

Cosmic Chemistry: Planetary Diversity

Stochastic Processes: Out of Chaos

TEACHER GUIDE

BACKGROUND INFORMATION



From the time when humans first began to contemplate the celestial bodies, they have been intrigued by the regular patterns that were observed in their movements. For most civilizations these patterns of movement led to the notion that nature is ordered. It was held that this order was a reflection either of the magnificence of the supreme being(s) that formed these bodies or the natural forces that resulted in their formation.

An overall design or pattern does not govern the outcomes of random chance events. However, such a pattern may emerge as the result of random chance events. For example, the pattern of the net movement of a substance from an area of greater concentration to an area of lesser concentration (diffusion) results from the random atomic/molecular motion of that substance.

The pattern of the planets in our solar system is interpreted by some scientists to mean that the formation of the planets from the solar nebula, or from the nebula of a passing star, could not have resulted from strictly stochastic processes (random chance events). The stochastic model of planetary formation developed in this activity will challenge that interpretation, as many opposing models often vie with each other for credibility. This activity introduces students to some of the characteristics of stochastic processes and gives them experience applying the concepts of simple probability reasoning.

Stochastic processes are those that involve the occurrence of random chance events. The outcomes of stochastic processes (and random chance events) occur without a governing design and do not result in a specific pattern of outcomes. The enigma is that some random chance events often result in patterns of outcomes that do not appear to be the outcomes of random chance events. One reason for this "appearance" may be a characteristic of random chance events—that the degree to which predicted and observed outcomes agree is a function of the number of trials of the events. Part 1 of this activity is designed to acquaint students with this characteristic.

Part 2 of this further activity develops the students' understanding of this concept as they model one possible origin of the planets in our solar system. This model, in which it is assumed that the planets arose by stochastic processes from a relatively uniform mixture of chemical elements found in the solar nebula, is not intended to be a vehicle for the exploration of a widely held theory of planetary origin. Rather, it is intended to give students experience dealing with the outcomes of random chance events *for a limited number of trials*. The prediction of a stochastic model is that the elemental composition of all of the planets will be similar, if not the same. This prediction does not agree with the observation. There are two possible reasons for this disagreement: 1) the planets were formed from non-stochastic processes, or 2) the observed planetary diversity arose from random differences that can be attributed to low event trial numbers.

NATIONAL SCIENCE STANDARDS ADDRESSED

Grades 5-8

[Science As Inquiry](#)

Abilities necessary to do scientific inquiry

[History and Nature of Science](#)

Science as a human endeavor

Nature of science and scientific knowledge

History of science and historical perspectives

Probability

- Model situations by devising and carrying out experiments or simulations to determine probabilities
- Appreciate the power of using a probability model by comparing experimental results with mathematical expectations
- Make predictions that are based on experimental or theoretical probabilities
- Develop an appreciation for the pervasive use of probability in the real world

Grades 9-12

Science As Inquiry

Abilities necessary to do scientific inquiry

Earth and Space Science

- Earth in the solar system
- The origin and evolutions of the Earth system
- The origin and evolutions of the universe

History and Nature of Science

- Science as a human endeavor
- Nature of science and scientific knowledge
- History of science and historical perspectives

(View a full text of the [National Science Education Standards](#).)

Probability

- Use experimental or theoretical probability, as appropriate, to represent and solve problems involving uncertainty
- Use simulations to estimate probabilities
- Understand the concept of a random variable

MATERIALS

For each student:

- Copy of the [Student Activity "Stochastic Processes Out Of Chaos"](#)
- Copy of the [Student Text "Stochastic Processes: Out of Chaos"](#)
- Copy of the [Student Text "So, Mr. Holmes, What is the Problem???"](#)
- Copy of [Appendix A, "The Solar System or Do Nine Planets a Baseball Team Make?"](#)
- Copy of the [Appendix B, "How Did All of This Get Here?"](#)

For each group of students:

For Parts 1 & 2

- Marbles, 50 each of three colors of the same diameter
- Mixing bowl, 3-1/2 - 4 quart (Parts 1 & 2)
- Electronic calculator

In addition, for Part 2

- Measuring cups, one each of 1/3-cup, 1/2-cup, and 1-cup size

Alternate **Strategy Tip**
As an alternative, teachers may use M&M's® rather than marbles for a reduced cost.

PROCEDURE

1. Before class make copies of:
 - Student Activity " Stochastic Processes: Out Of Chaos"
 - Student Text "Stochastic Processes: Out of Chaos"
 - Student Text "So, Mr. Holmes, What is the Problem???"
 - Appendix A, "The Solar System or Do Nine Planets a Baseball Team Make?"
 - Appendix B, "How Did All of This Get Here?"
 Collect materials as listed above for those parts of the activity that you plan to assign.
2. Distribute copies of the Student Activity, the Student Texts, and the Appendices.

STUDENT ACTIVITY—PART 1

3. Review the information that is contained in the Student Text, "Stochastic Processes: Out of Chaos" with the students. Conduct this review in the manner that best suits your style and that of your class, but make sure that the three following objectives are accomplished. Students should:
 - a) Become less intimidated by the concept of simple probability, which is a branch of mathematics that deals with the predictions of outcomes of random chance events, by demonstrating their ability to use probability to predict the outcomes of random chance events that occur in everyday life (see examples in student text).
 - b) Understand that the observed outcomes of random chance events often do not match the predicted outcomes, unless a very large number of trials (infinite?) are made, by comparing the predicted and observed outcomes after each successive trial of an event.
 - c) Realize that simple probability can be used to predict with relative certainty the outcome of a single random chance event, or it can be used to predict the proportion of expected outcomes of a large number of random chance events.
4. Clarify any questions students may have about the mathematical calculations in the Student Activity, "Stochastic Processes: Out of Chaos."
5. Prior to Part 2 of the Student Activity, have students study the materials in the Student Text, "So, Mr. Holmes, What is the Problem???" and in Appendix B, "How Did All of This Get Here?" at the end of this module.
6. Ask students to describe the principal tenets of the most prominent theories on the origin of the solar system planets.

STUDENT ACTIVITY—PART 2

Introduce Part 2 of this activity in wording similar to this:

"In Part 2 of this activity students will be modeling the random formation of three planets of different masses by random accretion of three chemical elements, all present in equal proportions, from the remnants of the solar nebula. How does this theory and the predictions about the elemental composition of planets made from this theory differ from those of the most prominent theories previously described?"

7. Use questions to assist the students in designing a model of the solar nebula using equal numbers of marbles having three different colors. Make sure they understand that each colored marble models one chemical element.
8. Distribute the materials required for this part of the activity to the students.
9. As a follow-up to the activity, engage the students in a classroom discussion in which they compare their results, using questions similar to the following:
 - a) The formation of each planet represented how many trials of a random chance event?
 - b) One of the weaknesses of this model is that the three chemical elements that are modeled by the three colors of marbles all have the same mass.
 - 1) Describe other ways in which the model does not accurately reflect planetary formation, including factors that probably influenced the elemental composition of the planets as they formed, but that are not included in this model.
 - 2) How would you change the initial conditions in the model of the solar nebula to make it more realistic, given that you are confined to three colors of marbles?
 - c) Give as many reasons as you can as to why there was a difference between the total observed mass of the three planets (whose formation was modeled in the Part 2) and the total predicted mass of the largest planet, based on the results for the two smaller planets.
 - d) In which planet does the proportion of chemical elements (not the total mass) deviate the furthest from the predicted ratio? Speculate on why this occurred.
 - e) How would you change the model so that it might incorporate different theories for the origin of the planets in our solar system?

