

How-To-Do-It

Why Reproduce? A Demonstration of Evolution and the Origin of Life

Alan R. P. Journet
Southeast Missouri State University
Cape Girardeau, Missouri 63701

One of the main goals of general biology programs is to explain the process of evolution. Despite long discussions of the process and its consequences, I have found students often retain their view of evolution as goal oriented, with organisms almost "shopping around" for a set of improved characteristics. This view is so locked into their minds that presenting a simple visual demonstration of the process seemed advisable.

As a countermeasure, I developed a simple model to illustrate several aspects of the biochemical theory of the origin of life and the process of evolution through natural selection. This model has students predicting the outcome of evolution in populations of beads. Since the underlying principles of evolution are so important in a general biology course, and, since student resistance to learning them seems so high, I spend 45-50 minutes (and an almost equivalent time in the laboratory) working through this model with the class. I want the students themselves to feel that the outcomes are obvious and inevitable so that their resistance to learning the principles is overcome.

This course segment fits typically between mitosis and meiosis. I begin it by addressing two questions: "why do cells divide?" and "why do organisms reproduce?"

The most frequent responses from students to these questions are, respectively, some variation on "to help the organism survive" and "to perpetuate the species." By having them think about the cells in their own hands and algal cells in a stagnant pond, I convince them (I hope) that such teleology is absurd. I then point out that I want to show them why my question "why reproduce?" is the wrong question.

A Model of Evolution

The model requires a large bag or box concealing many beads of two colors (I use red and blue) and a small beaker that will hold < 100 beads. Any beads or marbles are satisfactory.

The analogy concerns the primordial "soup" of organic molecules and macromolecules present at the origin of life according to the bio-

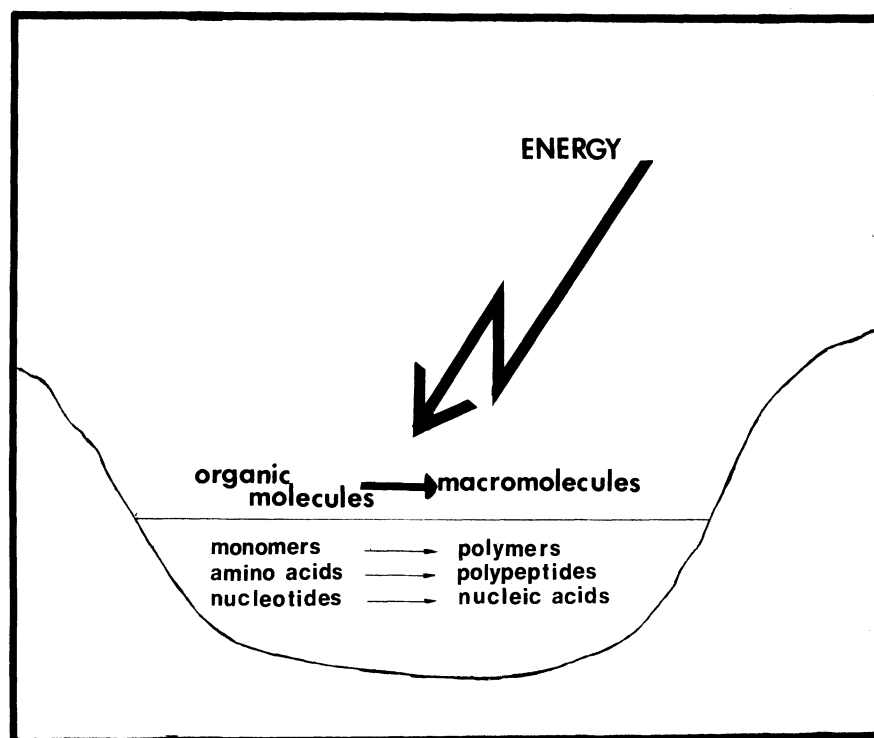


FIGURE 1. The early stage in chemical evolution may have occurred in small ponds or puddles where energy input allowed polymerization of organic molecules to macromolecules. However, replication is the key to biological evolution leading to adaptation.

TABLE 1. Class Counts of Beads Through a 10-Day Run (Sample Size of 60 Represents Complete Utilization of All Organic Molecular Resources)

		Red		Blue
Phase I	Day 1	28		32
	Day 2	24		37
	Day 3	22		40
	Day 4	31		27
			Red Rep- licators	
Phase II	Day 5	27	2	30
	Day 6	22	4	35
	Day 7	27	8	26
	Day 8	21	16	26
	Day 9	15	32	12
	Day 10	—	60	—

chemical theory (e.g., Fox 1965; Handler 1970) and as discussed in most general biology textbooks. In that "soup" many different monomeric organic molecules (amino acids, nucleotides, etc.) were combining to form larger macromolecules, as polymerized chains, and spontaneously breaking apart again (fig. 1). This is the point where I deal with views on the primitive atmosphere and current ideas and experiments on the formation of these organic molecules as a "soup" from inorganic precursors. This combination or synthesis may have occurred in localized regions, perhaps puddles or small ponds, where there was a significant input of energy (e.g., from lightning or volcanic heat).

For this model we concentrate on one of those puddles or ponds and simplify the process by invoking a number of rules:

1) The bag of concealed beads represents the puddle of unknown organic monomeric molecules. From the many different kinds of molecules present in the puddle, only two kinds of macromolecular polymers can be formed. These macromolecules are the red and blue beads. When formed, they occur with equal probability (the bag contains many beads with about equal numbers of the two colors).

2) The beaker also represents the same puddle. The input of energy

into the system which permits synthesis of polymeric macromolecules is represented by scooping beads from the bag into the beaker. At this time, according to the model, all available organic monomeric molecules have been polymerized into one of the two kinds of polymeric macromolecules, the red and blue beads. In my case, the puddle holds about 60 polymer/beads implying only sufficient space and resources (= monomers) for these 60 polymers.

3) All macromolecules form from their constituent organic molecules simultaneously at 2400 each night. Scooping the beaker into the bag represents this daily input of energy and polymerization. Later, all polymers in the puddle break down simultaneously, this occurring at 2355 rather than gradually. This breakdown is represented by dropping the beads back into the concealed bag.

There follows a more detailed illustration of classroom application of the model with discussion of the implications and variations.

Phase I

In the bag/puddle there are many organic molecules. It is 2400 hours. The sampling beaker is dipped into the bag indicating the input of energy and synthesis of polymerized macromolecules randomly

from the organic molecules in the puddle.

"Day" 1—In the beaker are the macromolecules of day 1. One student counts the beads and scores the number of red and blue beads present (table 1). There are, of course, about 50% red and 50% blue beads, but not exactly. At 2355 these macromolecules break down again into their constituent monomers indicated by returning the beads to the bag/puddle.

"Day" 2—At 2400 the energy input is available again and the macromolecules are polymerized again. Another beaker full of beads is scooped from the bag and counted by another student. Again the scores are recorded (table 1). There are again about 50% red and 50% blue beads, but a different number from day 1.

As this run proceeds through four "days" or more we discuss the students' expectations of the proportions of red and blue beads, making the points that:

- a) we expect the ratio of red to blue beads to fluctuate around 50:50;
- b) the numbers could be very far from 50:50, though we would only rarely expect this;
- c) the number of either color bead on day D does not influence the number of that color on D+1, D+2, etc.;
- d) no extinction will occur; even if one color is (improbably) absent on one day, it would be expected to appear on the next;
- e) the total number of beads is limited by the size of the region subjected to the input of energy (the puddle = bag = beaker), and the number of organic molecules present.

Phase II

A complication to the previous simple sequence is now included.

"Day" 5—At 2355 of day 4, when all the red and blue beads should break down and be returned to the

bag, one red bead does not. Instead, at 2359, when energy is available in the puddle, it replicates. It did not try to, it did not want to, it had no grand design. Nonetheless, it did replicate. What, then, do we find on day 5? To illustrate this event, all beads but one red one are returned to the bag as before. Then, to the one red in the beaker another red is added from the bag simulating replication. The one red replicator has utilized some of the organic molecular resources in producing two red replicators (RRs) which are now in the beaker. The beaker is then dipped into the bag to collect beads, illustrating that the rest of the puddle is filled with macromolecules synthesized from their organic monomers at random, this occurring at 2400 with energy input as throughout the previous days of the model run. The filled beaker contents are now counted, the result again being scored in the table (table 1). At 2355 the normal reds and blues break down leaving two RRs. Since these two RRs are identical to the initial RR, they also replicate. Again, they did not want to. Rather, they were programmed to do so only because they acquired from the initial RR all its attributes (inheritance) including its ability to replicate.

“Day” 6—At 2359, then, the two RRs replicate, illustrated by placing into the beaker two further red beads, making four in all. At 2400, with more energy, these four RRs are now surrounded (scoop into the bag again) by randomly formed normal red and blue beads. A count is made of the total RRs, normal reds and normal blues in the beaker. No clear pattern is yet emerging (table 1).

“Days” 7-9—The model continues, with RRs being added first and the beaker being completed by the addition of reds and blues at random from the scoop. The number of RRs increases to 8, 16, and then 32. This leaves, in my run, about 14 red (= 15) normal and 14 blue (= 12) normal (table 1).

TABLE 2. Phase III. Revised Counts and Estimates of Beads Based on Four Different Assumptions (see text for explanation)

	RR s	BQ s
Day 10, all assumptions	56	4
Day 11, assumption a	56	4
Day 12, assumption a	56	4
Day 11, assumption b	44	16
Day 12, assumption b	—	60
Day 11, assumption c	60	—
Day 12, assumption c	60	—
Day 11, assumption d	56	4
Day 12, assumption d	56	4
Eventually, assumption d	—	60

“Day” 10—Again, at 2355 of day 9, all but the RRs break down and at 2359 the RRs replicate. Now we place in 64 beads representing the 32 RRs that replicate. But there is only room for 60; four fall out. The available space has been occupied, and available resources consumed by the first 60 products of replication. The rest are eliminated, or rather, not produced. Once the organic molecules in the puddle have been used up by the RRs (to make the 60 RRs), there are no resources left so four potential products are unformed.

At this point it is possible to make the points that:

- a) the number of RRs on day $D+1$ is a function of the number on day D ; and
- b) once the ability to replicate appeared, the replicators eliminated the non-replicators in an inevitable process; the replicators had no goal to perpetuate replicators or eliminate non-replicators. Neither could they prevent the inevitable consequence of their replication.

It is now time to refer back to the initial question on the reason for reproduction. By extrapolation, it is possible to see that organisms do not reproduce to perpetuate the

population or species. Rather, organisms are here *because* their ancestors replicated.

Phase III

Another complication is added at this time which will illustrate competition and reproductive success.

This sequence replaces the previous sequence from day 10.

“Day” 10—At 2355 of day 9 the normal reds and blues break down, as before, *except* for one blue. The RRs are still present. Thus, in the model (table 1), 15 reds and 11 blues are returned to the bag. At 2358 this one blue bead, for no reason other than a chance attribute it has acquired, quadruplicates (BQ = blue quadruplicator). This could be described as a double DNA replication, or simply a mutation causing a change in polymer behavior. Thus, as we construct the beaker population for day 10, we start by inserting 4 BQs. Then, at 2359 the 32 RRs replicate as we have seen before. In so doing, these RRs consume all the resources remaining in the puddle. In fact, there are now only sufficient resources for the synthesis of 56 RRs. From this event on, in the revised model, there are only RRs and BQs since they consume all resources before

any random red or blue bead synthesis is possible on each subsequent day.

In order to examine subsequent events we must now explore the relationship between BQs and RRs in terms of competition for resources and relative reproductive success. Subsequent discussions should involve the students in predicting the numbers (exactly or approximately) and explaining the assumptions which led them to their predictions. It may be necessary to offer some possible assumptions about the interactions in order to promote discussion. I have identified four possible relationships between the BQs and RRs; there may be more. The point is to have the students explore competition for resources and differences in reproductive success in terms of the consequences of each for the number of BQs and RRs in the system. The discussion will deal with adaptations and survival of the "fittest" where fittest refers to the form most efficient at transforming resources into replicas of themselves. As in all such discussions, it is easy to slip into teleology, but since the objective of this model is to eradicate teleologic thinking, this should be avoided.

At 2355 of day 10 there is no breakdown since all resources are tied up in the BQs and RRs which do not break down but reproduce. At 2358 of day 10, the four BQs start to quadruplicate. But there are no resources available to them since all are locked up in the RRs. Then, at 2359 the RRs start to replicate. Effectively then, we now have a situation where BQs and RRs are reproducing simultaneously. What numbers do we expect on days 11 and 12? Competition for resources occurs. There are several outcomes depending on the relationship between the RRs and BQs (table 2):

a) If BQs and RRs retain their resources (the organic constituent monomers of which they are composed) such that the resources are not available to competitors,

numbers will stay at 4 BQs and 56 RRs through days 11, 12, and so on.

b) If RRs are susceptible to loss of component organic molecules to BQs, but BQs are not susceptible to loss of components to RRs, the number of BQs will become 16 on day 11 with fewer RRs (44 in my model). Then on day 12 there will be 60 (64, but there is only room for 60) BQs, and RRs will be extinct. Will RRs ever reappear in the system?

c) If BQs are susceptible to loss of resources to RRs but the reverse does not occur, then RRs will increase. On day 11 BQs will very quickly become extinct.

d) If each can consume resources from the other, competition occurs and BQs will increase at the expense of RRs as a function of the higher reproductive rate of BQs. The higher rate of resource consumption by BQs is a function of their higher reproductive rate and, therefore, the higher probability of utilization of resources that are available.

The competition equations of Gause (Emmel 1976) describe the interaction of different species and the outcomes of competition. That the BQs will increase at the expense of RRs is, I think, intuitively reasonable. I have not attempted, nor recommend attempting, discussion of these equations.

At this time discussion is directed toward making the following points:

a) The beads surviving competition were either those showing superior competition or those with the greatest reproductive success. In this example, this comprises more offspring produced earlier.

b) The inferior reproducers or competitors are eliminated, not because the superior reproducers or competitors wished to eliminate them; rather, elimination was an inevitable consequence of inferior reproduction and/or competition.

c) The blue quadruplicators did not become blue quadruplicators in

order to prevent their own extinction or in order to eliminate the red replicators; these ends were merely a consequence of the greater reproductive success of the earlier quadruplication process over the later replication process.

d) The key event in the biochemical sequence leading to the origin of life was the appearance of a process of reproduction (replication or quadruplication).

As the discussion continues, it becomes clear that the arguments developed here for the beads apply more widely. By extrapolation, then, each of the points made above can be generalized to populations and species of organisms:

a) organisms are each random experiments in reproductive success;

b) we are here because our ancestors reproduced; and

c) our ancestors were more successful reproducers than their competitors (they converted resources into reproductive output more successfully).

Any character which appears in an individual in a population and confers upon its bearer greater reproductive success or superior competitive ability than is exhibited by other individuals will spread through the population. Thus, one can discuss mutations, fidelity, and replication and the role of reproductive success in the process of evolution as it leads to adaptation.

After this discussion I find I can get from students a much more satisfactory explanation of evolutionary processes in populations, even prior to discussing genetics, population genetics, and natural selection. When presented with hypothetical problems (e.g., what would happen in a population of tasty brown insects that eat leaves if one green individual appeared, assuming there are predators present?), student responses tend to lack the teleology that I was attempting to escape. The ideas

they present also display a better understanding of the process of evolution.

This model fails to consider subsequent evolutionary events which might be usefully dealt with at this time. Thus, a discussion of the importance of the steps allowing biochemical trapping of energy from a) the breakdown of organic molecules (respiration), and b) synthesis using solar energy (photosynthesis) would be appropriate.

Indirect benefits of this discussion so early in the course are that it presents an evolutionary background

before the details of the process are discussed, and it provides a reference for future discussions of population genetics and allele competition, mutations, population growth, and interspecific competition.

I now argue that a reasonable response to the question "why reproduce?" is "that's the wrong question." We should more reasonably ask "why are we here?" to which the answer is "because our ancestors reproduced, and they did it more successfully than their competitors."

Acknowledgments—For assistance with developing and refining this model, thanks are due to my BI 100 and BI 101 classes at Southeast Missouri State University and, especially, R.G. Johnson and C.A. Shulko.

References

- EMMEL, T.C. 1976. *Population biology*. New York: Harper and Row.
- HANDLER, P. 1970. *Biology and the future of man*. Oxford University Press.
- FOX, S.W. (ed.) 1965. *The origins of prebiological systems and their molecular matrices*. New York: Academic Press.

Teaching Taxonomy—A Different Approach

Earle V. Core, Jr.
Wichita High School South
Wichita, Kansas 67217

Probably one of the most difficult tasks facing a high school Biology teacher is that of developing the concepts associated with taxonomy. Cognitive teaching through rote memorization has long been the only approach used. Of course, rote memorization cannot be eliminated; however, the problem of what to do with the new knowledge is always prevalent. The greater understanding and conceptualization of the affective learning is often a more difficult task than the teaching of the cognitive unit itself.

We have been using a different approach to developing the concepts of taxonomy with considerable success. The traditional outline

Ed. Note: Mr. Core is presently on a one-year leave of absence teaching in the American School in Kuwait.

of each phylum, according to the text in use, is presented and then this new approach is utilized. Thus, this different approach is applicable to all levels of teaching and can be tailored to meet the needs of any teacher's lesson plans.

Each student is given a copy of the chart shown in figure 1. Note that the levels are not named but rather are lettered. Level A (with its associated #1 block) can be Kingdom, Phylum, Class, Order, or any other category. In the example of figure 1, if Level A is Kingdom, then Level B contains two Phyla of this Kingdom, etc. If Level A is Kingdom Animalia, blocks #2 and #3 are any two Phyla of Kingdom Animalia, and blocks #4 and #5 are any two classes of Phylum block #2.

One could even go so far as to use Level A for a class—perhaps, Class

Insecta or even an Order of Class Insecta. The wide variations of use of figure 1 are limited only as far as your own particular teaching unit is concerned.

Let us now assume that Level A is Phylum Chordata. That automatically makes blocks #2 and #3 (Level B) any two classes of Phylum Chordata. Level C will be Order, Level D will be Family, Level E will be Genus, Level F will be Species, and Level G will be Subspecies. Now you can make up any number of questions you desire that fit your teaching unit. For example:

Q: If #53 is a goldfish, can #125 be a trout? And why?

A: No, because #53 and #125 do not belong to the same class, and goldfish and trout are both members of Class Osteichthyes.