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REALIZING THE EDUCATIONAL PROMISE OF TECHNOLOGY

# Why Are Progressions Important?

## A sequence of model-based activities supports student understanding.

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There is a disturbing tendency to treat educational materials as building blocks that can be assembled in any convenient order. "Knowledge engineers" think they can start with "learning objects" that can be automatically assembled into meaningful instruction.

Such designs ignore the central role of sequences of content and the importance of the progressive integration of ideas that creates knowledge and expertise. Core content needs to be returned to again and again, with each encounter deepening student understanding and increasing the web of associations that is a critical attribute of true knowledge.

At each step, a curriculum designer must consider what the student already knows, what misconceptions are likely, what can be learned now, and what is important for subsequent steps. This need not preclude inquiry, but is required to make learning of key ideas and processes successful.

Creating a coherent progression in science areas that are changing is particularly challenging. For instance, advances in molecular science in general and in molecular biology in particular are happening so rapidly that simply memorizing the tenets of yesterday no longer ensures true fluency in the field. Even biology's vaunted Central Dogma (DNA codes RNA, which codes proteins)—a cross between classical genetics and modern molecular science—is showing cracks. To truly understand new advances in molecular biology, students need molecular literacy that includes understanding the molecular concepts underlying the constructs of modern biology and the ability to apply these concepts

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to various biological phenomena.

Yet literacy in any field, particularly in molecular science, cannot be taught by treating curriculum components as building blocks assembled in any order. Proper sequencing that guides students to construct a rich molecular worldview useful for explaining a wide range of phenomena is critical.

## Students Need More than "The Chemistry of Life"

In the traditional biology curriculum, molecular science is presented in a fragmented way, highlighting limited concepts. Most, if not all, ninth grade biology textbooks include a section typically entitled "The Chemistry of Life." Students are introduced to atoms, ions, and small molecules. This chapter traditionally includes a colorful picture of water molecules, with dotted lines between them referred to as hydrogen bonds. Another picture shows sodium and chloride ions attracted into a crystalline structure due to opposite charges carried by the ions, though this may create a misconception that attractions exist only between ions. There is nothing or very little about polarity or van der Waals forces.

In the "Chemistry of Life" chapter, macromolecules come next. Here carbohydrates, lipids, proteins, and nucleic acids are introduced. Students memorize the four nucleotides—A, C, G, and T—that make up DNA, look up the chemical formulas of 20 amino acids capable of combining into polypeptide chains, and learn that proteins have primary, secondary, tertiary, and quaternary structures.

To address the genetic code, such a chapter has a table linking 64 possible triplets of nucleotides to 20 amino acids. As the finale, it mentions that when DNA code is translated into proteins, the proteins determine traits. Since Mendelian genetics usually comes much later in the course, students cannot question at this point how traits are linked with proteins. A couple of months later, by the time they study Mendel's Laws, "The Chemistry of Life" looks like a distant and disconnected mirage.

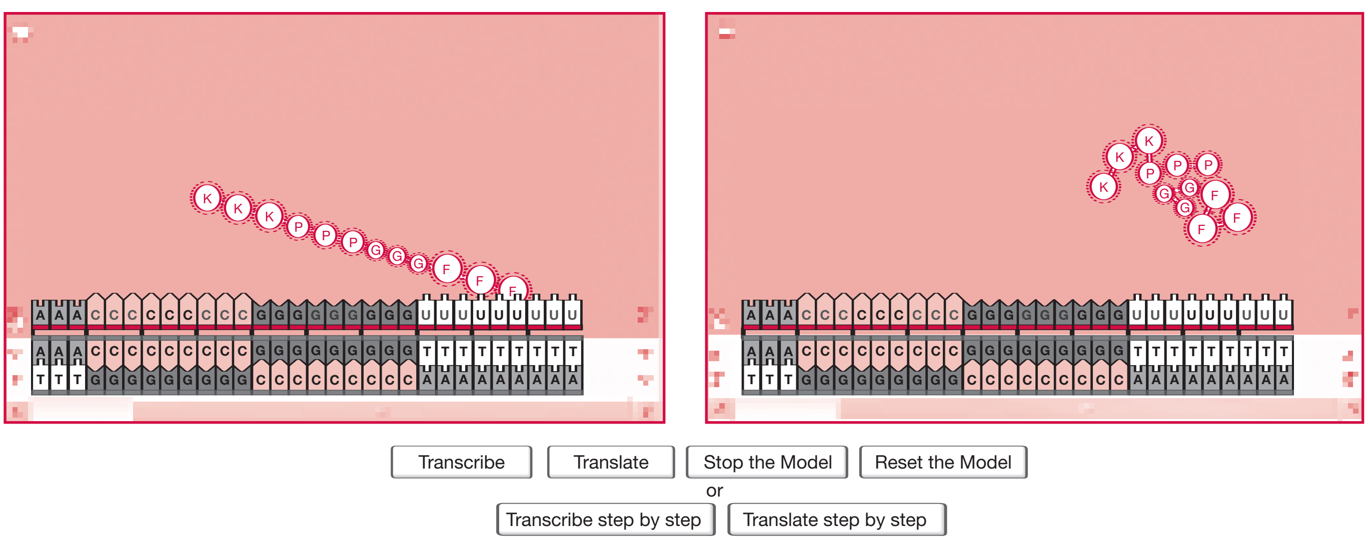
While this approach refers to atomic-scale interactions, it doesn't develop the connections necessary to build a strong understanding or reasoning skill at the molecular level. Because many critical molecular principles underlying these ideas had been considered hard to teach, they were often skipped, lightly touched upon, or taught quantitatively through mathematics. But unless students were mathematically literate, this was not an effective approach.

## Stepping Stones to Molecular Literacy

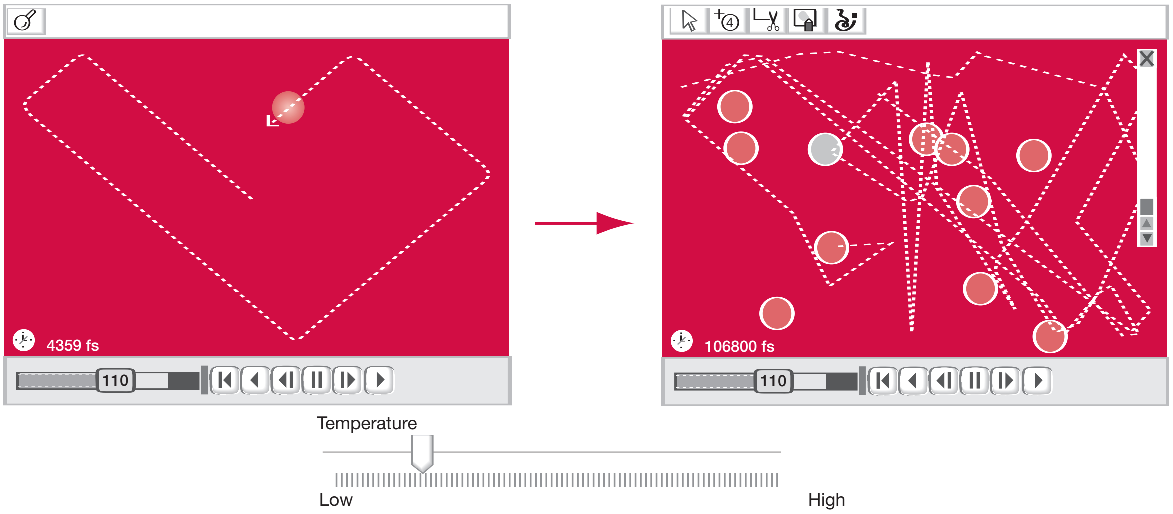
With the support of the National Science Foundation, we have developed a sequence of model-based activities to support student understanding of key concepts that underpin modern biology. *The Stepping Stones to Molecular Literacy* helps students reason about microscopic and macroscopic phenomena using what they learn about atoms, molecules and their interactions, and the resulting emergent phenomena. The specific sequence is critical because each activity builds upon the ones before it. Like Russian nesting dolls, each activity encompasses the prior ones, thus building a progression of molecular understanding.

The following is an example of a model-based progression of activities. (For the complete list of *The Stepping Stones to Molecular Literacy* activities see: http://molo.concord.org/database/browse/stepping-stones/)

**1. Atomic Movement Never Stops.** Students start with a single molecule in a virtual container and gradually add molecules to the system. As they add heat energy, they observe increased frequency of molecular collisions. Students can select a single molecule and trace its path to see how its motion is affected by collisions with other mol-




***Using the DNA to Protein model, students can compose any sequence of nucleotides, transcribe it into mRNA, and then translate that into a small protein. They can then view the protein folding in water or oil. This is how nature makes a 3D protein from a one-dimensional DNA sequence. Experimenting with such a model allows students to explore the relationship between a DNA sequence and the resulting protein structure, arguably the most important concept in molecular biology.***




*In the Brownian Motion activity, students observe the motion of a single particle, and then increase the number of particles in the model, as well as the amount of heat energy. They follow the motion of particles as they collide and discover the cause for their apparent random motion.*

ecules. By changing the amount of heat in the system, students can address issues of thermal motion, average kinetic energy of molecules, and temperature. This dynamic picture of matter composed of constantly moving and colliding molecules must be a foundation of students' mental models.

**2. It's a Sticky, Sticky Molecular World.** Few students realize that *all atoms* attract one another. This fundamental idea is central to an understanding of the atomic scale. It is quite common for students to think that only opposite charged ions are attracted to each other. Our model allows them to experiment with systems that depict attractive forces, such as van der Waals and hydrogen bonds that exist between atoms and molecules.

**3. Relating to Water: Hydrophilia and Hydrophobia.** The earlier models of random thermal motion and the attraction and repulsion between atoms and molecules are now applied to understanding the unique properties of water and aquatic solutions. Students simulate the attractive forces between water molecules called hydrogen bonds, experiment with adding ionic and non-ionic compounds, and observe the interactions between water molecules and the solute.

**4. Protein Chains and Water.** With the above knowledge, students investigate how a protein chain made of a combination of hydrophobic and hydrophilic amino acids behaves in water and lipids (the cell's environment). Students see how hydrophilic amino acids pull the chain toward water and how the hydrophobic amino acids are excluded by water and thus move inside the chain. Students learn how these processes shape the protein.

**5. Genetic Code and Proteins.** Students are ready to embark on experiments based on the Central Dogma. Using a model that contains a DNA coder and is capable of generating proteins according to the genetic code, students can create any sequence of nucleotides, launch protein synthesis, and observe the resulting composition of the chain of amino acids; they also can predict and observe the resulting shapes of the polypeptide chain in water, and develop a conceptual understanding of the genetic code and its connection with the shapes of the resulting proteins.

**6. Molecular Self-Assembly.** When students explore the folding of the polypeptide chain into a specific three-dimensional shape, and the assembly of proteins in a complex quarternary structure, they use fundamental ideas of physics and chemistry, including the idea that kinetic motion brings the pieces in contact and the charge and shape knits units together, creating shapes with biological consequences.

**7. Mutations and Illness.** If one truly understands the concepts leading to the Central Dogma, one should be able to reason about the molecular nature of mutations. To grasp the concept of mutations, students are able to alter the genetic code and compare how deletions, insertions, or substitutions of the coding sequences affect the amino acid composition and the shape of the protein. This molecular hands-on learning allows students to tackle the cause of a genetic disease, such as sickle cell anemia.

Thus, from simple concepts of random motion and the stickiness between particles, a sophisticated view of the molecular world emerges. Generations of biology teachers used their eloquence and tons of chalk to convey these ideas. For our students, modeling and visualizing the processes of molecular interactions are only a click away. *The Stepping Stones to Molecular Literacy* builds a unique progression of understanding. Armed with this foundational understanding, students can take on more complex explorations, all the way to the Central Dogma, and further, to new discoveries in molecular biology.

**LINKS** *Progressions*

**The Stepping Stones to Molecular Literacy**
*http://molo.concord.org/database/browse/stepping-stones/*

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