

## Science in 3D

# Build your own scientific experiment

### Introduction

Science is fun. Thanks to its achievements we are able to communicate with our friends on the other side of the world, we can travel rapidly on big distances or listen to music in an easily accessible way. Sometimes, science is also hard to understand through its thousands of formulas and theorems. However, they became easy understandable using spectacular experiments. Especially in Chemistry and Physics.

In order to make such an experiment we often need to have some materials and tools. That recently became straightforward thanks to the boom in 3D printing technology. All you need is to prepare some printing schemes on your computer and access to 3D printer, which are currently available in many schools in Europe

### Your task

To prepare a science (physics, engineering) experiment using 3D printed elements. You have full freedom in choosing the experiment! The only requirement is that the majority of the elements used to assemble the experimental set or device have to be made in a 3D printer.

The task consists of three stages:

1. The decision of what experimental set /illustration of which phenomena / the law of Physics you want to present, development of its concept, construction design (in particular which parts need to be made on a 3D printer), how the experiment applies to regular life.
2. Preparation of 3D printing plans using any software (preferably in STL file format) and printing them.
3. Assembling of the experimental set (at least one set for a team), performing a series of experiments (different scenario/conditions) and measure the results. Documentation of the experiments in the form of a video clip (uploaded onto shared drives or on youtube).
4. Prepare a report from your work
  - a. Describe why you have decided on this particular idea/experimental set.
  - b. Explain (in terms of Maths and Physics principles) the behavior of the device you have constructed.
  - c. Describe which tests (scenarios) you have carried out, which hypothesis you verified and how.



## International Student Competition

- d. Present final conclusions and broader aspects of the main phenomena you have observed. Which practical application do these phenomena have in our life?

We encourage you to use a 3D printer in your school. In case you do not have any, contact us ([student\\_competiton@stem4youth.eu](mailto:student_competiton@stem4youth.eu)) so we will print the elements prepared by you and send them back. However, please keep in mind:

- 1) You have to contact us at least 2 weeks before the submission deadline.
- 2) Not all definition of your 3D models (STL format) we will be able to print (due to potential design mistake, limitation of 3D printer, or other factors).



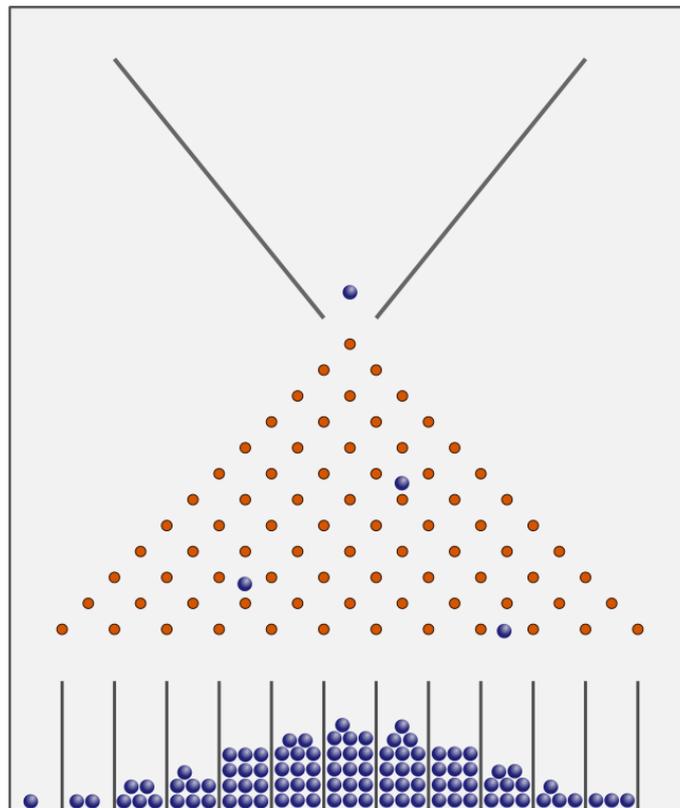
# Project example no. 1.

## Galton board (bean machine)

### Theoretical introduction

We can use Galton board as an example of how the statistics governs normal life. Before going into its details, it is worth to describe an example of a coin toss.

When tossing a coin in a random way, there are only two results: heads and tails. The chance of having heads is the same as of having tails. This means that the probability of heads and of tails is equal to  $\frac{1}{2}$ . If we toss a coin hundreds of times, then the



*Galton board (bean machine) diagram. Author: Marcin Floryan, license: CC-BY 2.5*

number of results with tails and results with heads will be equal or very similar. The more we do such tosses, the closer will be the results.

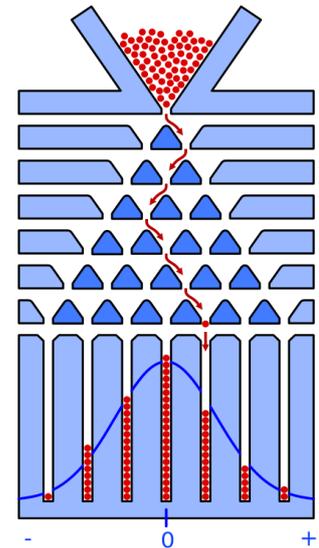
(this empirical observation is described in terms of statistics as Law of large numbers [https://en.wikipedia.org/wiki/Law\\_of\\_large\\_numbers](https://en.wikipedia.org/wiki/Law_of_large_numbers) )

## Idea of Galton board

We can think of Galton board as an extension of a coin toss. It is a board with many pins arranged in several rows and put in such a way that distances between the pins are the same and the pins form an isosceles triangle. Under those rows of pins there are bins. Above the pins there is an element that provides the balls to them.

The ball falls onto the pin which is on the top. It bounces left or right (with equal probability – just like in coin toss could result in heads or tails). Then it drops to a pin one row of pins lower and it bounces again left or right. Similarly, one level lower and so on until the lowest row of pins from where it falls to one of the bins. If we dropped a big number of balls through the Galton board, the balls in different bins will create a specific shape. It can be observed that the largest number of balls is in the most central bins.

Galton board is a very good visualization of a binomial distribution which is a kind of distribution for random variables where the probabilities of observing those variables are all the same. Such distribution has the same shape as the one as we can observe on the Galton board. For a very big number of balls binomial distribution becomes similar to a normal distribution (also known as Gaussian distribution, see the picture on the right). The normal distribution is used very often to describe events in our everyday life. For example, let's imagine a distribution of the height of people from one particular country or of one specific age. Many people have a height of about 170 cm, some of them 185 cm or 155 cm. Just a few of people have 210 cm or 130 cm. The height distribution creates the shape of a normal distribution.



In terms of difficulty, Galton board is quite a simple task for making in a 3D printer. The most important in the design stage is to put the pins in an interleaving manner and to have the equal distance between all of them. It is also important to have the distance between pins very similar to the diameter of a ball (so the balls hit a pin in every row).

The creation of an ideal ball is rather a difficult task for an average 3D printer, so it is a better idea to buy a big set of balls from ball bearing or a set of glass balls.

Having those requirements for the project, we only need to prepare 3D printing project files, print them and finally construct, check if it works, verify to what extent the number of the balls in the bins correspond to the normal distribution and present the experiment in the video clip.

## Alternation of the Galton board experiment

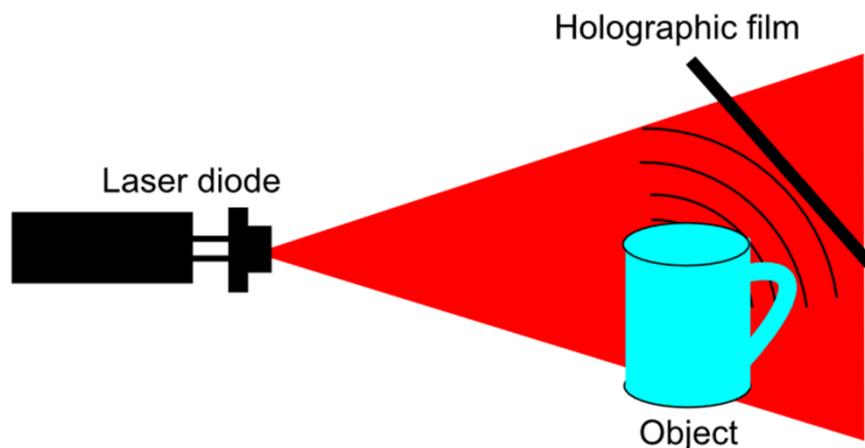
Galton board has been extensively described and tested in numberless experiments: it is a good example of 3D printing application, but all the same it is not an original research challenge. However, the experimental setting could be modified in a few ways. For example, the board may be slightly tilted; similarly the pins and the row could be shifted, so the probability the ball bounces right or left would not be the same. Finally the distances between the pins may be bigger than the ball diameter, so the ball would not necessarily hit pins in each row. All these alternations impact the resulting ball distribution in bins. Based on the classic Galton board theory, the students may try to foresee and explain modified Galton board behavior. The students may also simulate the experimental setting in a computer program and verify results obtained experimentally.

## Useful links

- 1) Theoretical bases of 3D printing (an output of MakeItReal project) <http://makeitreal.info/wp-content/uploads/2017/10/MakeItReal-Technical-Reference-Guide-1.pdf>
- 2) Examples of 3D projects (result of MakeItReal project) [http://makeitreal.info/?page\\_id=286](http://makeitreal.info/?page_id=286)
- 3) Educational resources containing free lessons about 3D printing
  - a. <http://www.thingiverse.com/education>
  - b. <http://www.stratasys.com/resources/education-materials>
  - c. <http://pages.makerbot.com/download-makerbot-in-the-classroom.html>
- 4) Model sharing websites for downloading 3D models
  - a. <http://thingiverse.com>
  - b. <https://grabcad.com>
  - c. <http://www.myminifactory.com>

## Project example no. 2. Holography

An example of an experiment where 3D printing comes handy can be a hologram making experiment. To perform such an experiment we need a laser diode powered by batteries, a holographic film and an object from which a hologram will be created. The experimental setup is very simple as shown in the Fig. 1. The laser diode partially illuminates the holographic film and partially the object. Some of the light reflects from the object interfering with the beam that illuminates holographic film directly. Such interference pattern is recorded on the film creating a hologram in this way.



*Fig. 1 Experimental setup for making hologram*

An essential part of the experiment is the high mechanical stability of the entire system. This stability will be ensured thanks to the 3D printed elements to which all components will be attached. The printed items will be firmly connected each other creating one solid insensitive to external vibrations. Fig. 2 presents an exemplary parts to be printed on a 3D printer. On Fig. 3 assembled model is shown.

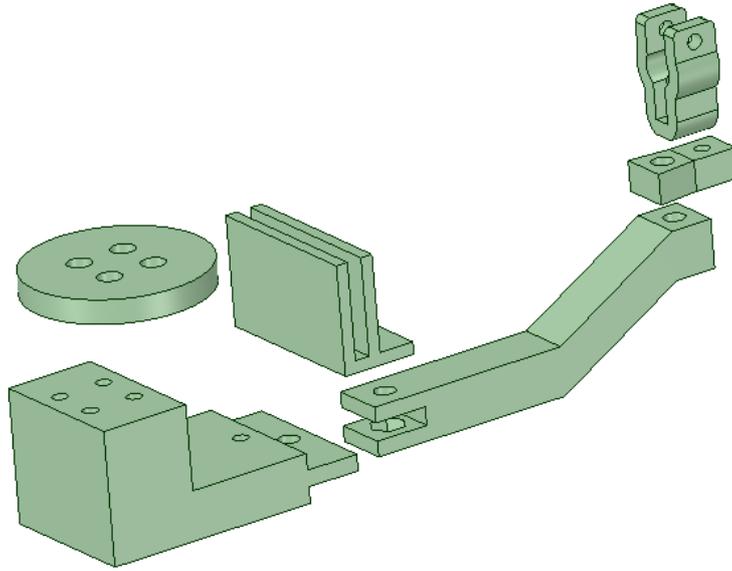


Fig. 2 3D printed parts for the hologram making experiment

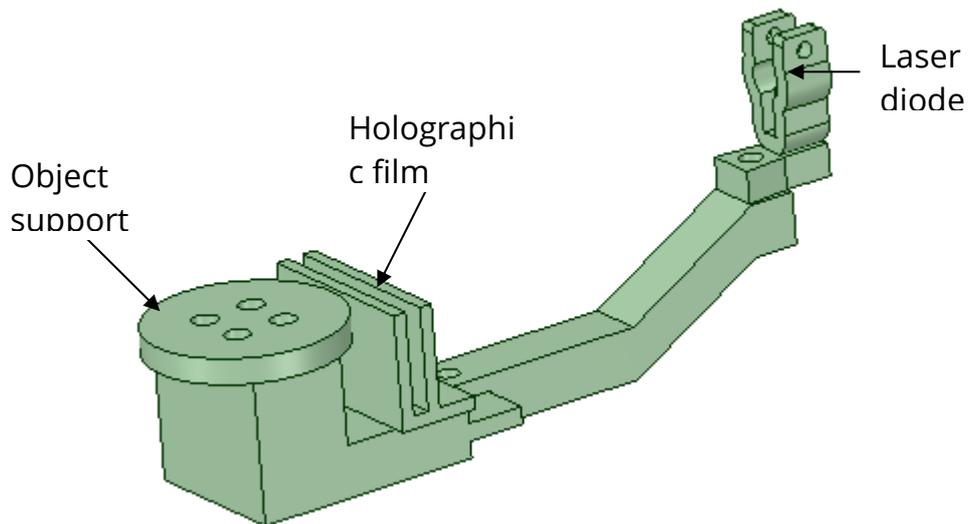
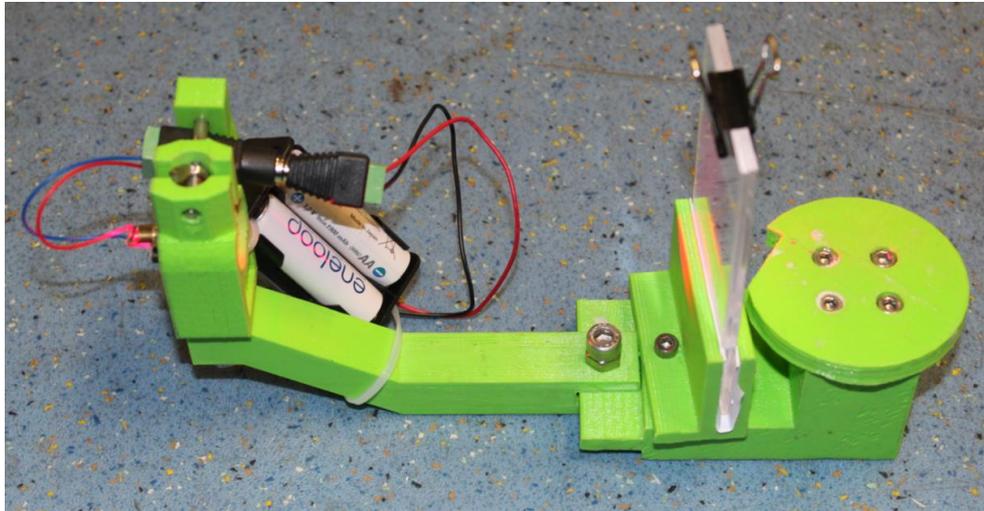
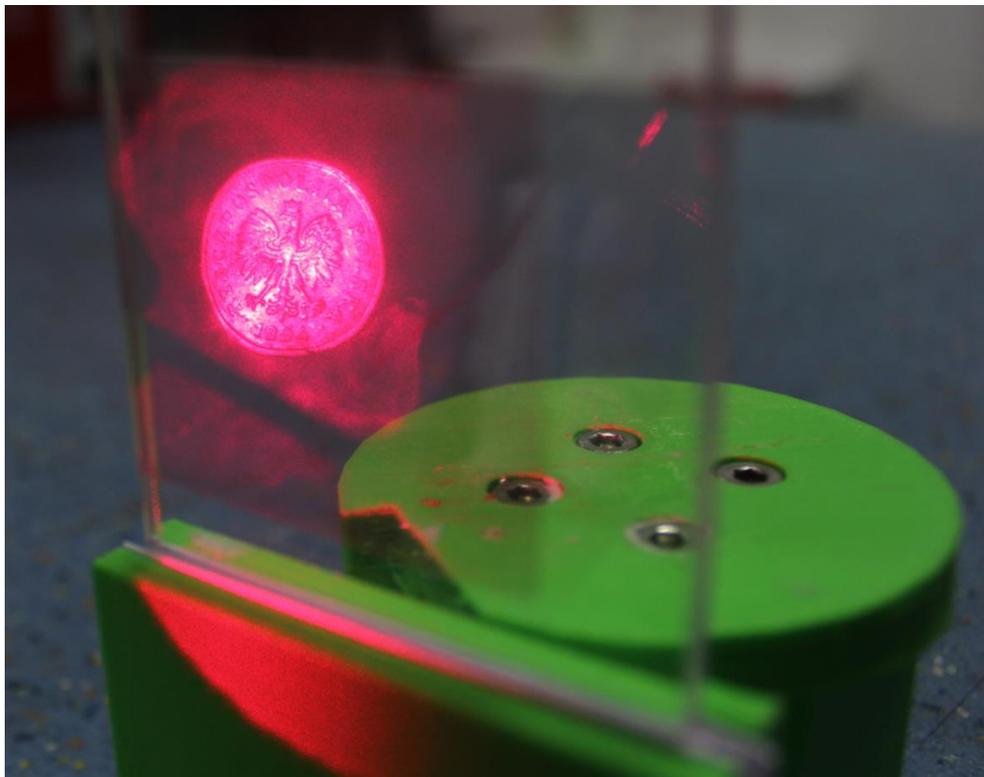


Fig. 3 Assembled parts makes one solid

Fig. 4 presents 3D printed and assembled set for hologram making. As an example, hologram of coin was recorded. Such hologram can be observed using the same setup as shown on the Fig. 5 and Fig. 6.



*Fig. 4 3D printed and assembled set for hologram making*



*Fig. 5 Recorded hologram can be observed*



*Fig. 6 Hologram of coin recorded in the experiment*