From the *dicey world* to the physical laws: dice toy models for bridging microscopic and macroscopic understanding of physical phenomena

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Abstract. We discuss an educational approach to some different physical phenomena that can be explained by means of stochastic toy models, and explored by students with rolling dice.
The discussion of the physical principles governing the phenomena, proceeds through a recurrent comparison between the outcomes obtained with the toy models and the results of real experiments.
The educational proposal allows students to compare experimental data they obtain to both analytical results and simulations.
The effectiveness of our approach was tested both with groups of undergraduate students and with a group of on service teachers.

1 Introduction

In this talk we present an educational approach to several different physical phenomena that can be explained with the help of stochastic toy models, and explored by students with rolling dice. The discussion of the physical principles governing the phenomena, proceeds through a recurrent comparison between the outcomes obtained with the toy models and the results of real experiments which students can made in a laboratory by themselves by using simple and inexpensive apparatuses.[1]
The educational proposal, founded on a microscopic basis, goes on by considering the problem in statistical and probabilistic terms, and allows students to compare experimental data they obtain to both analytical results and simulations
We analyze phenomena concerning different branches of physics from thermodynamics to optics, from material science to nuclear physics. We discuss some simple experiments easy to be carried on by undergraduates:

1. the measure of the exponential decay and the lifetime of the photoluminescent compounds contained in the coating of fluorescent compact lamp
2. the measure of the Beer-Lmbert's law which relates the attenuation of light to the properties of the material through which the light is travelling
3. the experiment on thermal contact of two masses of water at different temperature reaching the thermal equilibrium.

Each experiment can be explained by using an "*ad hoc*" stochastic toy model which can be realised using dice and directly explored by students as a real experiment.

2 The activities

In the first experiment low cost apparatuses based on the use of sensors for didactic lab or commercial digital photo cameras can be employed to measure the exponential decay and the lifetime of the photoluminescent compounds contained in the coating of fluorescent compact lamp.[2] In the simulation a large number of dice are thrown simultaneously. Those showing a particular number are deemed to have decayed like excited atoms. These dice are removed and the remaining ‘undecayed’ dice are counted. This number of ‘undecayed’ dice is recorded and represents the number of undecayed atoms remaining after a certain interval of time. The ‘undecayed’ dice are then thrown and so on. This goes on for a number of throws, resulting in a reduction in the number of ‘undecayed’ dice as time goes by. At the end of the simulation students can compare results of experiments and simulations. [3-5]

In the second experiment students use a smartphone based apparatus as a tool for investigating the optical absorption of a material and to obtain the exponential decay predicted by the Beer’s law.[6] The toy model is based on the use of a game board, where incident photons are represented by rows of squares, in each square of the table can be placed an X i.e. microscopic scatterers are placed random according the roll of a dice. During the activity, students rolled the die many times, each launch corresponding to a column, and inserted an X in the box corresponding to the line corresponding to the extracted number. In this way they distributed the scatterers in a stochastic manner one by one. Finally the can infer from the simulation the exponential decay of transmitted light and the mean free path allowed to the simulated photons. Thus a corpuscular derivation of Beer's law is given emphasizing the stochastic laws which rule the microscopic world. The discussion of the law in these terms is advantageous because it provides more physical insight than the common approaches.[7]

In the third experiment students, using temperature sensors, measured the time evolution of two bodies in thermal contact. The experiment was carried out using a thermos filled with water at room temperature, and a small metal cylinder, immersed in the thermos water, in which students poured a small quantity of water at much higher high temperature.[1] The corresponding toy model is based on a board with two rows of different length of numbered squares; on each square of the row one coin (at most) can be placed. Bodies in thermal contact are represented by rows of squares on a cardboard table, which exchange coins placed on the squares based on the roll of two dice. Students can deduce from the model the exponential approach to equilibrium, the determination of the equilibrium temperature, the interpretation of the equilibrium state as the most probable macrostate.

Some of the activities discussed in this work were tested both with a group of undergraduate students of the University of Trento and with a group of on service teachers. In order to provide the audience with a feeling of how the sequence was received by students, we discuss some excerpts from their answers to questions given at the end of the sequence.

References

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