Lessons in Biogeography: Simulating Evolution Using Playing Cards

By: Paul A. Knapp and James M. Thompson

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Abstract:
This exercise links our day-to-day understanding of probabilities with the concepts of evolution as it relates to biogeographic processes. The complex idea of natural selection is presented in a simple, nonthreatening, and fun way. A variety of scenarios can be used to illustrate the effects of evolutionary pressure. The effects of selective pressures along with the consequences of either lethal or strongly positive mutations can be illustrated through a number of generations. Genetic drift can also be shown.
Key words: evolution, biogeography, simulation, mutations, genetic drift, natural selection.

Article:
Teaching the concepts of evolution in both high school and college classrooms remains difficult. Evolution has been explained in a variety of ways, yet the slowness at which evolutionary changes occur through natural selection leaves students nonplused: we rarely see evolutionary change within our lifetime. In part, this confusion stems from the fact that natural selection works through many different mechanisms. The traditional explanation of Darwinian selection alone is difficult to visualize. Adding to this complexity are the many facets (i.e., mutations, genetic drift, genetic bottlenecks) that can confuse or overwhelm student understanding. Finally, many geography students do not have the background in biology that is needed to understand certain biogeographic concepts--especially ideas as critical as natural selection anti speciation.

The role of evolutionary change is important in under-standing and explaining biogeographic processes. In the southern Great Plains and desert Southwest, for example, consider-able interest is focused on a mechanism that may explain the increase in the abundance and density of woody shrubs in native grasslands (Mayeux et al. 1991). Along with the traditional theories of vegetation change—fire suppression, domestic livestock grazing, and climatic changes—are that increasing levels of atmospheric CO_2 provide antitranspirant and aerial fertilization effects that favor greater growth advantages to species with C_3 as opposed to C_4 photosynthetic pathways (Idso 1992). In many areas of the southern Great Plains and desert Southwest, C_3 shrubs such as Prosopis spp. (mesquite), Larrea divaricata (creosote), and Juniperus spp. (juniper) have increased in abundance in relation to the native C_4 grasses (Mayeux et al. 1991) such as Bouteloua spp, (gramas), Buchloe dactyloides (buffalograss), and Digitaria californica (Arizona cottontop), because plants with the C_3 metabolism are more responsive to increased levels of CO_2 than C_4 species (Mayeux et al. in press).

C_4 plants evolved from C_3 species with an increased carboxylation efficiency in response to reduced CO_2 levels that began during the Cretaceous and lasted until the Miocene (Ehleringer et al, 1991). During this period, C_4 plants were the dominant vegetation. However, since the beginning of the Holocene, there has been a doubling of CO_2 (with a 30 percent rise in the last 200 years) that has once again favored C_3 species and may have substantially facilitated the invasion of shrubs into grasslands (Johnson et al. 1993). The evolutionary change that conferred a competitive superiority to C_4 species and made them the dominant vegetation millions of years ago no longer is as beneficial as it once was; consequently, today only 5 percent of the world's plant species possess the C_4 photosynthetic pathway (Ehleringer et al. 1991).

The sagebrush-steppe of the Great Basin has also under-gone tremendous changes in plant community composition during the last 150 years (Billings 1990) and presents another example of the effects of evolutionary pressures. The major component for this change has been the invasion of exotic annual species, *Bromus tectorum* (cheatgrass), *Halogeton glomeratus* (halogeton), *Salsola australis* (tumbleweed), and *Taeniatherum caput-medusae* (medusahead rye), which have competitively displaced many of the native species. The exotic species evolved under centuries of heavy herbivore grazing in Eurasia and developed a high degree of genotypic and phenotypic plasticity that makes the species competitive under intensive grazing or variable climate (Young et al. 1972). Native Great 13asin grasses evolved without large ungulate grazing (Mack and Thompson 1982), and were rapidly overgrazed by domestic livestock beginning in the 1800s (Mack 1981); consequently, the exotic species found an ecological niche that they could exploit (Young et al. 1987). Clearly, the importance of evolutionary changes cannot be overlooked when examining the nature of vegetation shifts.

This exercise enables students to learn the concepts of evolution on their own. It is straightforward, flexible (the level of complexity can be increased substantially), non-threatening, and most importantly, fun. Key concepts underlying these ideas lie in probability. Yet, this presents a daunting task for students. Instead of treating probability in an abstract way, this lab lets us take a hands-on approach, where students can actually see a gene pool change over time. Poker is a card game popular with gamblers. Success requires a good grasp of probability, a clever use of strategy including bluffing and "reading" other players, and the appropriate use of betting strategies. This lesson eliminates the strategy side of poker and focuses exclusively on probability.

Procedures

Give all instructions first!

1) Place students in groups of four. Assign each group a number. The number of groups should be even.

2) Hand out one deck of cards per student and one copy of probability chart and tally sheet per group (Tables 1 and 2).

3) Students in groups of four then pair off. At this point, ask the students to make predictions as to the gene pool outcome.

4) Each pair will play ten hands of 5-card no-draw poker (see list of winning hands in Table 1). Each student will deal themselves the top five cards from their deck.

5) After each hand, place the winning hand in one pile and the losing hand in another "discard pile." After playing ten hands, you will still have two cards remaining. Place these two cards in the discard pile as well.

6) Count the number of cards in the winning pile. It must equal 50. Any number other than 50 indicates that you have made an error. All decks beyond round one will have 50 cards.

7) In the winning pile of 50, sort the cards by value (i.e., ace, king, queen, etc.). After sorting, count the number of cards of each value. Record this number on the tally sheet (Table 2).

8) In your group of four, repeat steps 4-7 using the two winning decks from round 1 (Figure 1).

9) Repeating steps 4-7 again, group "1" should play their winning deck (the deck should be exactly 50 cards) against group "2." Group "3" would play against group "4," etc.

10) Continue playing until only one deck of cards remains.

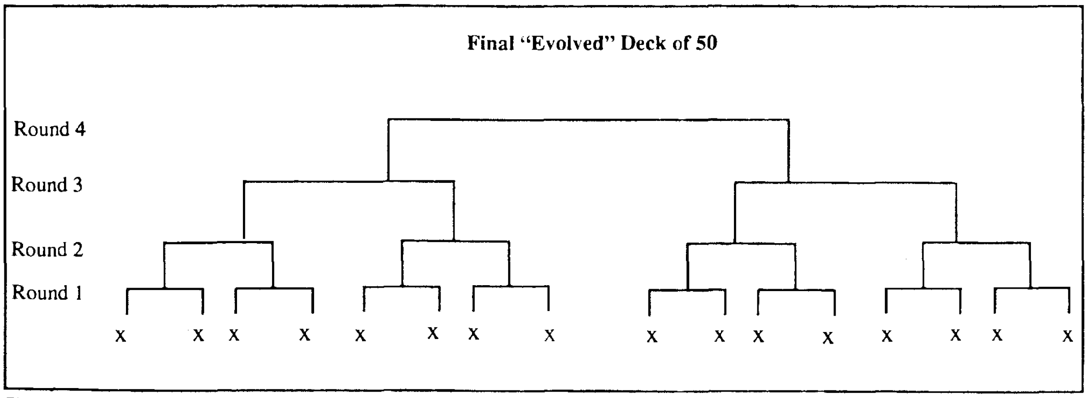

Figure 1. Playoff scheme based on four groups. X = students.

Discussion

A Standard Game

The first way to simulate evolution would be to show preferences for higher cards over lower cards, pairs over "bust hands," etc. This is the simplest way to illustrate evolution. What should be noticeable is that little preference is apparent for higher cards in the first round showing how slowly selective pressures work (Table 3). This is probably contrary to what many students would predict (in fact, it would be worthwhile to ask the students to guess what the outcome will be prior to play). It is typically only by the later rounds (round 3 or higher), that the high card preference is shown more strongly. Further, when performing simulations, it becomes apparent that straights and flushes (optimal combinations) have little effect on the outcome of card distribution. This is a classic example that natural selection does not necessarily produce the best genome, but rather selects a gene pool that consistently produces acceptable though perhaps not optimal individuals (Lester and Bohlin 1989). For example, even though a royal flush is the best possible hand, it occurs so infrequently that its contribution to the formation of the gene pool may be minimal. Further, one (or more) of the required cards for a royal flush may drop out of the evolving deck prior to the final round. In our trial run (Table 3), only one 10 remains after the final round (see column 4-1). In this example, the probability of a royal flush occurring with the final deck is smaller than in the original round 1 deck.

Table 1
Examples and Probabilities of Dealt Hands

Probability Chart[a]

Poker Hand Values in Ascending Order

Hand	Example	Probability[b]
One pair	Two Jacks	1.4:1
Two pair	Two Jacks and two Queens	20:1
Three of a kind	Three Jacks	46:1
Straight	7, 8, 9, 10, Jack	254:1
Flush	Five cards, all the same suit	508:1
Full House	Three Jacks, two Queens	693:1
Four of a kind	Four Jacks	4164:1
Straight flush	7, 8, 9, 10, Jack, all same suit	72192:1
Five of a kind[c]	Five Jacks	?:?
Royal Flush	10, Jack, Queen, King, Ace, all same suit	649739:1

[a] Source: McKnight, 1964.
[b] These are odds that woud occur during the first round only, dealing from a normal 52 card deck.
[c] Possible in later rounds.

One Card = One Gene
One Hand of Five Card = One Species' Genome
One Deck of Card = A Population Gene Pool

Five Standard Game Variations

1) Wild Card— Just like in the game of poker, a "wild card" may be designated to be anything that will improve the dealt hand. For example, if "7s" are declared wild, you can change both the suit and value of the 7 to whatever improves the hand. While this wild card does not guarantee a winning hand, the odds of this gene

advancing to later rounds (i.e., becoming a high frequency gene in the gene pool) improve. Over successive rounds, it is likely that the number of 7s should increase relative to other genes (cards). This example would be a loose approximation of what would happen if a highly beneficial gene was present in the population, such as pesticide resistance in insects. The few insects that are resistant initially to the pesticide live to pass on their genetic material to future generations, and that genetic material then becomes predominant in the population.

2) Dominant Lethal Mutation—This is a simple variation that all students should be able to grasp. This example involves declaring a card (e.g., all 6s) as making a hand an automatic loser, If both hands have 6s, then they are both losers. What this example will show is that there should be rapid elimination of 6s from the deck, illustrating why there are virtually no dominant lethal mutations in a gene pool. This would be equivalent to being born without a heart. It is simply impossible to carry on this mutation.

3) Recessive Lethal Mutation—This variation is similar to the dominant lethal mutation, but this time the lethal mutation does not occur unless two or more 6s are dealt in the same hand. If this combination occurs, then the hand is an automatic loser. This process will cause a decrease in the frequency of 6s, but the rate at which the 6s drop out should be substantially slower than for the dominant lethal mutation example. In humans, hemophilia is a classic example of a lethal recessive gene found in only small numbers in the populations.

4) Genetic Drift—This is the most random means by which evolution occurs. It requires small populations that make the gene pool susceptible to chance alterations in gene frequency. Instead of determining the winning hand based on the best poker hand, the winner is determined by the flip of a coin. Each person is dealt 5 cards like in all other instances, but heads means that person A's hand goes to the winning pile and person B 's hand goes into the discard pile. Tails would mean that person B's hand goes to the winning pile and person A's hand goes into the discard pile. What is interesting about doing this is how quickly cards will deviate from the standard deck. Using 16 decks, it would not be surprising that some card values would be gone while others occurred in large numbers. Asking the class to repeat this process a second time would undoubtedly lead to a very different looking gene pool (deck). This is an extremely important concept in biogeographic studies as speciation can be driven by genetic drift (i.e., allopatric speciation) working on small, isolated populations. Because genetic drift within two populations that have been separated by a physical barrier (e.g., a mountain range) will work to ensure a difference in the gene pool (if only because of the randomness of genetic combinations), at some point the drift will have created two distinct species (Moraine 1984; Brown and Gibson 1983).

Round-Game

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	2-1	2-2	2-3	2-4	3-1	3-2	4-1
2															
3															
4															
5															
6															
7															
8															
9															
10															
Jack															
Queen															
King															
Ace															
Total															

Figure 2. Blank tally sheet to be used in classroom scoring.

Round-Game

	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	2-1	2-2	2-3	2-4	3-1	3-2	4-1
2	5	3	6	4	6	3	3	5	2	8	7	6	3	7	1
3	4	5	6	3	1	4	3	3	2	1	4	4	1	2	0
4	2	3	3	4	3	6	3	2	3	5	1	2	4	3	2
5	0	2	2	1	3	3	6	4	5	2	1	0	1	0	1
6	6	3	3	4	5	3	2	2	2	3	2	5	2	3	3
7	4	4	4	3	6	3	4	4	3	5	4	5	5	3	4
8	2	2	4	4	2	4	4	5	6	3	3	1	4	0	3
9	5	4	1	2	3	2	4	4	2	1	2	4	1	3	2
10	5	4	4	4	4	4	2	2	3	2	2	2	3	0	1
Jack	5	3	5	6	4	6	6	3	7	3	6	5	9	6	10
Queen	3	5	4	5	3	4	4	4	3	4	5	3	3	6	7
King	4	6	4	4	5	6	4	4	6	8	7	7	6	9	8
Ace	5	6	4	6	5	4	5	7	7	4	6	6	8	8	8
Total	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50

Figure 3. Tally sheet of evolution simulation beginning with 16 card decks) (16 students). Numbers represent card count for winning pile in each round.

5) Major Environmental Alterations-This example involves "changing the rules" in the middle of a game. If the values of the cards are reversed in the middle of a game (i.e., 2s beat 3s, 6s beat 7s, etc.), one will quickly see the importance of selective pressure on the frequency of different cards as the lower cards cease declining and begin to increase, These changes could be brought about by a multitude of environmental factors (i.e., climatic variability, human land-use changes, and species introductions). For example, the accidental introduction and sub-sequent dominance of cheatgrass in the Great Basin has substantially altered fire regimes. Prior to the existence of cheatgrass, fire frequency in the sagebrush-steppe aver-aged between 32 to 70 years because of the lack of continuous fine fuel necessary to carry fire (Wright et al. 1979). Because cheatgrass provides the continuous cover, fire frequencies have increased in these cheatgrass dominated areas anywhere from 10 to 500 times (Hull 1965). The result is both the absolute increase of cheatgrass cover and the relative increase of perennial shrubs that have the capability of resprouting following fire. Perennial species that benefit are the sprouters such as *Chrysothamnus nauseosus* (rubber rahbitbrush) and *Tetradymia* spp. (horsebrush), while non-sprouters such *Artemisia tridentata* (big sagebrush) are greatly reduced in number because they reestablish by seed. In essence, the introduction of cheatgrass has changed the rules for competitive success among the native species.

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