Poster 3 (#13, subtopic B)

The Difference between Total and Inexact Differential Using 3D Printing Technology and LEGO© Bricks: Application on the First Law of Thermodynamics

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Abstract.
The poster presents two educational kits created with the help of 3D printing technology. Both kits are used as a part of the course of advanced thermodynamics aimed specially at future high school teachers. The kits deal with multivariable differential, emphasising the difference between total (exact) and inexact differential, and the First Law of Thermodynamics.

Why we need aids for these purposes

Understanding the meaning of the differential in the advanced course in thermodynamics is crucial, but also very difficult for the students. Because we teach a course specifically designed for future high school physics teachers, we consider understanding the meaning and building the geometric view to be more important than mastering calculations with differential. For this purpose we have developed specially designed tasks and various educational tools that help us reach our goals. Use of 3D printing technology enables us to show complex concepts with excellent precision. Moreover, by manipulating tangible objects, we try to engage students' touch with their sight, hearing, and thinking. Such an approach is beneficial for studying the given topic as well as for enrichment of their pool of didactic methods.

Technology

We decided to work with functions of two variables because the third dimension can be used for visualizing the functional value and such functions are very common in thermodynamics (e.g. temperature as a function of volume and pressure). Technology of 3D print has enabled the production of prisms with precisely inclined surfaces, which would have been very difficult to manufacture manually.

The first educational set shows the differences between total and inexact differential. It consists of two sets of 25 chamfered blocks with a square base (see fig. 1). The inclination of the upper base of green blocks corresponds to the total differential $\mathrm{d}F = y\,\mathrm{d}x + x\,\mathrm{d}y$ (it corresponds to the function $F(x, y) = xy$). The slope of the upper bases of the red blocks set corresponds to the inexact differential $đG = y\,\mathrm{d}x - x\,\mathrm{d}y$ (such function G does not exist). The blocks are placed on sliding bars, so it is possible to clearly demonstrate the meaning of differential $\mathrm{d}F$, resp. $đG$ and calculation of the curve integral by changing the height of the blocks.

The second educational kit is based on the laws of a single atom ideal gas. It consists of three sets of 49 chamfered blocks (see fig. 2), which represent the differentials of internal energy (total differential), heat and work (both inexact differentials). The lower sides of blocks fit into Lego© cubes and baseplates, that's why we do not need to create a special construction or print many other cubes for "line integration". Moreover, we tuned the slope of the upper surfaces, so that the

integration increment “between the two cubes” corresponds to a multiple of the height of the thinnest Lego cube. The whole set thus enables quantitative considerations and numerical verification of the first law of thermodynamics.

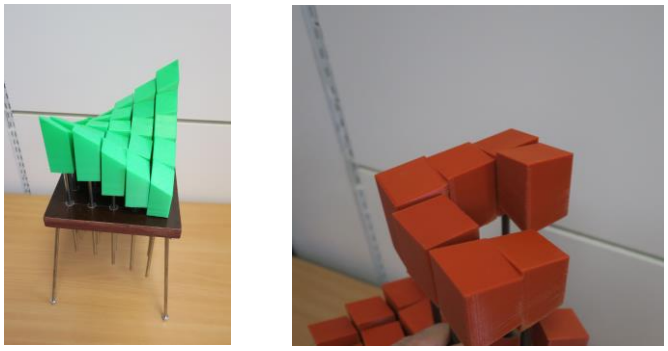

Fig. 1. The first kit – total differential assembled as a function of two variables (left), the line integral along the closed curve of the inexact differential (right).

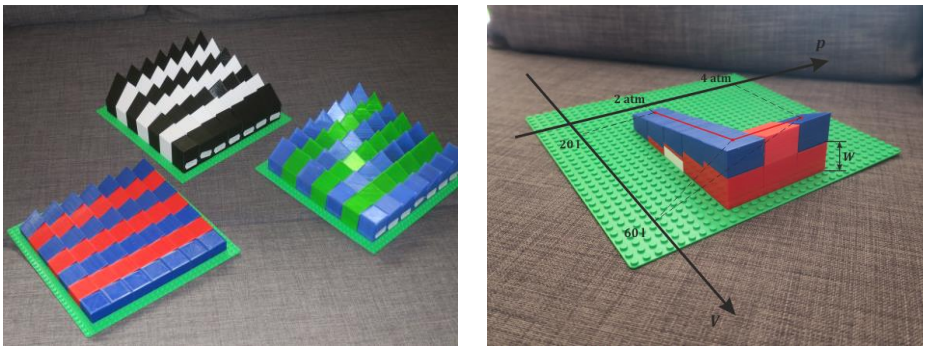

Fig. 2. The second kit. In the left: Three differentials of one atomic gas on the left photo (work has red and blue blocks, internal energy has light blue and green blocks, heat has black and white blocks. In the right: Work of ideal gas in the isobaric and isochoric process on the right photo.

Teaching experience

We have been using the first educational set as a lecture demonstration tool for six years (one of them in distance learning). According to both the students’ opinion and their results in solving problems, the understanding of the meaning of multivariable functions’ differential increased significantly, as well as understanding the differences between total and inexact differential. Usage of this educational set creates a geometric view of differential that serves as a base for following discussions about the differential of real physical quantities later in the course.

We used the second educational kit once in distance learning (the lecture demonstrated ideal gas properties) and last year we piloted its usage in standard educational setting (i.e. in a classroom). Students used the kit independently and solved assigned tasks with its aid. These tasks allowed them not only to explore the mathematical properties of differentials, but also to understand that the First Law of Thermodynamics is not only the law of energy conservation.

Summary

The use of 3D printing enabled the creation of visual educational kits showing the mathematical and physical significance of the differential, including emphasizing the difference between total and inexact differentials. The first one is more suitable as demonstration tool during the explanation of the basic ideas of the topic. The second one is accompanied by assignments for independent student work, so it can be used for deeper hand-on exploration. The long-term impact on student understanding will be a subject of further research.