LIVING ON THE EDGE
CHAOS, ORDER & COMPLEXITY
A Working Analogy for Natural Selection

Created by Doug Fraser
Timiskaming District Secondary School, Ontario, Canada

TEACHING INSTRUCTIONS

SYNOPSIS

This activity provides an excellent introduction to the concept of biological complexity while at the same time demystifying and debunking Paley's argument that a complex "watch" is compelling evidence requiring a (complex) "watchmaker" (designer or creator). It employs an elegant, simple mathematical exercise to demonstrate this. It involves a randomizing component (a die), and a simple mathematical rule (the *non*-random component), resulting in the repeated plotting of points. Repeated cycles eventually produce an orderly pattern.

CONCEPTS

1. Simple rules, acting on random events can easily produce complex, seemingly "designed" patterns.
2. Natural selection is a process of non-random events (selection) working on random events (mutations), resulting in the production of complex systems (new species).

ASSESSABLE OBJECTIVES

1. Recognize examples of random, chaotic, events.
2. Recognize examples of non-random, orderly events
3. Recognize examples of the results of the interaction of random and non-random processes, as orderly, complex, patterned systems.
4. Recognize that natural selection, as an example of such an interaction, can produce complex changes in living organisms (micro-evolution).

EXTENSION:

5. Recognize that when selected features accumulate over time, new kinds of structures and species can arise (cumulative selection).
6. Recognize that the accumulation of new species from ongoing selection over time can produce new groups which we recognize in the hierarchy of our modern classification (genera, families, orders, etc.), a process of cumulative speciation, or macro-evolution.

MATERIALS

For each team (of 2-4 students):

sheet of blank paper	one die
ruler	pen or pencil

overhead transparency of the Sierpinski Gasket, the fractal design produced in the activity
Optional: "Chaos Game" computer simulation, on CD (see source information at end of lesson)

TIME

Depending on whether the computer routine is used or not...

Without the computer routine: could be all or most of 45 minute period.
With the computer routine (on CD): probably no more than 20-30 minutes.

HANDOUTS

Living on the Edge: Order, Chaos & Complexity (4 pages)

Introduction, background, questions for discussion, activity directions.
Available in PDF format (click on title)

TEACHING STRATEGY AND PREPARATION
This lesson should be a critical part of any presentation of natural selection. It could be done as part of a dramatic **introduction** to natural selection, anticipating possible (popular) doubts about complex or orderly systems being able to arise from random events. This also provides an opportunity to emphasize the NON-random element of SELECTION which is integral to the process.

Alternatively, this lesson could be used **following** one of the classroom activities which models natural selection (see the several examples on this site). In this way, it could provide a powerful answer to objections students may have heard about the creative powers of natural selection. If students don't raise this challenge, then the teacher should bring it out as a popular criticism, based on a popular misconception and a misunderstanding of the process.

Be sure you have all needed materials for each team, and sufficient copies of the 4-page handout.
If you have the CD with Chaos Game on it, be sure it's ready to go and be displayed to the entire class.
Otherwise, have the "Sierpinski Gasket" fractal diagram ready to display on your overhead.

CHAOS GAME
The Chaos Game is only one of several very useful items on the **Evolution in Motion** CD:

EVOLUTION IN MOTION: This is a very clever interactive computer simulation of natural selection, in which students can observe shifts in population numbers over many generations, with natural selection operating on several different types of "organisms", each with its own traits. The program realistically models the interaction of random mutations and non-random selection. Printable instructions are on the disk. A series of discussion questions are available from the author, Doug Fraser (see below). There are two additional versions of this program, each with its own characteristic results and lessons:

SPECIATION: Involves one or two islands (with higher concentrations of "food") which can be varied in their proximity, with the population results reflecting classic principles of natural selection and speciation, and the simulated formation of new "species" which results.

ANTIBIOTIC RESISTANCE: Involves student-controlled exposure of the populations to different amounts of antibiotics, in which they discover why bacteria can become resistant to antibiotics, and why the full regimen of antibiotics must be taken as prescribed.

THE CHAOS GAME: Graphically presents the multiple cycles of random events interacting with a simple rule, producing the complex fractal pattern of the Sierpinski Gasket. The speed of cycling can be controlled selectively from slow to "turbo".

In addition to this, there is a similar interaction which produces the fractal pattern of a fern frond.

Finally, the process of **accumulative selection** (another often-overlooked but critical aspect of the natural selection process) is illustrated in the simulation of a monkey typing "Methinks it is like a weasel", a supposedly random process in which hits which fit, survive (stay) and accumulate, until the entire phrase has been typed. The educational impression of this routine and the basic Chaos Game alone are worth the price of the disk, but the Evolution in Motion makes this a real bargain.

CAUTION: This is a DOS or Windows executable program. It will run on an IBM-compatible PC. To use this application on a Macintosh computer, you need an emulation program, such as VirtualPC from Connectix (www.connectix.com), or SoftWindows from Insignia (www.insignia.com). Other options include using a DOS-compatibility card. Contact Apple (www.apple.com) for more information.

AVAILABILITY OF CD: See details under RESOURCES below.

PROCEDURE
1. Briefly provide a logical context for the lesson, and introduce it.

2. Hand out the lesson (one per team, to be read aloud within each team, or enough for everyone to read quietly).

3. After the teams have a chance to interact on the first set of questions (1-6), give one person per team a turn at sharing team responses with the class in a class-wide discussion.

4. Repeat step 3 with each subsequent set of questions (7-10, 11-14). You might find it works better to allow teams to go through all 14 questions in one sweep, THEN engage the class in sharing their answers.

5. Go on to Part II: Complexity, and the "Chaos Game". Depending on your class, you might want to demonstrate how to plot each point (die, measure, make dot, etc.)

6. After the class has done a few dozen cycles (or less, if time is short), do one of the following:
   a. project the Chaos Game (on CD) on the screen (for the whole class to see), and RUN the program, slowly at first, then click on faster speeds. Repeat a few times, each time letting a different student place the initial dot.
   b. project the Sierpinski Gasket fractal diagram on the overhead, and point out that this is the result of many hundreds of cycles of what they've been doing. Ask if any team can see the beginning of that pattern in their individual efforts so far.

7. Carry out a class discussion (items #1-25), or allow students to do this within their teams, followed by class sharing at least a sampling of the questions. Allow some time for reflection and conclusions about what they've learned from the lesson.

ASSESSMENT

1. Provide unlabeled examples of various events and objects, and ask students to identify which are examples of chaos (random events or randomly produced objects), which are non-random events/objects, and which are the products of both random and non-random elements.

2. Ask students to explain how natural selection is like the Chaos Game (e.g. which element is random, which element is non-random, and how the product is like the fractal product of the Chaos Game).

EXTENSIONS & VARIATIONS

1. The Chaos Game program can also be used to demonstrate another biological phenomenon: **homeostasis**. If you interrupt the cycling by clicking anywhere on the screen outside the triangle "boundaries", the dynamic system just works the "spot" back into the same pattern, and "life goes on...."

2. If you get the CD, be sure to take advantage of its other programs (see descriptions above). These could be done either using a computer screen projection system with the entire class, or by giving the class time to interact directly with the programs.(1-2 per computer). The Monkey typing "Methinks it is like a weasel" routine would be especially useful to bring out the critical, often overlooked **accumulative** aspect of natural selection.

3. As a further analogy to natural selection, one which also emphasizes the **accumulative** nature of this process, take a look at "**Natural Selection... a Cumulative process**" on this site. It's taken directly from a recent article in The *American Biology Teacher* by Werner Heim, in which students select a sequence of playing cards two different ways: one cumulative, the other non-cumulative. It's at <http://www.indiana.edu/~ensiweb/lessons/ns.cum.l.html>. The chaos game does a great job showing how a combination of random and non-random elements can create order. However, the physical engagement with the cards, and the direct comparison, provides a real sense of the statistical probabilities involved, and may even be more compelling. This is especially true for those who have heard and believed the old creationist argument and the appeal to intelligent design.

4. Another topic which strongly indicates that life has NOT developed by intelligent design is the study of pseudogenes. In fact, this is an excellent opportunity to give your students a chance to see the power of MILEs (Multiple Independent Lines of Evidence). Take a look at our Pseudogene Suite <http://www.indiana.edu/~ensiweb/lessons/psa.ball.html>, and consider doing at least the first two lessons there, based on the existence of a pseudogene in humans which is very similar to the gene which enables many other animals to make vitamin C, suggesting common ancestry.

5. In addition, we would encourage you to extend the unit on natural selection by addressing, at some point, the concept of **accumulative speciation** and how this results in the phenomenon often called **macro-evolution**. There seems to be a growing acceptance for natural selection at the micro-evolution level (within a species) amongst creationists, but they still insist that there is "no-evidence" for macro-evolution, so we feel that the mechanism and evidence for this continuum should be clearly presented. See our **Intro to Evolution** page, in the section on **What Evolution IS**: <http://www.indiana.edu/~ensiweb/lessons/ns.cum.l.html>, and click on the **Macroevolution Diagram** which can be used to show this (along with directions on its use). You could also use the similar diagram in the NAS book on *Teaching About Evolution and the Nature of Science* (page 32). Partly for its historical significance, you should also show **Darwin's Tree**, also accessible from the What Evolution IS section.

6. For further experience with macroevolution, consider using at least one of the following lessons:
Classroom Cladogram of Vertebrate Evolution <http://www.indiana.edu/~ensiweb/lessons/c.bigcla.html>
Hominoid Cranial Comparisons (skulls lab) <http://www.indiana.edu/~ensiweb/lessons/hom.cran.html>
Becoming Whales lesson <http://www.indiana.edu/~ensiweb/lessons/whale.ev.html>.
In each of these, examples, traits are seen accumulating in fossils over time, clearly showing gradual changes in the mosaic patterns of those traits.

7. Finally, you should also take this opportunity to present a sampling of the many **transitional forms** in the fossil record, something creationists persist in denying, in spite of the plethora of examples. We have a nice condensed version of Kathleen Hunt's treatment of **transitional fossils** (from her *Talk Origins* paper). <http://www.indiana.edu/~ensiweb/lessons/c.bkgrnd.html>. It's called the "Background" and is also accessible from the Classroom Cladogram lesson.

RESOURCES
AVAILABILITY of CD:
Single User License: US $19.95 ($29.95 CDN)
Secondary School Site License: US $39.95 ($59.95 CDN) - no limit on number of students or classes at a single institution
University/College License: US$59.95 ($89,95 CDN)

SOURCE:
Ourniche Software
Box 63,
Haileybury, ON P0J 1K0
Canada

Queries: email Doug Fraser at: dfraser@ourniche.net

Dawkins, Richard. *The Blind Watchmaker*.1987. Norton.

ATTRIBUTIONS
The original concept and version of this lesson came from Doug Fraser, a biology/environmental science teacher and biology text co-author in Ontario, Canada. The CD is a product of the joint efforts of Doug Fraser and programmer/friend Matthew Allen.

With the kind permission of the author, the Chaos lesson was adapted to the ENSI format by Larry Flammer, 2/2003.