

# Natural Selection

## Among Playing Cards

---

WERNER G. HEIM

---

**I**n his book *The Origin of Species by Means of Natural Selection or the Preservation of Favored Races in the Struggle for Life*, in a chapter ominously called "Difficulties of the Theory," Charles Darwin wrote a section with the heading "Organs of extreme Perfection and Complication" (Darwin 1872). It begins: "To suppose that the eye with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest degree."

Today we know, and Darwin knew, that such an organ as the eye is not formed complete and whole in one stroke. Rather, such an organ begins in organisms living very long ago as a simple structure or process. Just being able to determine

whether light is present can be of considerable advantage to an organism allowing it, for example, to tell "up" from "down." Perhaps the next step might be the development of a bit of dark pigment at one side of the light sensitive spot. This would allow gathering at least some information about the direction from which the light is coming. Next, depressing the light sensitive area into a bowl shape allows a still better determination of the direction of the light. A lens across the top of the bowl yields the possibility of image formation, etc. Indeed, animals with such organs are extant. A similar process can be envisioned for the evolution of complex molecules. An enzyme need not be created in its full-blown, highly efficient, modern version. In the absence of a superior competitor, even a simple, small molecule that slightly speeds up a useful reaction is an immense improvement over having no catalytic activity available.

This line of thought hits at much of the argument behind the creationist position, especially the recent variety known as intelligent design theory. The basic argument put forth is that molecules,

---

WERNER G. HEIM is Professor Emeritus of Biology at The Colorado College, Colorado Springs, Colorado 80903-3294; e-mail: [wheim@coloradocollege.edu](mailto:wheim@coloradocollege.edu). He served as Associate Editor of ABT from 1970 to 1974.

structures and organisms as we see them today are much too complex to have evolved in small steps (for a recent example, see Anonymous 2001). This is sometimes “proven” by calculating the probability of all the monomers of a protein or DNA molecule coming together simultaneously and in the right order, given that each step is a random event. The result, of course, is always an enormously small probability.

What is wrong with this argument and with these calculations? They ignore the fact that evolution progresses by *cumulative* natural selection acting on random mutations. A new molecule or structure that yields a greater Darwinian fitness than an existing one is not begun from scratch but by selecting a mutation that improves upon the existing version. This is the key idea in understanding the process of evolution but, unfortunately, a difficult one for students to grasp.

There are many ways to illustrate cumulative natural selection acting on random mutations. Dawkins (1986, pp. 46-50), for example, has developed a computer program that assembles a specified phrase by selecting and saving successively closer approximations of the phrase as random mutations occur in a string of letters. This is the correct version of the old puzzle as to how long it would take a thousand monkeys pounding away at a thousand typewriters to produce one line from Shakespeare.

However, for teaching the concept of cumulative natural selection acting on random mutation such a computer demonstration has a great disadvantage: the real action takes place in the entrails of the computer, away from the touch and sight – hence the understanding – of the student. Here, a pair of simple card games will demonstrate the same point right in the hands and before the eyes of the student.

## The Game

Two versions of the same card game will be played, one with and one without cumulative selection. In each, mutation will be represented by shuffling the cards. Each round of playing is equivalent to producing a new generation of an organism. The object is to determine how many generations are needed to produce an “organism” with a specific and improbable set of properties. That “organism” is a suit of cards sorted into ascending order from ace to king. When the game is played with cumulative selection, the number of rounds needed to produce the organism is fairly small; when it is played without cumulative selection, the number is likely to be so large that the goal will not be achieved in any reasonable period of time such as a class session.

## Materials

The only items needed, aside from a piece of scratch paper, are one deck of playing cards for each group of four student teams and one envelope sufficiently large to hold one suit of cards per team. The teams optimally consist of two students each but can be as large as four students. Thus two to four decks of cards will be sufficient for a class of 32 students.

First, number the envelopes from “1” to whatever number of teams you will have. Second, remove the jokers, if any, from the deck. (They can be awarded as prizes to students who make good puns using biological terms.) Finally, sort the cards into suits and put one suit into each envelope. If you wish the game to go faster, use less than whole suits; perhaps remove the four face cards and play with only the nine numbered cards.

## Playing the Game

Divide the class into as many teams of two to four students as desired. Each team has at least a “recorder” and a “player” but the role of the player may be subdivided, perhaps into those of a shuffler, a card handler and an observer. The instructions for those teams receiving envelopes with even numbers are slightly different from those for teams receiving envelopes with odd numbers. You may wish to hand out copies of the following instructions:

For odd-numbered teams:

1. Shuffle the cards thoroughly.
2. The recorder keeps track of the number of rounds played, increasing the count by one each time the shuffling is completed.
3. Examine the cards. Are they in the order ace, 2, 3 ... jack, queen, king?
  - A. If so, inform the instructor of the recorder’s count, i.e., of how many rounds have been played. Then stop as the goal has been reached.
  - B. If not, play another round, i.e., repeat Steps 1, 2 and 3.

For even-numbered teams:

1. Shuffle the cards thoroughly.
2. The recorder keeps track of the number of rounds played, increasing the count by one each time the shuffling is completed.
3. Examine the cards. Is the top card an ace? If so, use it to start an “organism” stack. After this

stack has been started ask whether the top card is the next one needed to construct the “organism.” If, for example, the top (and only) card in the “organism” stack is the ace, then the next card needed is the two. Or if the top card in the “organism” stack is a seven, the next card needed is the eight, etc.

- A. If the top card is the next card needed for the construction of the “organism,” place it face up on the “organism” stack. Then repeat Steps 1, 2 and 3.
  - B. If the top card is not the next card needed for the construction of the “organism,” do not place any card on the “organism” stack. Instead repeat Steps 1, 2 and 3.
4. When all the cards are in the organism stack (with the king on top), inform the instructor of the recorder’s count, i.e., of how many rounds have been played. Then stop as the goal has been reached.

## The Discussion

In most cases, the games will have to be stopped at some arbitrary time, perhaps 10 minutes after the last of the even-numbered teams finish, because most or all of the odd-numbered teams will not have finished and probably will not finish before the end of the period. That is precisely the point of the exercise.

You may wish to discuss the following questions with the class:

1. In what ways is shuffling the equivalent of genetic mutations? In what ways is it not? Does the model distinguish between phenotype and genotype?
2. What is the one, critical respect in which the actions of the odd- and even-numbered teams differed? What is the biological equivalent of this difference?
3. What, in the game, represented selection?
4. Why, in the game, was selection cumulative?
5. What was the average number of observed generations needed to evolve the organism by the even-numbered teams? How does this figure compare to the calculated average number of generations? (Hint: On the average, in each round, the ace has a 1:13 chance of coming up, the “2” has a 1:12 chance, etc. The sum of the numbers from 1 to 13 is 91.)

6. What was the average number of observed generations needed to evolve the organism by the odd-numbered teams? Do we have the data to answer this question? What is the calculated number of generations? (Hint: We need to have the ace show up first, with a probability of  $1/13$ , then the “2,” with a probability of  $1/12$  ... to the king with a probability of  $1/1$ .  $1/13 \times 1/12 \times 1/11 \dots 1/1$  is approximately  $1.6 \times 10^{-10}$ .  $1/1.6 \times 10^{-10}$  is about  $6.2 \times 10^9$ . Shortcut:  $13! = 6,227,020,800$ .)
7. How many times faster is the evolution of our model organism with versus without cumulative selection among the mutations?

## Conclusion

It takes millions of times longer to assemble an organism, a complex organ or a process such as a metabolic sequence if all the necessary mutations have to assemble simultaneously in one organism compared to accumulating such mutations one or a few at a time. Considering that even the latter method takes from perhaps 10,000 to 1,000,000,000 years or more, there simply has not been time since the origin of the Earth for the former process to work. Therefore, we can be confident that evolution proceeds by cumulative selection of favorable mutations (plus some ancillary processes such as genetic drift and recombination) rather than by purely random processes.

Creationists are often heard to claim that an organ such as the eye or a structure such as a complex enzyme could not have arisen by pure chance within a reasonable length of time, concluding therefore that evolution could not have produced a complex organ, organism or process. Their premise is correct, but their conclusion is wrong because evolutionary biology does not make this claim. Rather, it claims that such organs, structures, etc. arose largely by the accumulation of favorable mutations through the process of cumulative natural selection. Mutation is a chance process; selection is an anti-chance process. And, as the card game showed, evolution by cumulative selection of favorable mutations is a relatively rapid process.

## References

- Anonymous. (2001). 1,500 attend creation/evolution debate at James Madison University. *Acts and Facts*, 30(4), 2-3.
- Darwin, C. (1872). *The Origin of Species by Means of Natural Selection or the Preservation of Favored Races in the Struggle for Life*. Chicago and New York: Rand, McNally & Company.
- Dawkins, R. (1986). *The Blind Watchmaker*. New York: W. W. Norton & Company.