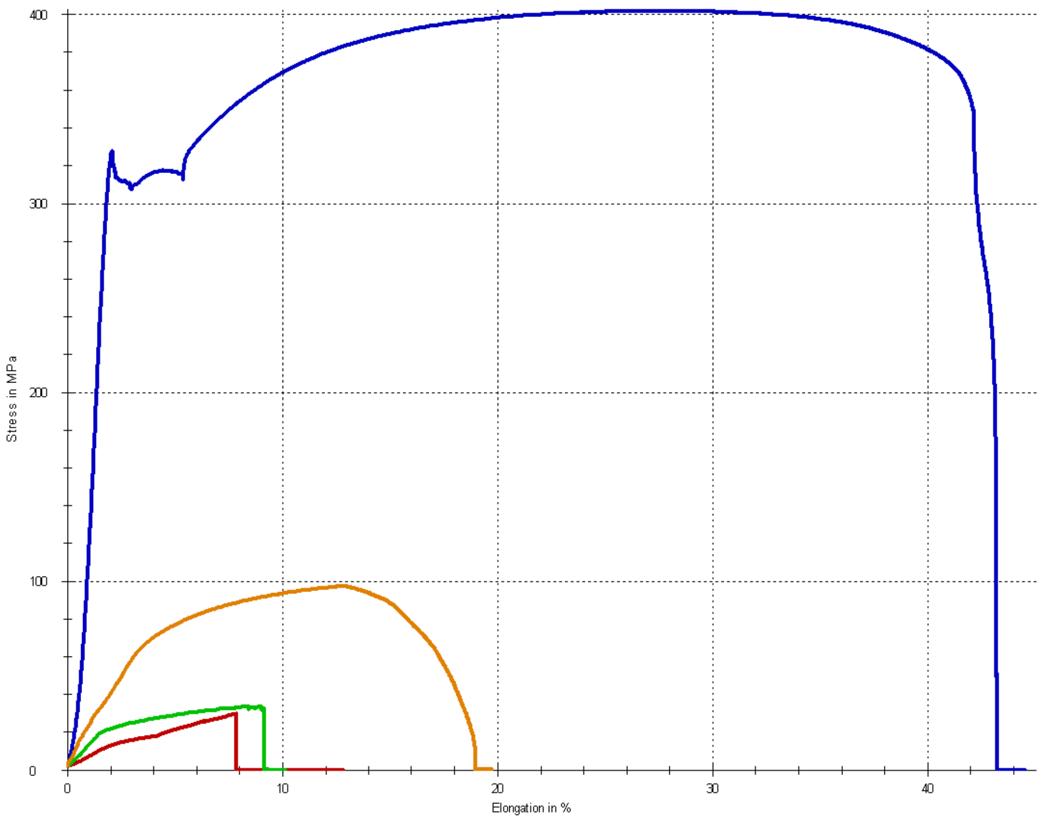
All experimental tests were performed under laboratory conditions in Riga Technical University "RTU Laboratoriju Māja"

In the table below information from tests in the videos is gathered. Information about the maximum

load that the sample could withstand is provided in 3 ways and cross-section parameters are given, with that we have obtained comparable results for these materials.
From here we can see that the highest load was put on the Wood 1 sample (5495 kg), it is because it was the biggest material by the cross-section, if we compare these 3 materials from the engineer's perspective then the material with the most strength is achieved by Steel sample, R max = 402 MPa. For comparison, this is the highest strength.
And in the last column, comparable data is calculated so you can compare the amount of force each of the 4 samples could hold if the sample size would be equal and would be a round bar 10 mm in diameter. You can see that both wood samples have not equal, but very near force results, but the highest loading is as expected for the steel sample it would hold a bit more than 3 tons of longitudinal tension. The aluminium alloy sample could be loaded 3 times more than the wooden sample but at the same time 4 times less than the steel sample.

Sample type	R_{max}	F_{max}	**F_{max}**	L_0	S	a	b	**F_{max} if D=10mm**
	MPa	kN	**kg**	mm	mm²	mm	mm	**kg**
Wood 1	30	53.89	**5495.49**	174.16	1800	20	90	**240.4**
Wood 2	34	26.8	**2732.9**	264.18	790.5	17	46.5	**272.5**
Steel	402	40.18	**4097.18**	101	100	2	50	**3221.7**
Aluminium	97	4.76	**485.73**	89.11	49	0.7	70	**777.4**

R_{max} - maximum strength in MPa (megapascals), a parameter which is calculated - force divided on samples cross-section. This parameter is most common for competing for material mechanical properties.
F_{max} - maximum force achieved in Neutons
F_{max} - maximums force achieved in kg for your easier understanding.
S - a cross-section of the sample and L_0 the testing length.
a – sample thickness
b – sample width
$F_{\text{if } D=10mm}$ – a maximum force that this material could hold if it would be a round bar sample with a diameter of 10 millimetres, force given in kg.

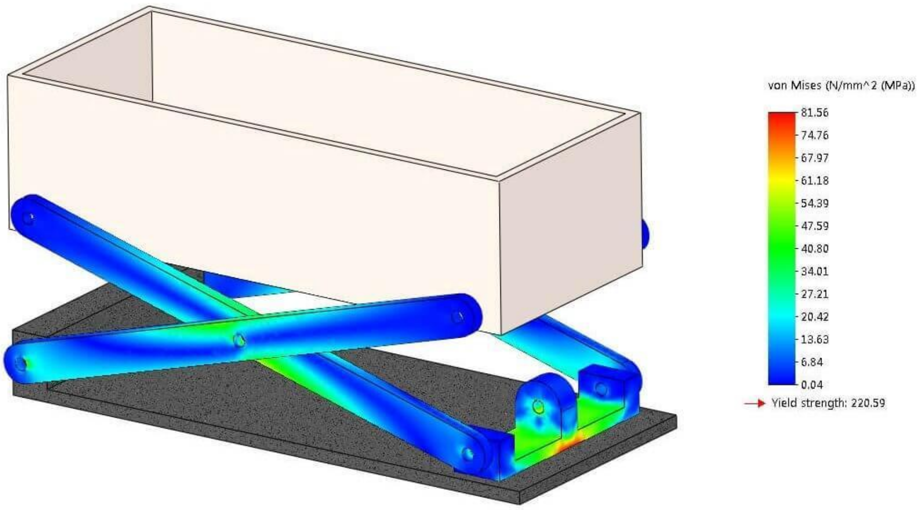


Test curves, from the above-given table you should be able to determine which curve is for which sample, *(hint: use the R_{max} column from the table)*

Steel is available with a variety of properties, some are soft and formable with lower strength, some are with high strength at the same time, less elastic and formable. The strength of steel depends on the materials added when it was melted.
In the material world, we have a variety of materials that can perform even stronger, for example, composites where it is possible to manage its mechanical properties in desired strength by adding layers with the orientation of fibres in the needed direction, most strength is achieved in the fibre direction. The most common composites are glass fibre and carbon fibre composites. A good example of how the composite is made is a veneer that is glued from layers of wood, where each layer is laid in a 90-degree direction to the previous and we get an even better wood composite.

When we know the material properties, we can think about using a material wisely by taking into account its properties and choosing accordingly. To achieve that engineers, use these properties to calculate if their design will withstand planned loads. For simple calculations, engineers have formulas to estimate if the design will work. Earlier entrepreneurs and engineers needed to build sample models to test if the design is safe and good enough to give to production, this is an expensive process because involves a lot of trial and error iterations. Nowadays most designs are modelled in 3D design software, this allows to bring design models into simulation software and to do calculations on near to real-life conditions on a virtual model. Such virtual experiments do save one of the most expensive resources - time, because no intermittent production is not needed, if all conditions are met during simulations then the demo product is already the end product. During this process, if the engineer sees that something is failing, he can react immediately and do the change by himself or in a bigger company to raise an issue and request a change.
So what we understand under Simulation - it is simply a replication of a physical test by using a virtual world in the software, it can cover a range of something you would like to know, for example, how strong something is, how hot something gets, how fluids behave around it or do flow

inside, how fluids and gases mix in the flow, whether there something will shake more than we would like, how light will shine from the object and what will happen with lamps heat and many more applications simulation is useful. Physical tests cost a lot of money because you need to produce sample tests in many ways where results should meet certain requirements if they are met, rarely tests are redone with a simpler model. On another hand in a computer simulation, it is possible to make changes and simulate the product with for example lighter construction and afterwards save money on materials. This all saves not only money but time to production, allows to create of better products and enables innovation.



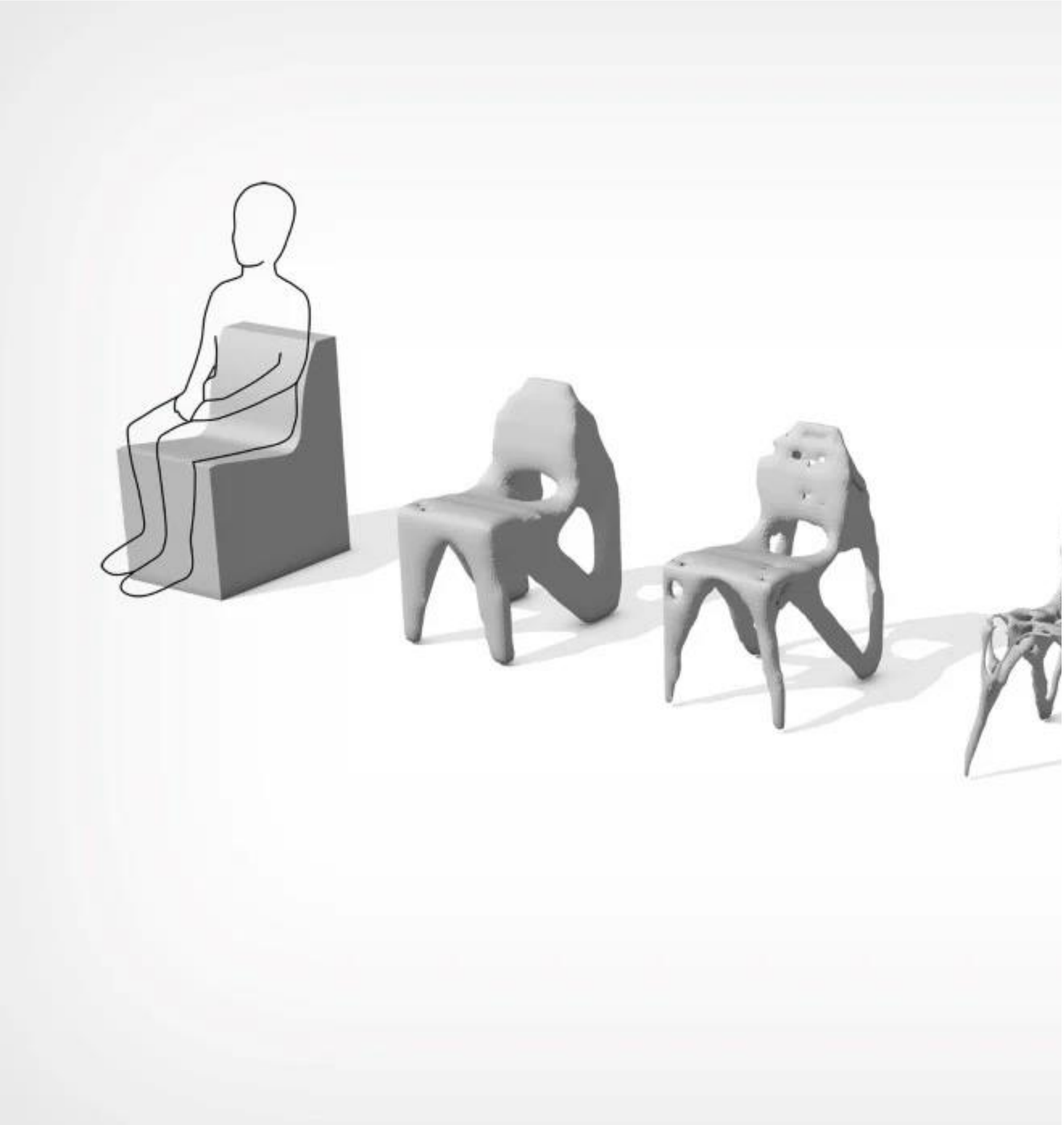
The colour chart model indicates places where the highest (yellow–red) forces in the construction act.

(SIM picture or video)

Or even software today allows building parts by defining loads and constraints, the designer needs to define how the element will be fixed, what loads it should withstand and the geometry gets modelled by software, this is called generative design.
The second similar process is Topological optimization where the engineer creates a geometry that does fulfil needs, but then after defining constraints, the software does optimize material, by removing material where it is not functionally needed. The difference is like in Generative design material grows nature-wise, but in topology study, most of the time materials are removed, but the results look very similar. An interesting example is in the picture below, where you see stepwise the optimization process, from primitive geometry to something that will withstand the defined loads. Afterwards, the result can be updated and refined for production needs.

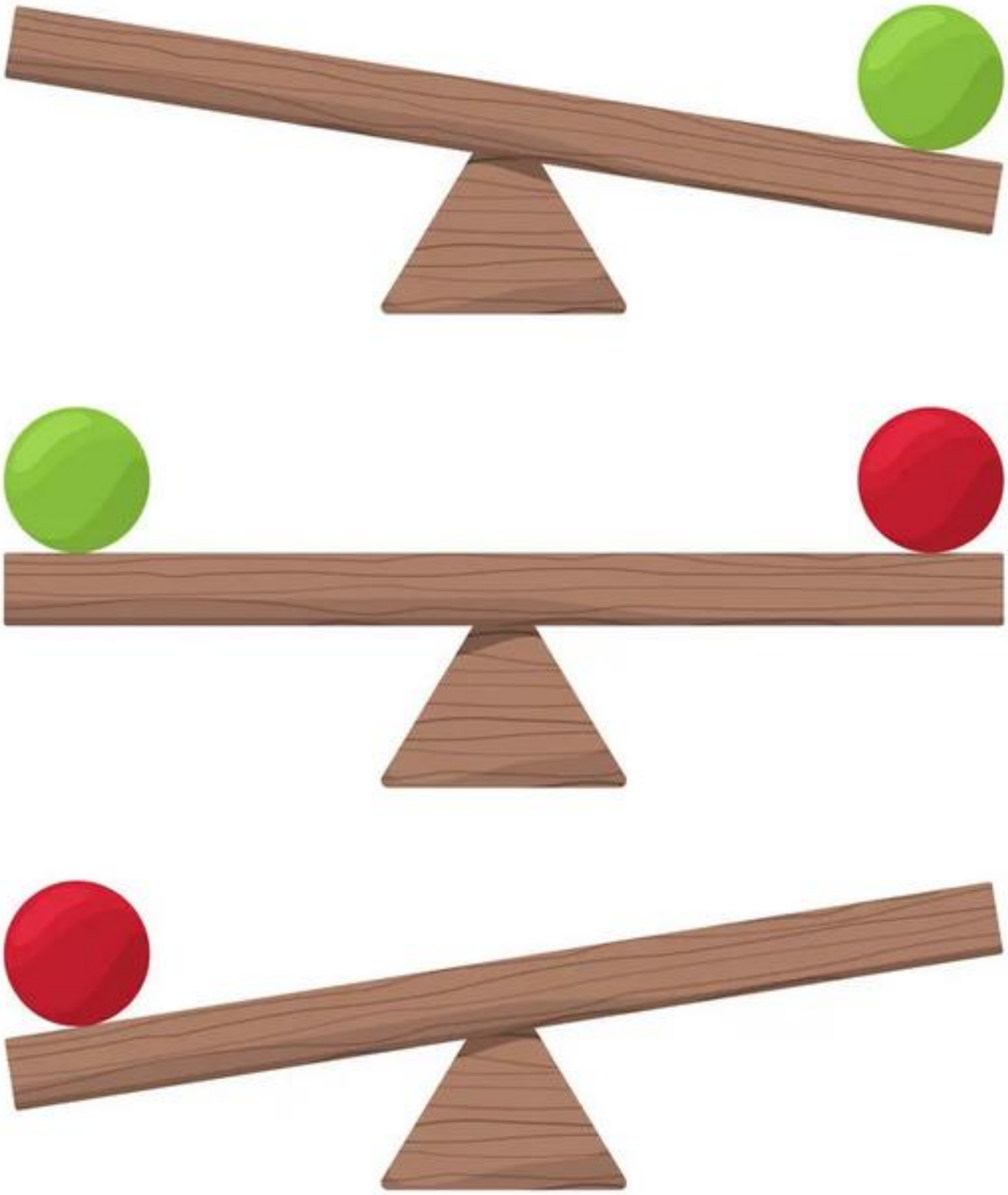
Lab4STEM

Co-funded by the
Erasmus+ Programme
of the European Union



(source https://www.gizmodo.cz/?tag=generico-chair)

Next, an interesting thing to observe is **power transmission mechanisms**. Engineers need to create moving elements, which can do some tasks, like move, lift, rotate etc. and with that do some job, even your bicycle can be considered such a mechanism. Firstly, we will look at some simple mechanisms like chains and gears, belt drives or two or more connected gears. Such drives we see in our bicycles, car gearboxes, many household goods and other devices where rotational motion is used.
The first and most simple mechanism is a lever, for example, balance swings or the same principle could be applied to weights.

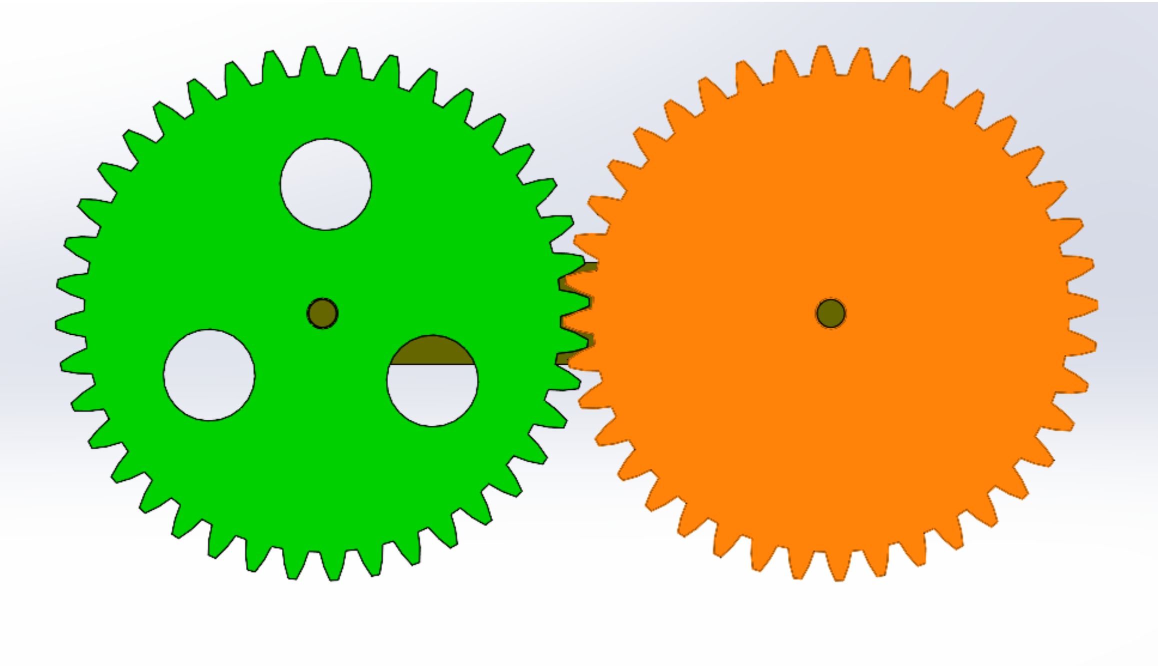


If both sides are weight equal, then the swing takes a horizontal position, if one side makes a greater effort to the axis then it tends to go down. In the physics course, you will learn that the mass effect on the axis can be changed by moving it along the beam, to increase the force by moving away from the axis, reducing, move closer to the centre axis. From this, we can evaluate the equation to calculate one mass if we know one mass and both distances from the axis.

What you can conclude about boxes from the picture above?
One thing could be, that matter in the left box is denser than in all right-side boxes, but the answer is correct if you say that the left box has something heavier than the right-side boxes.

From the lever principle it is easy to explain gears and power transmission, please evaluate this classic educational video: https://www.youtube.com/watch?v=JOLtS4VUcvQ (text translation in subtitles can be turned on).

Let's look at 2 disks or gears, the mechanics are similar in both only in case of gear force or motion is transferred with help of teeth on others with help of friction force, but for engineers, the most important parameters will be working diameters and to know which is input shaft, the direction of input and speed and applied torque (we can consider it as applied force).

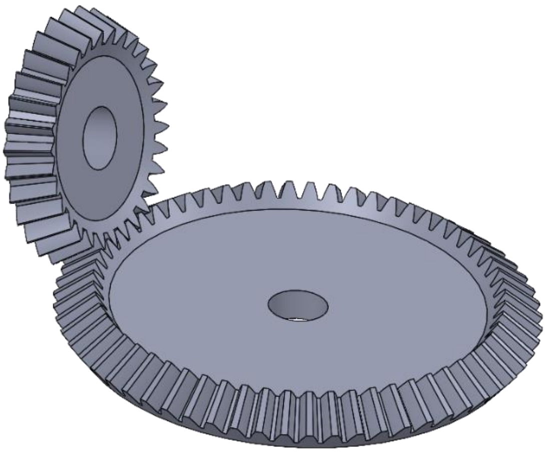


In the picture above we have 2 equal gears, which means the diameters are the same and they have the same number of teeth. And you can figure out in which direction they will move. For example, if the green one will turn clockwise then the orange one will turn counterclockwise. This was about movement, in this case, we can consider gears will move equally, but in opposite directions. What about force transmission? Since gears are equal, we will be able to transfer the same amount of torque as in input.

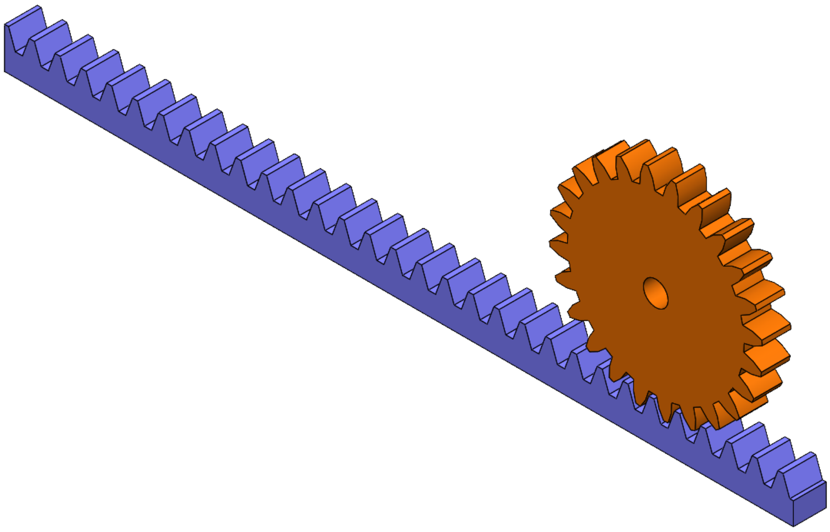
Similar mechanics work in bicycles only their gears are connected with a chain or belt. And connection type change changes the direction of rotation too.

But a bicycle is only one and maybe the simplest example, you can find both mentioned power transmissions in the car's engine, factory lanes and many other places. Gears can not only be used to change speed, and power transition but even the direction of movement, by angle or rotary to linear and so the applications of similar mechanisms get even wider.

Bicycle gear example, gif - *https://images.app.goo.gl/fBxt81tVGGttAmLA6*



In the example above we see that with such a setup is possible to change the direction of rotation and axis of power transmission by 90 degrees. Depending on which of the gears is the input gear, we can evaluate mechanics, for example, if the bigger gear is the input then we will see an increase in speed on the output shaft, but a decrease in power transmission. If the smallest gear is input then we could get the opposite – an increase in power transmission and a decrease in output speed. The difference in speed and power transition can be calculated by defining an equation that compares gear size like gear diameters, and gear teeth count will give us the ratio of change.



In the example above we see one more gear mechanism where longitudinal movement is transferred into rotational or rotational movement into longitudinal, depending on which side will be the input.

Simple mechanisms video examples: https://youtu.be/HlSCn0esufk

https://www.youtube.com/watch?v=jtk2V0M6k3M

Previously mentioned and other mechanisms are used to complete their intended task, some to transfer a load, some to change speed or direction of movement, but many other things are done by various kinds of mechanisms. The engineer who designs these not only thinks of their tasks but does some calculations. If mechanisms involve some movement, then there could be speed and force calculations, when these two parameters are clear, then the question arises about forces which will work in it, if those are noticeable that it is important to create parts of the mechanism from corresponding materials so the end product can full fill all needs in its planned lifetime. If the product is precisely designed and calculated then it is possible to predict the lifetime of the product or vice versa, if we know how long the product should work, for example, its warranty time and we know how it will be used on average, we can choose precisely what kind of materials should be used. We could always put higher durability materials, but this goes always together with costs. Costs are many times very critical because if you make the product too expensive nobody will buy it and even in this process engineer's role is very important for the product or even producing companies' success.

There are many examples where engineers and society have learned their lesson the hard way, one of the most popular examples is the Tacoma Narrows bridge collapse in 1940, which did collapse because its geometry was created so, that under special circumstances high-speed wind could initiate large displacements and in one day all circumstances happened, wind direction and speed was exact to initiate resonance in the bridge and it did collapse. Luckily for us, it was filmed and well documented and it is used as an accident in civil and mechanical engineering teaching.

Here you can find the video: https://youtu.be/3mclp9QmCGs

Wikipedia in English: https://en.wikipedia.org/wiki/Tacoma_Narrows_Bridge_(1940)
I guess there should be available web pages in each language about Tacoma bridge accident.

Practical experiments

Paper column strength (for materials topic)
Roll and glue cylinder from different thickness paper (or glue sheets together) and try buckling test by adding some board on top and plastic glass for water, try to keep the top and bottom of your desired form parallel – try determining how much such construction can hold as a column before buckling starts and column collapses. For differentiating between teams in class other forms could be used, like square, and triangle. Then would be interesting to estimate which form did hold better and maybe even to estimate for comparison material amount for each form. For loading water or books could be used.
Additionally:
+ try to fill it with sand (or water or books). Which construction will withstand longer?
+ make a hole on one or opposite sides, and see how it collapses then. Describe the collapse difference.
+ experiment, how important is it that ends are parallel and horizontal?
+ can be done as a competition for groups.
Similar https://www.youtube.com/watch?v=ZwMIEQs9WJU https://www.youtube.com/watch?v=rkH-0dpYbkc
For deeper knowledge, I would recommend reading some scientific papers about buckling, this phenomenon is still researched, similar cylinders, only from composites, are tested and computer-modelled to make lighter fuselages for rockets, planes and columns for civil engineering.
(for example https://www.researchgate.net/publication/315370348_An_Experimental_Buckling_Study_of_Column-supported_Cylinder)

Pulley phenomena (mechanics movement/force):
Crate pulleys system and test how one or two pulleys can enlighten lifting of load.

for a practical experiment – simple practical work: https://www.youtube.com/watch?v=In8uqKZdVIQ

Gears on bicycle explained:
Observe mountain bike type bicycle, where more than one gear combination is available. Discuss in the group and try to understand:

1. In which case it is very useful to have in front the smallest possible gear and in the back on the wheel the largest one?
2. In which case would be preferable to have the biggest gear in the front and the smallest in the back?
3. How, when you turn the pedals, you should act on the force needed to turn the pedals:
    a. If you turn the pedals very lightly what combination would be better (where larger gear, where smaller)?
    b. If you turn the pedals with a big force almost you cannot turn those, what combination of gears would be preferable to use?
    c. If you plan to ride on the hill what gear combination would be preferable?

Find a mechanism in your surrounding and describe it *(for example even a hinge or bolt and nut can be addressed as a mechanism, but I am sure you can find even more interesting mechanisms around you).*

Additional interesting resources:

A) Materials and strength (mater)
https://www.youtube.com/watch?v=340MmuY_osY (Liquid, hard, flexible, strong – mostly chosen by purpose) Solid, liquid, gas, magnetism (not all metals are magnetic)

B) Gears, chain (bicycle, gearbox) – speed change (multiplier) or torque, ratio (spin times as fast), input-output, direction
https://www.youtube.com/watch?v=uz436Ixbl-I
https://www.youtube.com/watch?v=D_i3PJIYtuY
https://www.youtube.com/watch?v=yYAw79386WI

C) Pulley https://www.youtube.com/watch?v=M2w3NZzPwOM mechanical advantage https://www.youtube.com/watch?v=oBYa28i_K9Q

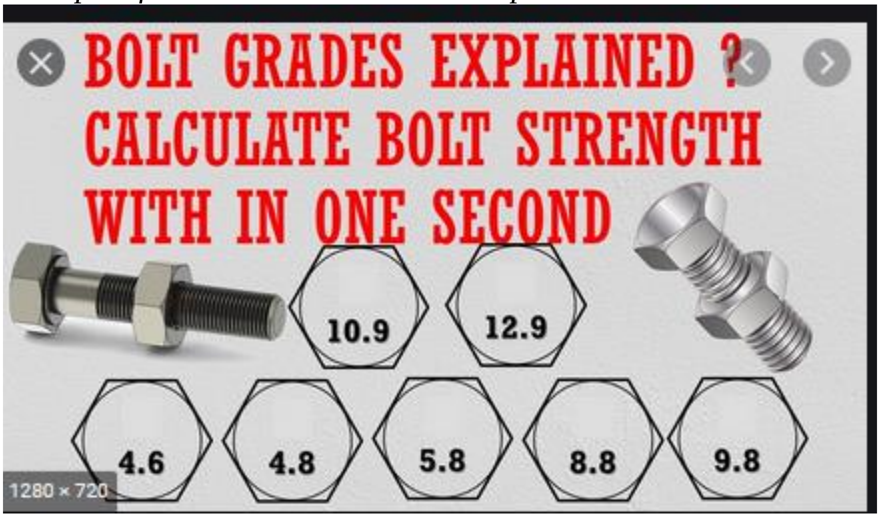
D) Simple machines https://www.youtube.com/watch?v=LSfNYpCprw4

E) Inertia and mass https://www.youtube.com/watch?v=hwmf73Bwky8 newtons 1st law – stay at rest https://www.youtube.com/watch?v=RyASDbAPenU https://www.youtube.com/watch?v=Za3DGUEpW2U

F) **Virtual experiments**
Projectile Motion https://www.brainpop.com/games/projectilemotion/ a car out of a cannon and challenge yourself to hit a target! Explore projectile motion by firing everyday objects out of a cannon and investigate the factors that affect the trajectory. Interesting other things too, even STEM program plans https://www.brainpop.com/technology/simplemachines/

Pendulum Lab https://tryengineering.org/game/pendulum-lab/ Play with one or two pendulums and discover which factors affect its swing. Take your experiment to the moon and determine the value of gravity on an unknown planet!

For those who want to know more, please search the internet and try to answer what the numbers 4.6, 4.8, 8.8 and 10.9 on the bolts mean.
Is it possible if, us to know this number and the bolt's diameter to calculate the maximum strength of the bolt?
Example of numbers on the bolts in the picture.



(Property class or bolt grade https://youtu.be/-_BxnhLyuH8)

Solidworks apps for kids MECH IT part https://www.swappsforkids.com/apps/mech-it/
And you can find similar things under Autodesk products too, try to evaluate and play!

(I think more for the teacher's manual, not for pupils)
Interesting presentation on materials
https://www.teachengineering.org/content/uoh_/lessons/uoh_matlsci/uoh_matlsci_lesson01_intropresentation_v4_tedl_dwc.pdf

Some interesting questions can be found here: https://www.helpteaching.com/questions/Physics/Grade_8
7th grade even more interesting than 8th

Solidworks apps for kids MECH IT part https://www.swappsforkids.com/apps/mech-it/

Autodesk Digital STEAM Applied Mechanics “Energy & Work,” “Force,” “Power,” “Loading,” and “Mechanisms.” https://tryengineering.org/game/autodesk-digital-steam-applied-mechanics/
https://tryengineering.org/game/tinkercad/
https://tryengineering.org/game/how-to-be-an-inventor/

Questions:

Name 2 important material properties? (strength, stiffness, density, electrical and heat properties, mass)

How do we call real-life product modelling = calculation in the computer? (Simulation)

Name a unit of load. (Force, Newtons, N, kg, kilogram, pressure, heat)

Can heat produce similar loading on material as an applied force? Yes / No (hint: Yes, if enough heat is applied, the material is expanding and stress in the material rise)

If the bicycle has 3 gears at the pedals, which gear is preferable to ride on a steep hill? Biggest, middle, smallest.

If you have 3 connected gears in the row, in which direction will turn third gear if the first turn clockwise? Counterclockwise, clockwise

If two gears are connected with a chain, in which direction will turn the second gear if the first is turning counterclockwise? The same, the opposite of the first gear.

If you have 11 connected gears in the row, in which direction will turn third gear if the first turn clockwise? Counterclockwise, clockwise

If you have 4 connected gears in the row, to which direction will turn third gear if first turns clockwise? Counterclockwise, clockwise

Unit of stress in the material mechanics?
Choose: MPa, megapascals, pascals, N/mm2 (all answers correct □)

Can bolts strength be calculated if property class (4.8, 5.6, 8.8) and diameter is known? No /Yes (Yes it can, because from property class strength and yield strength can be evaluated and from diameter cross-section of the bolt evaluated and maximum strength can be calculated.)

Material is produced within Erasmus+ programme Strategic Partnerships for school education Project “Mobile laboratories for improvement of STEM knowledge (Lab4STEM)” (Project No.2020-1-LV01-KA201-077502).