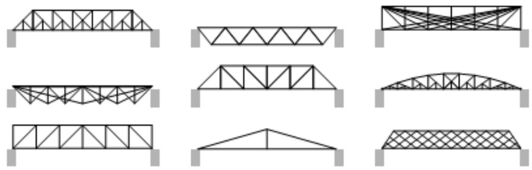
Appendix 2: Building Bridges Assignment Instructions

Collaboration and Natural Selection: Building Bridges



I. Learning Goals and Outcomes

Overarching Learning Goals

1) Collaborate with people of different backgrounds and abilities to reach a common goal
2) Make evidence-based claims
3) Use and implement design thinking to make and revise a model

Specific Learning Outcomes

1) Work with your peers to construct two generations of bridges that are designed to carry balls of different weights and sizes across a void
2) Assess evolutionary predictions (below)
3) Use R to manipulate, visualize and analyze data

II. Background and Overview

At its core, the process of adaptive evolution is relatively simple: there is variation among individuals, and the individuals that are best suited to the current environment will contribute disproportionately more offspring to the next generation than other individuals. As a result, the population changes over time and the “match” between the phenotypes and their environment increases.

This lab is designed to practice **culture of collaboration** in the lab while providing a **simple demonstration of evolution by natural selection**. A bridge is a functional feature designed to serve a purpose: to transport objects from one side of an abyss to the other. There are two important axes of function: span (the length of the bridge) and load (the weight a bridge can support). With a group of your peers, you will construct two bridges using an assortment of materials that will be provided by your TA. Your “first generation” bridge will compete with the bridges produced by other groups by comparing their success in supporting balls of different weights that are rolled across the structures. The “fitness” of a bridge will be determined by its span and the weight it can hold. The bridge with the highest fitness score is considered the “survivor” (i.e., most successful phenotype) and becomes the template from which all teams construct their “second generation” bridge. The second generation of bridges will also compete to test if there is evidence for adaptation (an increase in fitness) and evolution (a change in the characteristics of the population) from one generation to the next.

III. Specific Tasks

A. Bridge-building and testing

1) Form groups with 4 individuals per group (or a maximum of five groups per class)
2) Choose a team name
3) Each groups obtains one set of the following <u>materials</u> from the TA:
   - 5 sheets of paper
   - 6 paper clips
   - 5 straws
   - 4 rubber bands
   - 1 paper cup
   - 1 paper plates
   - 2 labels
   - 3 mounting squares
   - 1 paper bowl
   - 1 plastic knife
4) Each group has **8 minutes** to make a bridge out of the materials provided.
5) Each group has **1 minute** to set up their bridge so that it spans an abyss.
6) <u>Length score</u>: Measure the length (i.e., distance spanned, in centimeters) of the bridge with a meter stick or measuring tape.
7) <u>Load score</u>: A designated roller—the TA or LA—will roll four different balls (ping-pong, golf, tennis, and billiard) across the bridge in order of increasing weight (the lightest ball is rolled first, the heaviest last). Each ball is worth a different number of points, depending on its weight: ping-pong = 1, tennis = 2, baseball = 3, and billiard = 4. To receive points for a ball, it must make it all the way across the bridge without the bridge collapsing. The load score for the bridge is the sum of the balls that successfully cross the bridge. For example, a bridge that successfully supports all four balls will have a load score of **1 + 2 + 3 + 4 = 10**.
8) <u>Phenotype</u>: Count the number of building materials of each type used to construct the bridge
9) Record the data for your bridge on the **lab data sheet**: length (cm), load score (0-10), and phenotype (building materials).
10) <u>Fitness</u>: Calculate the overall fitness score of the bridge as its load score* length.
11) The TA or LA should use Google sheets to record the data for each group.
12) After each group's bridge is tested, the bridge with the highest fitness will be displayed and each group will make a second generation of bridges from another set of materials. The second generation starts with the structural design of the winning bridge but modifies it try to increase its fitness score.
13) The design challenge (steps 3-8) is repeated for each second-generation bridge.
14) The completed Google sheet should be made available to each student. Make sure it contains the following columns or vectors: section #, team name, generation, bridge length, load score, phenotype (a vector for each type of material = 10 vectors).

B. **Data analysis and visualization**

This lab emulates the process of evolution by natural selection: there is variation among phenotypes in the population (different bridge designs), the phenotypes vary in their success (fitness) based on their performance (function), and the traits that influence fitness are heritable (used as the template for the following generation). Given that this process mimics evolution by natural selection, we can make a couple of predictions:

1) There is variation in fitness among bridges
2) Fitness increases from one generation to the next (adaptation)
3) There is a **trade-off** —when an increase in one trait causes a decrease in another—across correlated variables. Here, there should be a trade-off between the length of the bridge and the load it can support.
4) Phenotypic complexity increases from one generation to the next. We will estimate whether evolution resulted in an increase in the **economy of nature** (few building materials used) or an increase in **complexity** (more building materials used) by describing the diversity of structural components of the bridge using the Shannon index of diversity:

$$\text{Shannon Index (H)} = - \sum_{i=1}^{s} p_i \ln p_i$$

where S is the number of different structural materials, and p_i is the frequency of each type of material used in the bridge (for example, if a total of 31 items are used and 6 are paper clips, paper clips would contribute -0.318 to the sum above).

C. **Lab Write-Up**

Follow the R code prompts to visualize the data you collected in this lab. Refer to the figures that you generated in R and associated descriptions to make **evidence-based claims** from your data about the process of evolution by natural selection. Finally (prompted in the R script), provide a brief assessment of how your group collaborated while making the bridge.

This lab is worth **20 points.** Use the following checklist to ensure that your write-up is complete:

Checklist

1) Your name and the names of your group members (1 pt)
2) Plot showing the mean and variation in fitness for the two generations (2 pts)
3) Description of fitness plot (2 pts)
4) An evidence-based claim about adaptation (2 pts)
5) Trade-off plot produced in R (e.g. plot of length x load score) (2 pts)

6) Description of the trade-off plot (2 pts)
7) A graph showing the change in characteristics of individual bridges for each group based on the diversity and number of items used to construct the bridge (i.e., plot of Shannon diversity across generations) (2 pts)
8) A description of the change in characteristics of the bridge (2 pts)
9) An evidence-based claim about the change in the structural diversity of the bridges across generations (3 pts)
10) Self-assessment of group collaboration. This should include a statement about whether everyone played a role or whether the contributions were very unbalanced, and your overall impression of your individual ability to contribute in positive ways towards your group's bridge. (2 pts)

Submit your write-up as a single **html** file (i.e., 'knit' your R Markdown code to html). **Each student should submit a document** and write his/her **own evidence-based claims** even though the graphs and data may be the same.