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MS Excel Spreadsheet: A Teaching-Learning Tool for Statistical Physics

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ABSTRACT:
Background: Grasping the relationship between theoretical and empirical probability is essential in learning statistical physics, especially for undergraduate students. Traditional hands-on methods such as coin tosses and dice rolls, while pedagogically valuable, often require considerable time and effort to generate statistically meaningful data.
Purpose: This study aims to explore how simulation using Microsoft Excel can serve as an effective alternative to manual probability experiments in undergraduate physics education.
Methods: Simulations of two classical probability experiments—coin tosses and dice throws—were conducted using Microsoft Excel. The number of trials ranged from 10^1 to 10^5. These simulations tracked how empirical probabilities evolved and whether they converged toward the known theoretical probabilities with increased trials.
Results: The results demonstrated a clear convergence between empirical and theoretical probabilities as the number of trials increased. The use of Microsoft Excel significantly reduced the time and effort needed for data collection while maintaining high accuracy.
Conclusions: Microsoft Excel can effectively replace manual methods in undergraduate physics labs, enhancing both teaching and learning experiences. It enables students to focus on analyzing results and deepening conceptual understanding, making it a valuable pedagogical tool for reinforcing statistical ideas in a more engaging and time-efficient way.

Keywords: Probability, A priori probability, Empirical probability, MS Excel Spreadsheet, Physics Simulation, Statistical Physics

1. Introduction

Probability theory forms the foundation of many branches of mathematics and science, playing a crucial role in predicting outcomes and analyzing systems. The formal framework of probability, established through Kolmogorov's axiomatic approach in 1933, provides a reliable basis for practical applications across disciplines [**?** 2]. In the context of experimental design and prediction, a priori probability (App) refers to theoretical estimates made before an experiment is conducted. In contrast, empirical probability (Ep) is derived from actual experimental outcomes. The difference between App and Ep typically depends on the number of trials: smaller datasets often show greater deviations, while larger numbers of trials tend to yield results that converge toward theoretical expectations. This principle is central to statistical physics, which involves analyzing large collections of particles or systems. The present study aims to demonstrate the relationship between App and Ep through simple simulations of coin-tossing and dice-throwing, implemented using Microsoft Excel. This Excel-based model offers an accessible and time-efficient tool for teaching and learning fundamental concepts in probability and statistics at the undergraduate level.

The App predicts the likelihood of an event's occurrence before any physical trial, whereas the Ep is determined with reference to actual trials [3, 4, 5]. This work elaborates on the dependence of prediction

accuracy on the number of particles and trial. Despite probability theory's reliance on counting, integrals, and measures, Excel is likely to address these issues, paving the way for deeper understanding and its novel applications [6]. Excel remains a vital tool for education and research, offering an accessible platform for exploring such developments.
The following components were required for this experiment:

i Personal Computer (PC) with MS Excel-2016 installed

ii Probability theory knowledge

iii Basic knowledge of Excel functions and programming techniques for probability simulation.

MS Excel Functions used in the code
All the Excel-functions used in to execute the coding for the coin-tossing and dice-throwing simulations have been described in the "Table 1".

2. Method & Materials

The purpose of the experiments was to investigate Eps and Apps in both experiments: coin-tossing and dice-throwing. The number of trials for both experiments varied from one to X., where X had the following 5 values: 10, 100, 1000, 10000, and 100000. Thus, each experiment was repeated 5 times for single value of X. The Eps for all 10 trials of the experiments were then calculated. Physically, it would be a very time-consuming process to evaluate the Eps for the above experiment, but MS Excel makes it an easy task.

2.1. Simulating Coin Tosses

The coding adopted for coin tossing ranging from 1-X trials: where X can have any value from 10,100, 1000, 10000, and 100000.

i In cell A1, enter the formula =IF (RAND () <0.5,"H,""T"). Here, "H" and "T" denote the head and tail, respectively.

ii This formula is copied down from cell A1 to AX cells for generating the outcomes for each coin toss across X trials.

Counting Outcomes:

iii In cell B1, use = $COUNTIF(A1 : AX, "H")$to count the occurrences of "H"

iv In cell C1, use = $COUNTIF(A1 : AX, "T")$for "T"

Calculating Eps:

v To calculate the empirical probability of heads in cell D1 with = $B1/X$.

vi Similarly, for tails in E1 =$C1/X$.

2.2. Simulating Dice Throwing

The following procedure was adopted for Dice Throwing from one to X Trials:

i In cell A1, enter formula = RANDBETWEEN (1,6), which simulates throwing a fair six-sided die.

ii This formula is copied to AX to simulate X-dice-throwing.

Counting Outcomes:

iii For each face of the die (1 through 6), use =COUNTIF (A1:AX, 1), =COUNTIF (A1:AX, 2), and so on in cells B1 to B6.

Calculating Eps:

iv For each face, calculate the empirical probability using =B1/X, =B2/X, ... B6/X.

3. Pseudocode

3.1. Tossing coins (1 to X Trials)

Step 1: In Excel cell A1, enter the formula:
$= IF(RAND() <= 0.5, "Heads", "Tails")$

Step 2: Drag the formula from A1 to AX to simulate X coin tosses.

Step 3: To count the number of outcomes: $= COUNTIF(A1 : AX, "Heads")$ßCounts"Heads" $= COUNTIF(A1 : AX, "Tails")$ßCounts"Tails"

Step 4: Calculate empirical probabilities (Ep): $Ep\_Heads = COUNTIF(A1 : AX, "Heads")/X$ $Ep\_Tails = COUNTIF(A1 : AX, "Tails")/X$

Compare both Ep_Heads and Ep_Tails with the a priori probability (App = 0.5) Refer to Annexure I for more details.

Table 1: Excel-functions used in the present coding.

Sr.No.	Function	Purpose
1	RAND()	Generates a random decimal number between 0 and 1, simulating binary outcomes for coin tosses.
2	RAND BETWEEN (a, b)	Generates a random integer between a and b, which is used to simulate dice faces between one and 6.
3	IF(logical_test, value_if_true, value_if_false)	Evaluates a condition; returns specific values based on the outcome, classifying heads or tails.
4	COUNTIF(range, criteria)	Counts occurrences in a specified range based on given criteria, calculating frequencies for out-comes.
5	AVERAGE(range)	The average is computed to compare empirical means to theoretical probabilities.
6	MAX(range)	The maximum value is computed from the speci-fied range.
7	MIN(range)	The minimum value is computed from the speci-fied range.

3.2. *For throwing Dice (1 to X Trials)*

Step 1: In Excel cell B1, enter the formula: $= RANDBETWEEN(1, 6)$

Step 2: Drag the formula from B1 to BX to simulate X dice throws.

Step 3: To count occurrences of each dice face:
$= COUNTIF(B1 : BX, 1)$
$= COUNTIF(B1 : BX, 2)$
$= COUNTIF(B1 : BX, 3)$
$= COUNTIF(B1 : BX, 4)$
$= COUNTIF(B1 : BX, 5)$
$= COUNTIF(B1 : BX, 6)$

Step 4: Calculate empirical probabilities (Ep) for each face: $Ep\_i = COUNTIF(B1 : BX, i)/X$ for i = 1 to 6

Compare each Ep_i with the a priori probability (App = 1/6) Refer to Annexure II for more details.

4. Results and Discussion

Using Microsoft Excel to simulate simple probability experiments—such as tossing coins and dice throwing—provides students with a visual and interactive way to explore the principle of convergence in probability. This principle states that as the number of trials increases, the empirical probability (Ep) tends to approach the theoretical or a priori probability (App). The following points explain that why this method is pedagogically effective:

i **Immediate Feedback and Visualization:**
Excel allows students to observe real-time changes in outcomes and probabilities as they increase the number of trials. Seeing the percentages stabilize around theoretical values reinforces the concept of convergence intuitively.

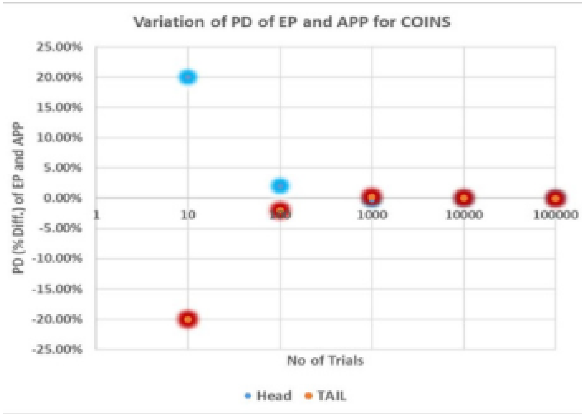
ii **Hands-on Learning:**
By building and running the simulation themselves, students actively engage with the process. This hands-on approach deepens understanding compared to passive obser-vation or rote formula application.

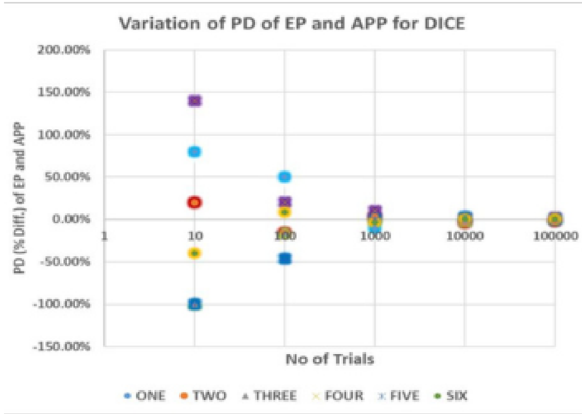
iii **Repetition without Fatigue:**
Unlike manual experiments, Excel enables thousands of trials to be completed instantly. This allows students to explore large-sample behavior without the physical or time constraints of real-world experimentation.

Figure 1: Coin-Tossing and Dice-throwing observational data (first 6 Figs. 1a-1f)

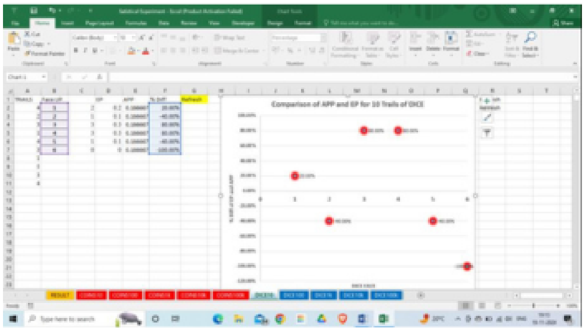
i **Bridging Theory and Practice:**
The simulation demonstrates how abstract mathematical ideas manifest in practical scenarios. Students can compare theoretical values with simulated results, fostering a stronger connection between textbook knowledge and experimental evidence.

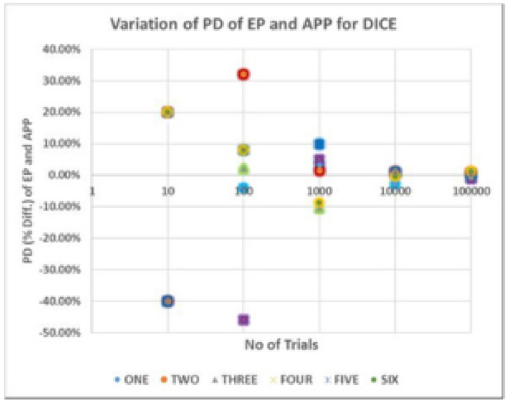
ii **Encouragement of Hypothesis Testing:**
Students can formulate predictions about outcomes and test them using the spread-sheet. This cultivates scientific reasoning and analytical skills, especially when dis-crepancies arise in small trial sets.



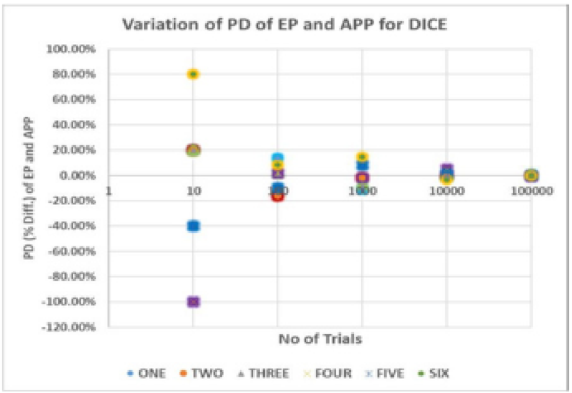


(a) **(b)**





(c) **(d)**



(e)

Figure 2: PDs for Coin for the 5 experiments (Figs. 2a-2e)

iii **Accessibility and Ease of Use:**
Excel is widely available, user-friendly, and requires no prior coding experience, making it an ideal platform for students at the undergraduate level.

Thus, by integrating such simulations into classroom activities, educators can demystify complex statistical concepts and encourage deeper conceptual understanding of key ideas like convergence. For both experiments, Coin-Tossing and Dice-throwing observational data were used to plot graphs (Figs. 1a-1f) for the cumulative Eps for heads and tails against the number of trials. According to statistical physics, the Ep

Figure 3: PDs for Dice for the 5 different experiments (Figs. 3a-3e)

approaches the App as the number of trials increases. Figure (1a) explains the percentage deviation (PD) of Ep and App for Coin tossing 10 and 100000 trials, whereas Figure (1b) compares the both. It is clear from both figures that the number of PDs has been reduced considerably from 40.00% to 0.23%, indicating that Ep approaches App as the number of trials increases. This result is consistent with the basic laws of statistical physics. Similarly, Figs. (1c) and (1d) show the PDs for 10 and 100000 Dice throwing trials, respectively. It is clear from both figures that for Dice faces ranging from one to three, the PDs of Ep and App have been reduced considerably from 20.00% to -0.36%, -40.00% to 0.34%, 80.00% to 1.17%, and so on, up to face 6 of the Dice. Figs. (1e) and (1f) show the combined variation of PDs for the various trials of coin and dice in MS Excel spreadsheet. It is evident from both of these graphs that, analogous to the above experiment on coins, the Ep approaches the App as the number of trials increases. Another interesting observation is that for Coin, the PD values for both H and T are the same, but in the case of Dice, it is different for all faces.

The Figs. 2a-2e described similar variations in the PDs for Coin for the 5 experiments, whereas Figs. 3a-3e indicated the variations in the PDs for Dice for the 5 different experiments.

5. Conclusion

It was concluded that coding in MS Excel spreadsheets is a useful tool for teaching and learning the purpose of the laws of statistical physics by saving time and effort. The empirical results (Ep) closely resemble the theoretical predictions (App) of comprehensive testing. This experimental demonstration highlights the teaching value of MS Excel's built-in functions for visualizing results in a straightforward and reproducible manner.

This study not only demonstrates the pedagogical value of using MS Excel for simulating probability experiments, but it also opens several promising pathways for future research and curriculum development. For future studies, more complex probabilistic models—such as radioactive decay simulations, Monte Carlo methods, or particle distribution scenarios—can be developed using similar spreadsheet-based tools. These could enrich the understanding of randomness and statistical trends in more advanced physics courses. From an educational standpoint, integrating such Excel-based simulations into the undergraduate curriculum can revolutionize how statistical physics is taught. Rather than passively absorbing formulae and concepts, students actively participate in building models and observing outcomes in real-time. This approach fosters a deeper conceptual grasp while developing digital literacy and data analysis skills that are crucial in modern scientific practice.

Educators may consider incorporating guided Excel activities into lab sessions, assignments, or flipped classroom modules. Furthermore, cross-disciplinary use—with applications in data science, economics, or biology—could broaden students' appreciation of probability and statistical thinking beyond physics alone. By blending theory, computation, and visualization, this method can transform abstract ideas into accessible, interactive learning experiences.

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Similarity Index: The authors hereby confirm that there is no similarity index in abstract and conclusion while overall is less than 10% where individual source contribution is 2% or less than it.

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