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Building bridges: how do structures stay upright?

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Still standing: have you ever wondered how buildings stand? Or why they sometimes fall? Let's explore this through bridges, from construction to collapse.

The students will learn about the concept of balance and how to find the centre of gravity of flat figures. They will also learn how to design a bridge to create a robust structure.

The activity starts as an individual experience of balance, and it grows into a group project to create an actual bridge.[1]

This project is for students aged from 11 to 14, although the second part could be used as a project for older students too.

Activity 1: Looking for balance

Firstly, the students, in the school gym or classroom, take a photo of themselves while in a particular balanced position. Using sticks, cardboard, or other easily accessible materials, they have to try to recreate their pose from the photo.

After this first experience, the students try to find, empirically, the centre of gravity (*G*) of different flat figures, starting with a cardboard rectangle, upon which, after identifying *G*, the students will glue pieces of cardboard to one of the vertices, modifying the mass of the figure.

Finally, the teachers will propose irregular flat figures with which the students can recreate the experiment.
This activity takes 2–3 hours.

Safety notes

Use rounded-tip scissors, and perform the first balance activity away from obstacles.

Materials

- Cardboard (240 g m^{-2})
- Scissors
- Pencil
- Glue
- Smartphone
- Ruler
- Sticks, straws, or other recycled materials

Procedure

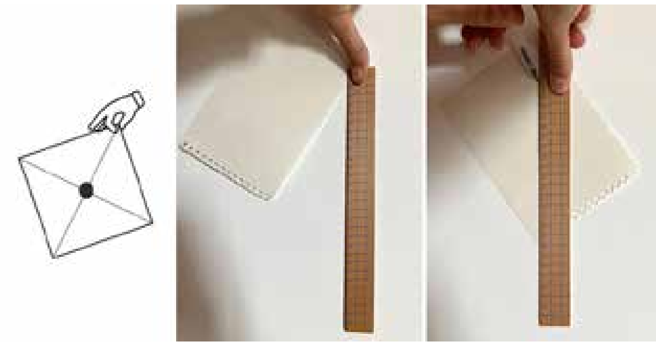
1. In the school gym or at home, take a photo of yourself in a position of balance.

Image courtesy of the authors

2. Recreate your pose using sticks, straws, or other recycled materials, so the model can stand.

Image courtesy of the authors

3. Take a piece of cardboard.
4. Trace the verticals to identify G.



Images courtesy of the authors, scheme made using elements by [Caputo/Noun Project, CC BY 3.0]

5. Add some pieces of cardboard (at least 4) to one of the four vertices.
6. Follow step 3 and verify if the position of G changes.

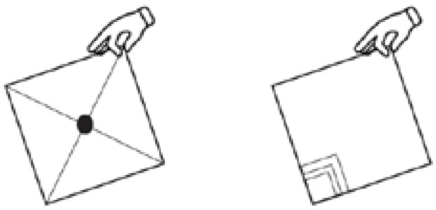


Image courtesy of the authors, made using elements by [Caputo/Noun Project, CC BY 3.0]

7. Create an irregular flat figure from another piece of cardboard and repeat steps 2 and 3.

Image courtesy of the authors

Results

Was it harder to find balance with your body or with the figurine? What changes the position of *G* in the cardboard model?

Discussion

The activity lets the student understand the concept of the centre of gravity and mass variation, without using physics formulas, which aren't yet in the curriculum for younger students.

Step by step, the students become more and more aware of what they are learning, and they can test themselves with more complex models over time.

In this activity, if the students find the wrong *G*, they can try again and again until they get the right centre of gravity, in both the figurine and the cardboard model.

Activity 2: Building and collapsing a bridge

With the design, construction, and breaking test of a bridge, the class experiences the loss of equilibrium of a complex structure. To do this, in the first lesson, the teacher introduces the force diagram in an elementary way using simple geometric models. Then the teacher illustrates the different types of bridges with particular reference to reticular and suspended ones. At the end of this first lesson, the challenge is launched and the teacher organizes the class into work groups. During the following lessons, the students design and build their bridges by autonomously choosing the shape and materials. The activity concludes with load testing of the structures and with a final reflection on how the bridges break.

This activity should take around 2 hours of lessons (introduction and testing at the end) and up to 8 hours of workshop time (designing and building the bridges).

Safety notes

Burning risk with glue guns: supervision should be provided. Alternatives like sticky tape or wood glue could be used, depending on bridge design.

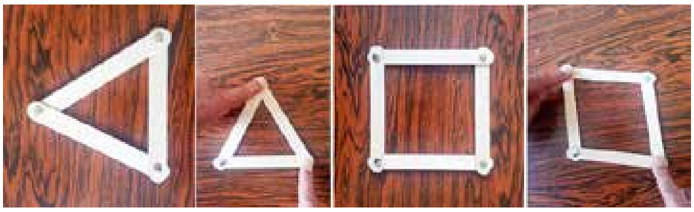
Anticut gloves should be used with cutters and hot glue.

Materials

- Hot glue or alternative adhesive (see safety note)
- Cutters
- Scissors
- Smartphone
- Wooden skewers, ice lolly sticks, or other rigid materials
- Pencil
- Ruler
- School diaries, textbooks or other weights
- Straps to hang the weights from the bridges if necessary

Procedure

1. Using some examples, the teacher introduces the concept of balance of forces on triangular and rectangular shapes. The students are then asked to reflect on the way each of the two models bend under pressure.



2. To enrich the activity, we suggest organizing a brief lesson on the most common ways to build a bridge. Relevant links can be found in the Resources section.

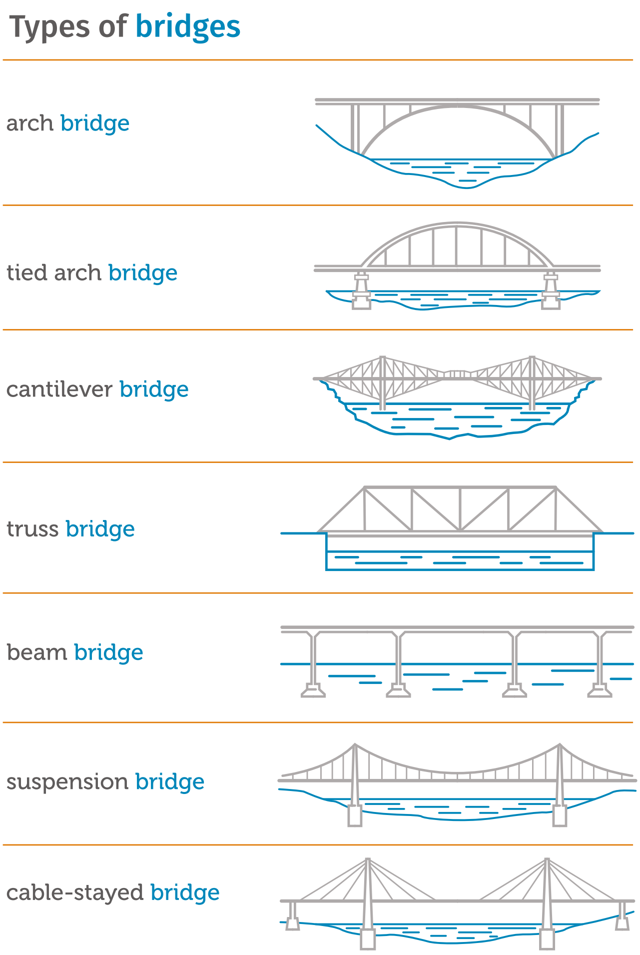
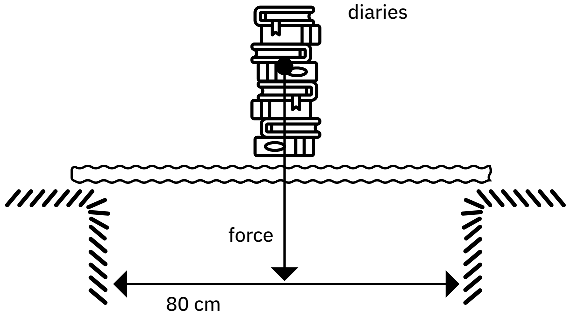


Image: A7880ss/Adobe Stock

3. Once this introduction is over, the teacher launches a building challenge: the students have to build a bridge to span an 80 cm gap using materials of their choice. Each bridge will be put between two desks and then weighed down with a stack of school diaries. The parameters of evaluation are the resistance of the structure, its weight, and its construction coherence relative to the materials chosen.



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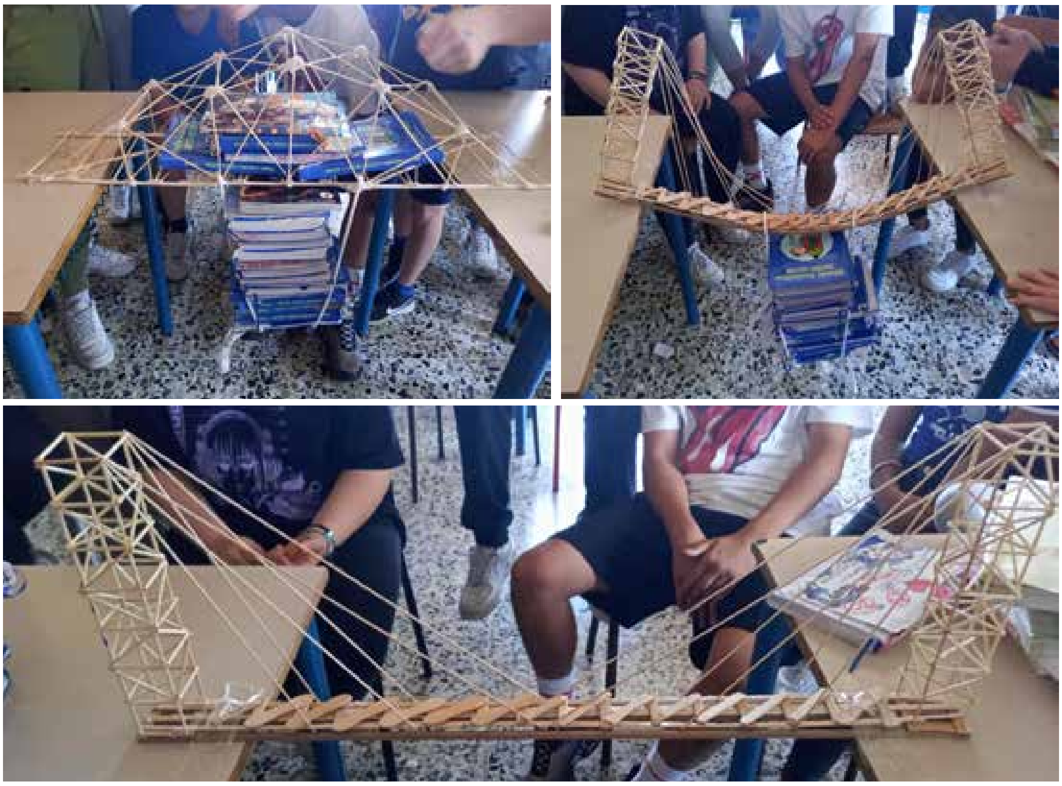
4. The class is split into different groups (max. 4 students in each group). Each team documents, step by step, the development of the project using drawings and photos of their work.
5. Design, construction, and documentation of the bridge. During this step, the teacher acts as a guide for the various groups, without interfering with their choices but supporting them when asked. In particular, the teacher checks that the materials chosen are consistent with the structural typology adopted by the individual groups before building starts.
6. When all teams have finished building their project, they are asked to draw a scale replica of their bridge: students measure the bridge and, based on the paper they have available, the teacher helps them choose the most suitable scale factor.
7. The students present their creation to the whole class. In this phase, they also share all the photos and notes taken during the process.
8. The groups weigh their bridge and add the number to the class results table.

GROUP	BRIDGE WEIGHT (g)	BREAKING LOAD (g)	LOAD/WEIGHT RATIO (g)

9. Then, each model undergoes a load test by adding school diaries or other weights to the bridges. The bridge should be placed over an 80 cm gap and the diaries either placed on top or hung from the underside of the bridge. The total breaking load is calculated by adding the weights of the school diaries the bridge has managed to hold before collapsing.



Images courtesy of the authors

10. At the end of the test, the results are discussed with all students. It is useful to record or take photos of each test to help the students reflect on their project.

Discussion

- How many diaries were needed to collapse your bridge?
- Were the materials chosen adequate for the construction?
- Did the structure suddenly collapse or did you notice any deformation beforehand?
- Were only some parts of the bridge broken or was it completely destroyed?
- Did the bridge tip over and fall without breaking?
- Did the failure occur at the joints or along the elements of the structure?
- What is the best substructure to use, triangles, squares, etc., and why?
- If you could repeat the activity, how would you improve your project?

Conclusion

By the end of the activity, the students will have had the opportunity to get involved in the project, with first-hand experience of choosing materials, building the bridge, and evaluating the breaking load.

The drawing of the bridge on paper allows the students to reflect on the importance of the concept of scale in technical drawings.

Finally, the team challenge develops soft skills, such as group work, creativity, and critical thinking.

During the course of the activity, the teacher is free to go into more detail about different parts of the structure, by dedicating some brief collective moments to reflection, starting from the models the students are building.

References

[1] Salvadori Mario (2000) *Perché gli edifici stanno in piedi.* Bompiani, Milan 2000.

Resources

- Find information on some of the main bridge types.
- Watch a longer video where an engineer explains the key features of different bridge types and the forces involved.

- Use the PhET simulator to learn more about balancing.
- Teach the science of levers with a fun and interactive activity: Bilišňanská M, Kireš M (2017) Balancing act: the physics of levers. *Science in School* **42**: 49–55.
- Learn about construction bionics and how biological structures can be applied to engineering constructions: Wegner C et al. (2017) Bionic structures: from stalks to skyscrapers. *Science in School* **40**: 12–16.
- Explore the conservation and transfer of energy with Rube Goldberg machines: Ferguson S et al. (2022) Conservation and transfer of energy: project-based learning with Rube Goldberg machines. *Science in School* **56**.
- Explore the principles of form and function in relation to evolutionary adaptation by engaging with biomimetic design: Toro S (2021) Biomimicry: linking form and function to evolutionary and ecological principles. *Science in School* **52**.
- Encourage your students to think like an engineer and design a glider wing: Holligan B (2015) High flyers: thinking like an engineer. *Science in School* **34**: 36–40.
- Learn about data visualization by sketching graphs from 'story' videos of everyday events: Reuterswärd E (2022) Graphing stories. *Science in School* **58**.
- Explore the processes materials science engineers use when selecting fabrics by designing a parachute: Miranda I (2023) How do materials science engineers choose fabrics for parachutes? *Science in School* **61**.

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In 2021, they presented their project Sfera e Basta? at the Science on Stage Italy fair in Faenza. In 2023, they were speakers at a workshop organized by the University of Genova and dedicated to teachers, with a talk entitled *The verticality of teaching science: the scientific degrees plan experience in Liguria.*