



Toober Variations

SMART Teams

Exploring the
Molecular World

There are many variations to the basic Toober folding exercise described in the “15 Tacks and a 4 foot Toober” handout. Each one can be used to emphasize a different point related to molecular structure. Some examples of variations are described below:

Reversible Denaturation.

Many proteins undergo reversible denaturation. The proteins can re-fold into their original shape (native structure) following their complete unfolding (denaturation) by heating.

1. Have each group of students document the “native” shape of their folded protein with a digital photo.
2. Unfold the protein and then ask them to re-fold the toober into the original shape.
3. Check the refolded protein against the photo of the native structure.

Reverse Engineering.

Some students will randomly generate a sequence of tacks that is very difficult to fold into a shape that simultaneously satisfies all 3 (or 4) laws of chemistry. This is a good “teaching moment” in that the teacher can use these examples to emphasize that such “proteins” would not have been selected from the enormous pool of possible protein sequences.

But, how can students arrive at a perfectly optimized sequence of tacks that have been selected over evolutionary time to always fold into the same globular shape? ANSWER: by reverse engineering the sequence.

1. Have each group of students fold their toober into a compact globular shape, without any tacks.
2. Have each group of students then add the tacks to the pre-folded toober, positioning them such that all of the “laws of chemistry” are satisfied in the folded structure.
3. Unfold the toober and document the sequence of tacks.
4. Can the students then re-fold the sequence into the original shape (see reversible denaturation above)?

The Effect of Mutations.

Some mutations inactivate a protein by destabilizing its native shape.

1. Starting with the “reverse engineered” sequence of tacks as described above, mutate one of the hydrophobic amino acids (yellow tack) to a positively-charged amino acid (blue tack).
2. Can the students fold this mutated sequence back into its native shape?

Share your variations! Let us know what other variations you use with your students, herman@msoe.edu.

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