Technische Universität Berlin

Stability and failure of functionally optimized structures
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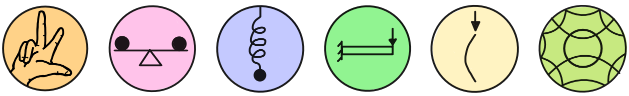
GAMEchanics

the first

Mechanics Escape Room



Accompanying booklet

Klaus Tschira Stiftung

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Hello!

Great that you made it out of the first mechanics escape room. Now you´re ready for the mechanics! :-)
We hope you had as much fun playing the game as we did preparing it. In this booklet you will find a few explanations of the puzzles and the mechanics background, some information about the scientists and the topic of gender equality in science.

The escape room on mechanics was developed as part of the one-year project "GAMEchanics – Mechanics meets Gamification", funded by the Klaus Tschira Foundation.
You are welcome to build it yourself. For this further information and open source documents can be found under the adjacent link. The room and other puzzles are also available there as computer games.

www.tu.berlin/svfs/projekte/gamechanics

Sincerely,

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Acknowledgement

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The Mechanics behind the Puzzles

Mechanics is a branch of physics that deals with the movement and deformation of bodies and the forces acting on them. Classical or Newtonian mechanics developed in Europe from the 17th century onwards. Today, it is taught as technical mechanics at universities in the engineering sciences. The GAMEchanics games focus exclusively on solid mechanics. However, there are also fluid mechanics, quantum mechanics, etc.

Attention: Spoiler alert!!! If you haven't played the room yet and are planning to do so, please continue reading on page 8 first.

The Reference System

At the start of the game, you had to use the right-hand rule to find the correct password for the computer. In mechanics, this rule is used to determine the positive orientation of the coordinate system. This is important so that all quantities have a reference system. The solution word was *statics* and the discipline it refers to describes the study of forces on bodies that are in equilibrium.

Forces and their Effect: Lever Law

In the next puzzle, a static system, the seesaw in equilibrium, was considered. In order to achieve equilibrium with the drinks packs of different weights, they had to be positioned correctly. Due to their mass and gravity, the drinks exert a weight force on the seesaw that is directed towards the ground. This force can be determined using the law of grav ity described by Isaac Newton.

As the drinks are not positioned in the centre of the seesaw, their weight exerts a torque on the seesaw. The torque in relation to the centre is calculated from the weight force multiplied by the (vertical) distance to the reference point. This distance is called the lever arm. The longer the lever arm, the greater the torque. The seesaw is in equilibrium when the moments (not forces!) on both sides of the seesaw are equal.

The law of leverage can be felt, for example, when seesawing on the playground: when adults seesaw with children, it is most fun when the adult moves forwards a little. If the adult remains seated at the end of the seesaw, the child has no chance of touching the ground. Try to find your balance too.:-)

Material Law: Tensile Test

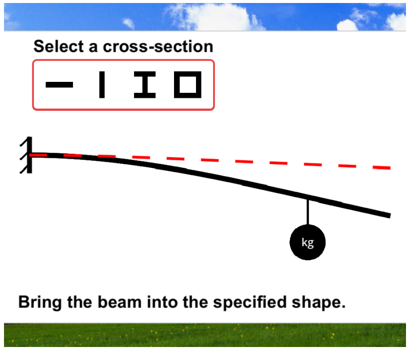
In this puzzle, you had to feel the stiffness of various springs by pulling on them. Unlike in the first station, the bodies are no longer rigid but deform. The extent of the deformation depends on the material. The material behaves elastically[1] This means that the spring returns to its original shape when it is no longer pulled. For very small deformations, many materials for technical applications exhibit a linear relationship between force and elongation. This relationship is known today as HOOKE's law and forms the basis of the theory of elasticity. It applies to both tensile and compressive loads.

In everyday life, we use Hooke's realisation of the linear relationship between spring force and change in length, for example in ballpoint pens or push-button switches, which are often used in stairwells.

[1] In order to make the stretching of the springs perceptible in the game, they had to be sufficiently large. This material behaviour is hyperelastic in this case.

Elastostatics: Beam Bending

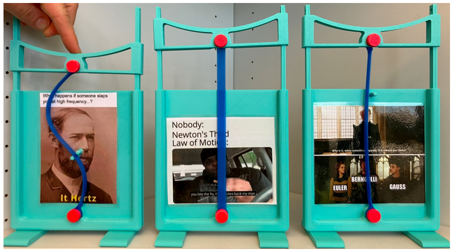
In the beam bending puzzle, the weight was suspended from the cross-beam. The load is now applied perpendicular to the longitudinal axis of the beam and is transferred by tensile (top side) and compressive forces (bottom side). The material behaviour of the beam is assumed to be in accordance with HOOKE's law. The extent to which the beam bends now depends largely on its cross-sectional shape and not on the material. You have seen the influence of different geometries in the virtual game when adjusting the bending line. The decisive parameter here is called the area moment of inertia, which is calculated from the geometry of the cross-section. If it is large, it is more difficult to bend the beam. The simplest model of a bending beam, the Euler-Bernoulli beam, was considered here.



You have probably already experienced bending in old floorboards. When you walk over them, the boards bend where there is no support. If, on the other hand, there is a crossbar underneath, you won't notice anything. The reason why the cross beam does not bend is because it has a greater moment of inertia.

Stability Theory: Buckling

In this puzzle, you had to bend various bars, so the load has now been exerted in the direction of the bar axis. From a certain compressive force, the so-called Euler critical load, the struts buckled into different shapes. These (large) deflections are called mode shapes and they depend on the material, the moment of inertia, the length of the bar and the position. After buckling, there are two equilibrium positions for the same load, e.g. for a bar either to the left or to the right.



Stability phenomena also often occur unrecognised in everyday life, for example when we use an umbrella. When you open the umbrella, the previously straight strut is in a deflected but stable equilibrium position. If there is a strong gust of wind, we have all been annoyed when the umbrella flips over and we get wet. The umbrella then jumps into the second equilibrium position, which exists with the same force. The only thing that helps is to always keep the umbrella facing into the wind. :-)

Dynamics: Plate Vibration

For the last puzzle, you had to feel and correctly match patterns of different Chladnic sound figures. The sound figures are created when a thin metal or glass plate sprinkled with fine sand is made to vibrate. The plate is clamped in the centre. The vibration is generated by stroking a violin bow along the edge of the plate. Natural modes are the various periodic movements of a vibrating system when it is left to its own devices after excitation (e.g. by the violin bow). Where the deflection of the eigenmodes is zero, the plate does not move and the sand remains stationary. These lines are called nodal lines. Sophie Germain researched plate vibrations, among other things.

Vibrations of strings, membranes and plates are important for the production of sound. For example, in instruments, such as guitar strings, or in loudspeakers whose membrane vibrates and thus generates sound that also spreads to other parts of the loudspeaker.

Scientists

The stories in the game are based on true events, but are interpreted fictitiously. All the scientists mentioned here were European. We only found one woman in the history of mechanics.

Isaac Newton (1643-1727) laid the foundations of classical mechanics with his laws of motion. However, his great passion was chemistry and alchemy.

Robert Hooke (1635-1703) established the law for linear-elastic materials by analysing various springs. Nowadays, the linear relationship between stress and strain, the law of elasticity, is often referred to as Hooke's law. However, Hooke was not yet familiar with the terms stress or modulus of elasticity. These were first described after his death.

Hooke and Newton were not friends. He accused Newton of having adopted his results on the law of gravitation without even mentioning him.

The Swiss **Bernoulli family** produced many important mathematicians and scientists in the 17th and 18th centuries. Jakob Bernoulli (1655-1705) researched the deformation behaviour of beams. The Bernoulli beam is named after him. He and his brother Johann supported the young Leonhard Euler, who lived in the same city, Basel.

Leonhard Euler (1707-1783) continued Jakob Bernoulli's investigations into the deformation behaviour of beams. His solution is known today as the Euler-Bernoulli beam theory. Euler also developed the theory of the buckling behaviour of beams and had 13 children. He is said to have been a real family man.

Ernst Florens Friedrich Chladni (1756-1827) created the Chladnian sound figures. He did not receive a professorship during his lifetime, which is why he earned his money by inventing new musical instruments, among other things. He is also said to have been an original personality who imparted knowledge in a pleasant way. So he was obviously already good at communicating science back then.

Sophie Germain (1776-1831) researched the calculation of plate oscillation. As a woman, it was not possible for her to study; she only acquired her scientific education independently through the library of her wealthy parents.

In order to enter into a scientific dialogue with mathematicians of her time, she initially used a male pseudonym in her letters. She was the first to attempt the calculation of plate oscillation. Although she arrived at the wrong result due to mathematical errors, her hypothesis led to the development of the recognised plate theory (today named after Kirchhoff).

Gender equality in science

Gender Ratios

The majority of professorships in mechanics are held by men. It was not until 2000 that the first woman was appointed to a professorship in mechanics! That is about 100 years after women were officially allowed to study in Germany.

Men[2] are still generally overrepresented in science. **Of all professorships at German universities and higher education institutions, just over 70 % are held by men**.
Among students, the quantitative gender ratio has been more balanced for a long time and has been more or less 50/50 for over 20 years.
However, the gender ratios in the various subjects differ greatly — in the STEM subjects overall, 66% of first-year students were male, while in engineering the proportion of men among first-year students was 74%. The lowest proportion of men was in the humanities at just under 30 %.

> The fact that the proportion of men is increasing along the academic career path in all disciplines because more women than men are lost to academia at the transition from one stage to the next is known as the ***leaky pipeline***. Some of the reasons for this are listed below.

Working Conditions in Science

There is currently a major debate, e.g. under #IchBinHanna and #IchBinReyhan, about working conditions in academia and especially about the widespread use of fixed-term contracts. Even among aca-

[2] **Because men also have a gender and there are more than two genders!** When it comes to gender relations in science, women are usually the main topic of discussion. We have turned the tables and shown the overrepresentation and privileged status of men. The statistics do not currently contain data on people with or without a gender entry. The data used here is from 2021.

demics who are still working in academia after completing their doctorate (but do not yet have a professorship)have **only 40 % permanent employment contracts, including more men than women**. There is also a gender pay gap in science. At TU Berlin, for example, professors at the highest salary level earn an average of 800 euros more per month than female professors.

Reasons for the Structural Inequality

The causes of the inequalities described are diverse and complex.
Science has historically had a male connotation: for a long time, only (selected) men were allowed to study and conduct research; women of historical, literary or scientific significance were only made visible through women's studies, which emerged in the 1970s. The link between science and masculinity is particularly strong in the STEM subjects.
Gender stereotypes and prejudices mean that men are often perceived as more "suitable" in selection procedures, that they are considered to have more potential than women and that their motivation is not questioned even if they have children. This happens unconsciously in some cases.
Women as well as trans*, inter* and non-binary people experience **individual discrimination based on their gender** in science, ranging from "smile more" and comments about their appearance to unwanted touching and other boundary violations.
Women still take on significantly more **care work** in heterosexual relationships. The traditional norm of science as a vocation, to which everything else is subordinated in terms of time, is therefore more harmful to women.

What can be done?

The main responsibility for realising greater gender equality in academia lies with university management and executives. Necessary gender equality measures include, for example, **data monitoring, reduction and prevention of discrimination, further training on gender equality and gender research**. Male scientists can act as **allies against sexism**, as so-called *male allies*, and e.g. decline invitations to panels without the participation of women and recommend two female colleagues instead.

Female students and academics should be **well informed about their rights and support services**. The **formal and informal networking** among each other is often experienced as empowering, because then it becomes clear that it is not the women's fault, it is the structures!

Fix the system, not the women!