Balancing with Archimedes and Roberval on a classboard

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Abstract

Hands-on apparatus to enhance students' understanding of center of gravity, torque, energy conservation, and other basic principles of Mechanics is presented and discussed. Roberval scales that seemingly defy Archimedes' Lever Principle are designed to be built real-time on the class board.

Introduction. Design suggestions

We suggest building demonstrational mechanical apparatus on the class board and discuss its approbation in a variety of teaching conditions. Among the strong advantages of this approach proved by our practice, is a very natural possibility to trace and measure all the motions of apparatus' parts directly on the black/white board with an ordinary chalk or a marker, thus skipping the scaled diagrams and other secondary schemes.

Such an approach also allows getting rid of the construction elements necessary for the traditional design but hardly required, if not misleading, in the explanation of the physical principles to operate the device. Thus, if the demonstration is about rotation, corresponding axes should be suspended or fixed by some holders. Not only those distract the students' attention during the demonstration, but too often decrease the device's stability caused by the inevitable vibrations and distortions under load or due to fast motion, especially for the large-sized models.

Fixing apparatus' axis on the massive class board eliminates the above problems and allows construction of stable large devices perfectly visible by students, easily reassembled, practical both for qualitative demonstrations and measuring experiments. For many the practical purposes, *20-50 cm* long wooden rulers may be used as the construction parts. They are light, easily cut and drilled and rigid enough to build models of loaded devices to perform two-dimensional motion, in particular, levers and balance on the class board or a wall. Small bolts (*M3-4* in our case) or nails/pins may perfectly serve for the axes. Ones to be attached to the board are put through the small pieces of wood (same rules cut *2x2 cm*) or cardboard and fixed by the doublesided adhesive tape. Those are durable under vertical load but easily removed leaving no trace on the black/white board. A variety of weights suspension ideas could be applied.

On-board lever (Archimedes) balance

Figure 1 presents flat on-board model of the simple lever balance. Triangular rigid structure attached from below to the basic arm of the balance provides for the stable equilibrium of the symmetrically loaded balance.

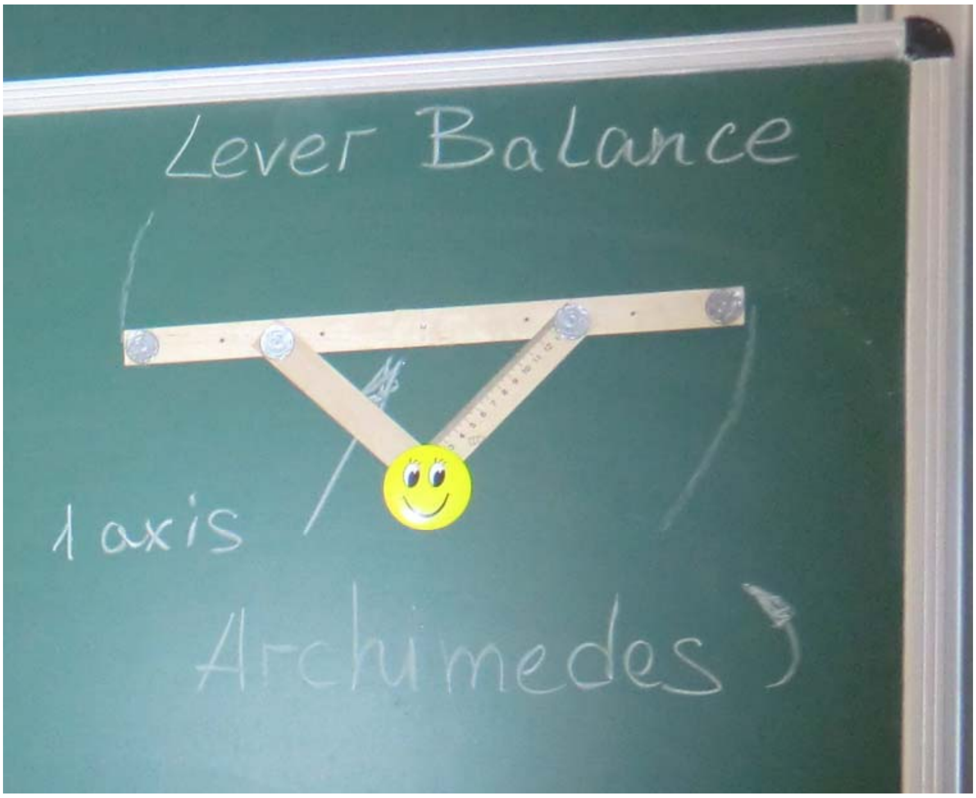

Figure 1. On-board model of stable equilibrium *lever balance* operating by Archimedes Principle.

The key ideas on Archimedes *lever principle* and its applications in operation of simple machines, including ones for weighing – *balances* or *scales,* may be mastered by the students by use of this on-board apparatus. As it is clearly visible in the *Figure 1*, all motions of the balance' parts and attached weights are easily and reliably traceable directly on the board. Corresponding measurements of weights' displacements are also done on-board to calculate potential energy and work performed at balance's rotation.

'Impossible' Roberval balance

After the students performed a series of measurements with the one-axis Archimedes balance they acquired good knowledge of the *lever principle*, being in particular convinced that equal masses could not be balanced when attached asymmetrically on the lever. High time to challenge (in perspective – of course to *reinforce*) their experience assembling by similar on-board technique another type of balance – an 'impossible' Roberval balance (*Figure 2*).

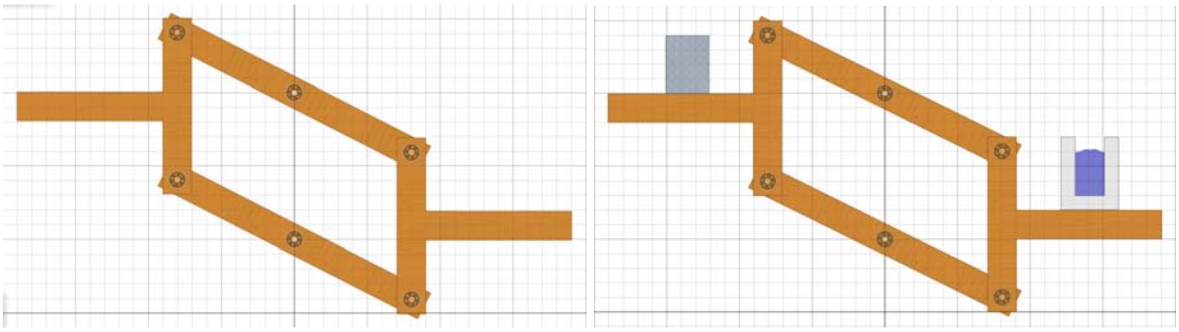

Figure 2. Model of *Roberval balance*.

During weighing, when lever balance is inclined, the horizontal position of the weight and the object (e.g. glass with liquid) must be established. For that reason the special construction of the balance was designed (Figure 2), where two levers are working together.

Even more surprising is that the equilibrium of the 6-axes balance pictured in *Figures 2, 3* is not violated when *equal* masses are loaded *any place* on the opposite-sided horizontal arms.

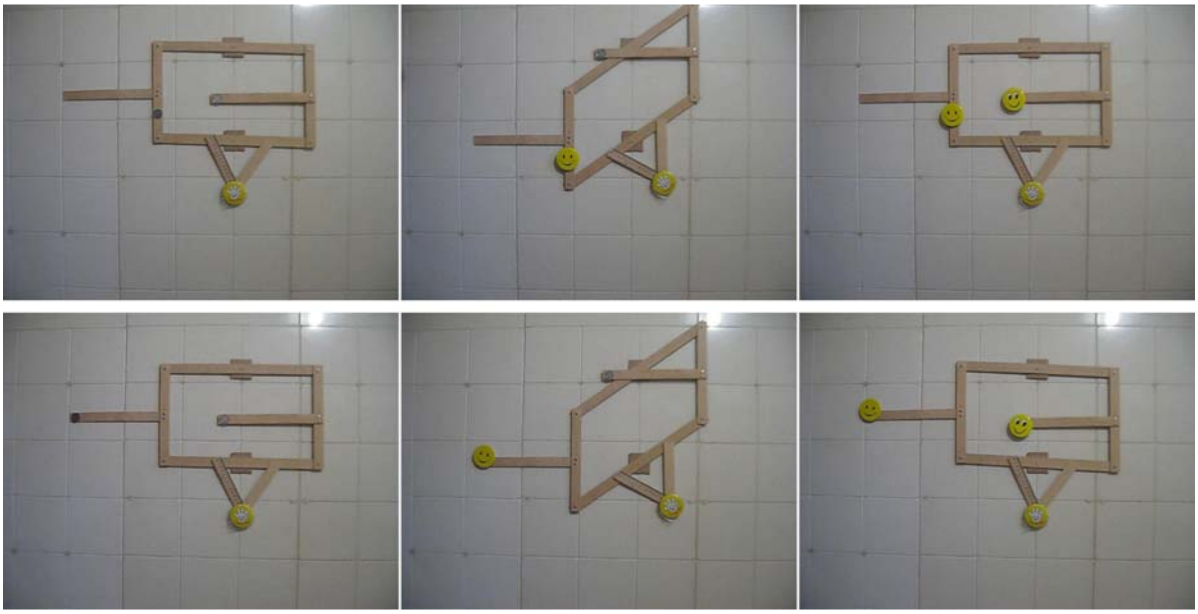

Figure 3. On-board model of stabilized *Roberval balance*, unloaded (left), loaded asymmetrically (center) and symmetrically (right).

Although work/energy explanation of how the parallelogram balance operates is explicit and refers to the basic principles of Mechanics [1-4], our on-board models allow for the even deeper insight into the Physics of this incredible device. Tracing the motion of the balance's parts with a chalk or marker (*Figure 4*), students may notice that every point of the structures attached to the vertical arms moves circularly in the same direction. All the radiuses of all the corresponding circumferences are the same, equal to the arm's suspension distance from the axis fixed on the board. Similar observation could be done by using of simulation from *Algodoo* online resources [5].

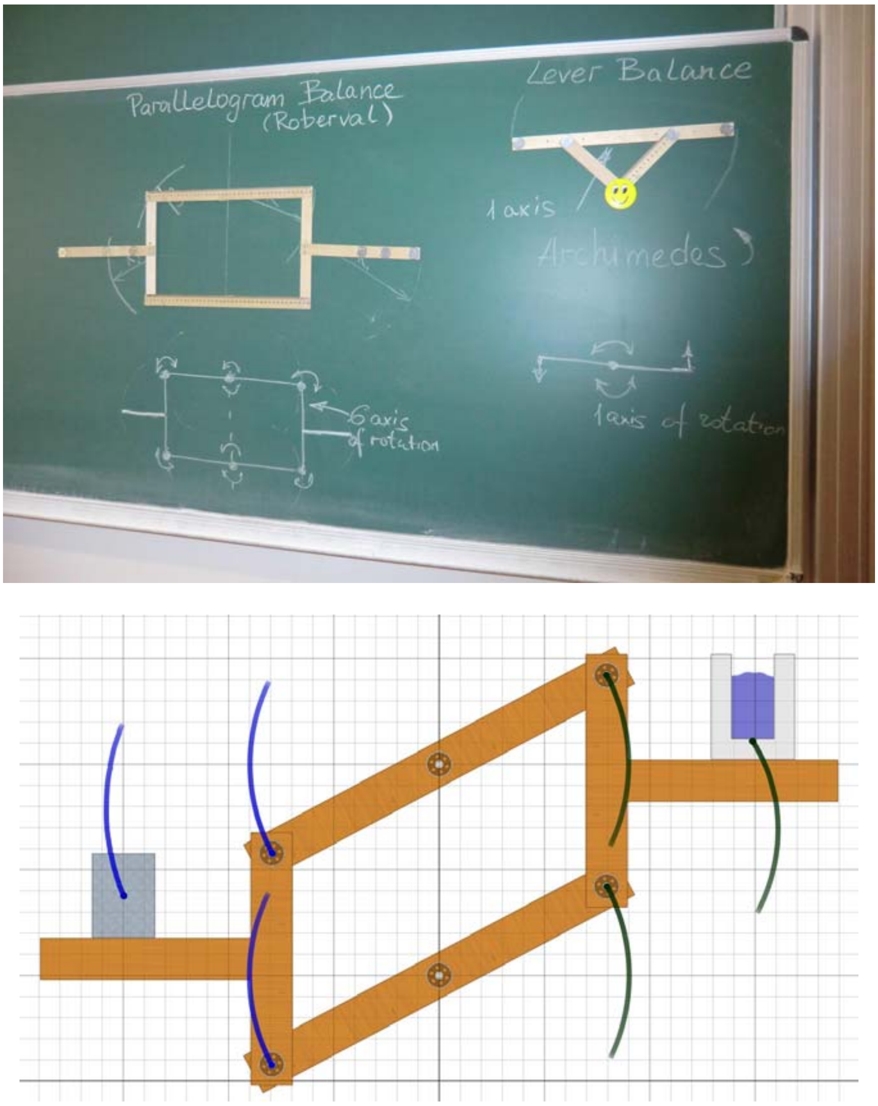

Figure 4. Archimedes and *Roberval balance* with the trajectories of their moving parts traced on the class board and in simulation.

As a result, instead of accounting for the torques due to 6 (!) axis of rotation, one may reduce momentums consideration to the regular lever balance: to stay in equilibrium *mass times distance* product must be equal for both arms. And those distances are measured from the line connecting central axes of the balance to the corresponding vertical arms.

Ideas for educational projects

Students may enjoy building asymmetrical and fancy-designed Roberval scales with their the arms going in literally any direction, or several vertical parts loaded simultaneously, multi-stage scales and other apparatus or the sort. Looking for the parallelogram constructions in industrial and household mechanisms, including weighing devices, could be another creative assignment. Even with the 'regular' Roberval balance an extra educational value may be added by their fast transformation into the lever scales. To do that the lower central axis is removed, while the flexible parallelogram structure is settled rigid by fastening one of the axis junctions.

Approbation and acknowledgements

This work is the result of the project implementation: Research and Education at UPJŠ – Heading towards Excellent European Universities, ITMS project code: 26110230056, supported by the Operational Program Education funded by the European Social Fund (ESF). Discussion and support from Eugenii Syrkin is acknowledged and highly appreciated.

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