imagene

Teacher's Manual

This game, containing 307 wooden pieces and four laminated tables, was created to help you to understand and to teach the biological mechanisms that are involved in protein synthesis, or in other words, in gene expression, starting from our genetic material and obeying a code that was created by nature over 3 billion years ago. The 307 wooden pieces are of different types, which are described in the following chart.

Chart 1. Description of the game components and their quantities.

Piece/items	Quantity
Table in A3 format	4
Rod/Stem (mRNA axis)	8
Round blue piece	50
Round red piece	50
Round yellow piece	50
Round green piece	50
Unpainted and numbered pieces: # 1, 3, 5, 6, 8, 11 to 18 and 20	4*
Unpainted and numbered pieces: # 2 and 9	10*
Unpainted and numbered piece: # 4	8*
Unpainted and numbered pieces: # 7, 10 and 19	5*

* how many copies of each piece type

Before starting to play, you must know what each piece of the game means. Let’s go!! The wooden piece in the figure below represents the **mRNA molecule** in eukaryotic cells. Notice that one of the extremities, at the left (round tip), represents the 5’ end of the mRNA, with its “cap” modification, and the extremity on the right (rectangular block) represents the “poli-A” tail that exists on the 3’ end of the mRNA.

Figure 1. Base of the information, wooden rod.

But, as you know, the mRNA molecule is composed of nucleotides, which are made of four **nitrogenous bases**: adenine, guanine, cytosine and uracil. That’s what the four colored pieces, shown below, represent. Let’s see who’s who: adenine (green), guanine (yellow), cytosine (blue) and uracil (red).

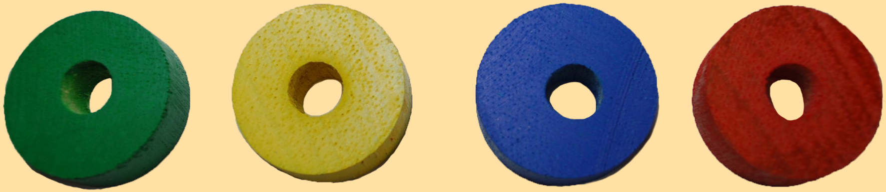


Figure 2. Units of the code.

Since one of the objectives of this resource is to work on protein synthesis, do you remember what proteins are made of? OK, so now you will meet the pieces that represent the **20 essential amino acids** that form the various kinds of proteins. Notice that every piece described below has a hole and a pin (for fitting together). Their numbers are carved into the wood.

1

Phenylalanine

2

Leucine

3

Isoleucine

4

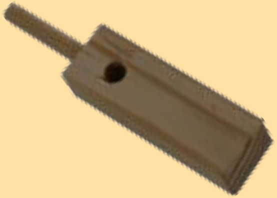
Methionine

5

Valine

6

Serine



7

Proline

8

Threonine

9

Alanine

10

Tyrosine

11

Histidine

12

Glutamine

13

Asparagine

14

Lysine

15

Aspartic Acid

16

Glutamic Acid

17

Cysteine

18

Tryptophan

19

Arginine

20

Glycine

But the amino acids don't bond randomly with each other to form a protein. Instead, the amino acid sequence that forms a protein is determined by what we call the "genetic code". Remember the mRNA? Starting from an initial codon* in the mRNA (a sequence of three nucleotides, which, in this game, are represented by the four colours corresponding to the four nitrogenous bases), an amino acid corresponding to each codon is added into the construction of a protein.

So, in order to assemble a protein, for every three nucleotides (starting from the round or 5'-end tip), the corresponding amino acid (unpainted wooden piece, with hole and pin) must be connected by its hole onto the previous amino acid's pin. The following table (Figure 3) contains all the sequences of three nucleotides (codons) with their corresponding amino acids, shown just beside them. Remember that different sequences can determine the same amino acid in the construction of a protein.

*Do you remember that the first amino acid to be added, as a rule, is a methionine? But with your students you can choose not to go into that level of detail and just use random sequences, even in this first codon, and work with the general principle behind protein construction.

DECIPHERING THE CODE

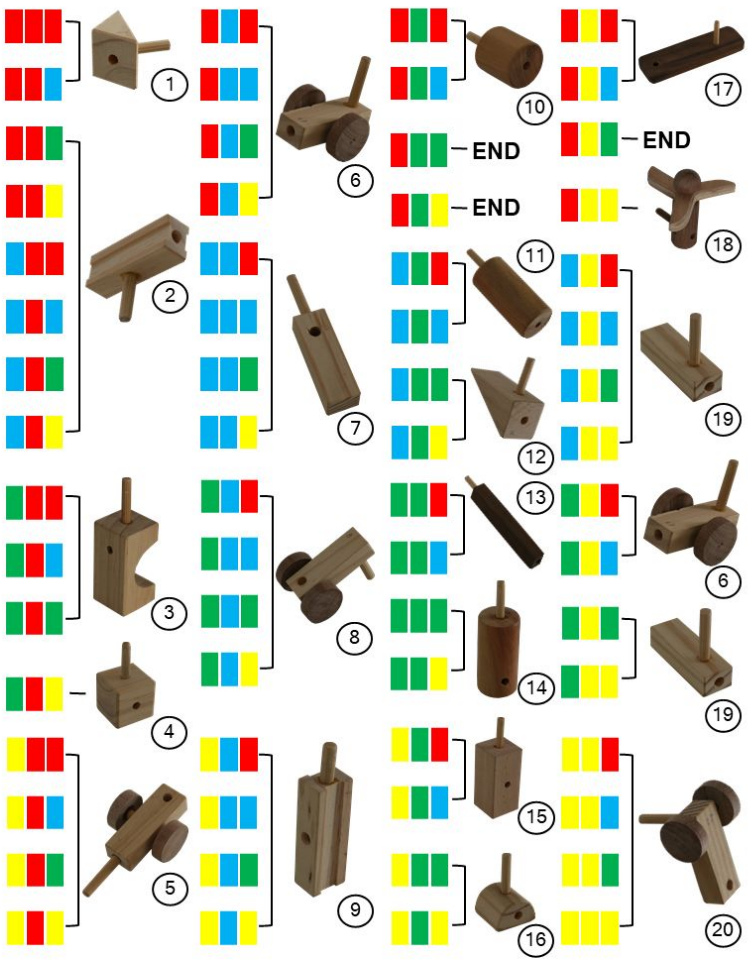


Figure 3. Combinations of colors representing the genetic code (nucleotide triplets or codons) that determine the amino acid to be incorporated into the construction of a protein.

Now that you already know all the pieces of the game and the genetic code, let's have fun!!

Before beginning to work with the game, see the observations below:

- Organize students in groups, preferably not too large. The size of the group will depend on the total number of participants, but we recommend at least two and a maximum of five people per group.

- **Important:** When assembling mRNA sequences, they may vary in size. You can fit a maximum of 30 nucleotides in the wooden rod. Remember that every coding sequence has at its end a triplet (codon) that doesn't determine an amino acid, but rather the end of the assembly of a given protein (see the sequences marked as END in figure 3).

Also remember that the initial sequence is located next to the round region of the rod (5′ end with a cap), and the final sequence is located next to the rectangular region (3′ end with a poli-A tail). When changing the order of the colored pieces, always detach the round piece from the rod, because the rectangular piece on the opposite end, representing the poli-A tail, is glued.

- **You have different options to work with:**

Option 1. Ask each group to assemble an mRNA sequence using the wooden rod (Figure 1) and the colored pieces of nitrogenous bases that represent the nucleotides (Figure 2), making sure that each group has received a rod and an X number of pieces of each color (for example, six pieces of each color per group).

Based on this mRNA, ask each group to assemble its corresponding sequence of amino acids using the unpainted pieces (shown on pages 5 and 6) and the genetic code in figure 3, which can be provided in the form of a laminated table that comes with the game. With this activity, smaller children will be able to understand the relationship between the color sequences and the pieces representing the 20 amino acids and hence will understand how codes work. In the case of older students who have been taught this content or who have the previous knowledge needed to learn it, they should be able to understand how proteins are made.

Important observation: In order to assemble the protein, the pieces that correspond to the amino acids must always be united by fitting the next piece's hole onto the pin of the previous piece, and never the other way around. For example, you should fit the hole of the second piece onto the pin of the first one.

Option 2. Exchange the mRNA sequence of a group for the mRNA sequence of another group, and then ask both groups to use the respective corresponding sequences of amino acids to assemble the protein. Proceed in the same way that was explained in Option 1.

What to discuss: Compare the proteins created by the different groups and note that they have different shapes. While comparing the different shapes, you can ask some questions to your students, for example: Did you know that the different proteins that we and other living beings have are like these objects, with different shapes and also products of a unique universal code? Why is that so? If there are objects with similar shapes, you can ask them if they could have the same function. These suggestions for discussion also apply to Option 1.

Option 3. This activity can be complementary to the one suggested in Option 1. Here, the ideal is to have an even number of groups in the classroom, so that groups 1 and 2 and groups 3 and 4 can interact with one another. In order to do that, ask each group to write down the color sequence that was used to assemble their protein.

Then, the proteins assembled in Option 1 must be exchanged between groups 1 and 2, groups 3 and 4 and so on. Each group must put together the color sequence that would have originated the protein they received, and must write down this sequence too. From the mRNA sequences that they've noted down, groups 1 and 2 (and the other groups that exchanged proteins) can compare their sequences and verify that both similar and unsimilar color sequences have been created from one same single protein.

What to discuss: Based on the different mRNA sequences that were deduced from one single protein, it's possible to discuss the degeneration or redundancy of the genetic code.

Option 4. Like in Option 3, this activity may also be a complement to the activity in Option 1, and it also involves interactions between pairs of groups. Ask the pairs of groups to put their colored sequences side by side and to compare the number of equal and of different pieces (for equal pieces attribute a value of 1 and for different pieces attribute a value of 0) at the same position. Then calculate the similarity percentage between sequences. For example:

0 1 0 0 1 0 0 0 1 0 1 0 0 0 1 0 0 1 0 0 0 0;

equal/different ratio would be 6/24 and the similarity would be of 25%.

What to discuss: At this moment, it's possible to relate the degree of similarity between the different colored sequences the degree of similarity that exists between related species or even between two individuals of the same species.

Option 5. Divide the students into four groups and give each group two previously assembled mRNA sequences, each of them corresponding to a different object (protein). Provide also a table of the genetic code (Figure 3). Notice that in order to assemble each object, there are two possible mRNA sequences (Figures 4 to 7). For example, give to group 1 an mRNA sequence that corresponds to the assembly of the train (mRNA1) and another sequence that corresponds to the hammer (mRNA3). Then give to group 2 the two other mRNA sequences that corresponds to these same two objects (mRNAs 2 and 4).

Proceed in the same way with the other groups when distributing the mRNAs that correspond to the assembly of the track and of the wind generator. Somewhere in the classroom where the students can have easy access to, like a table or a bench, randomly spread the uncolored pieces that correspond to the amino acids. After receiving their mRNA sequences and the genetic code table, the groups must assemble the corresponding objects. During the assembly, walk around among the groups to check if they're managing to make the intended final object. In order to do that, it's important that you know beforehand which objects/proteins each group is supposed to assemble. If they're doing it in the wrong way, don't stop them. Just tell them to pay close attention to what they're doing and ask them to discuss among themselves different assembly options that could generate more interesting and functional objects. If you feel that this procedure (of offering all the pieces together on a table) can produce too much mess in the classroom and take too much time, you can also previously prepare smaller sets of elements, containing only the necessary pieces to the corresponding objects that each group must assemble, and then distribute them to the groups along with the genetic code table in Figure 3 and the mRNA sequences, making the assembly process easier and faster.

What to discuss: After the groups finish assembling the objects that represent the proteins, start a discussion about the shapes and functions of the different objects.

Depending on the age and on the prior knowledge of the students, you can keep the discussion focused only on the properties of the different codes, or else you can stimulate them to provide possible explanations related to what they've learned in biology. You can stimulate the students to propose analogies between the shapes of the toys and the role played by real proteins, discussing how the shape of a protein (and hence its originating mRNA) is important for the role it plays in the cell. The intended final objects are: the **train** (Figure 4), which could represent a transport protein, like hemoglobin; the **hammer** (Figure 5), which could represent a breaking-down enzyme, like pepsin; the **track** (Figure 6), which could represent the proteins that make up the microtubules; the **wind generator** (Figure 7), which could represent a protein that generates energy, like ATP synthase. If your students show interest in the fact that all toys have one piece at their initial extremity that have no apparent function (the cube shaped piece), you can mention that in real proteins, that piece could represent the methionine, which is always the first amino acid to be incorporated into the the protein, but which is often removed after the end of the protein synthesis.

Now see the objects with their respective coding sequences!!

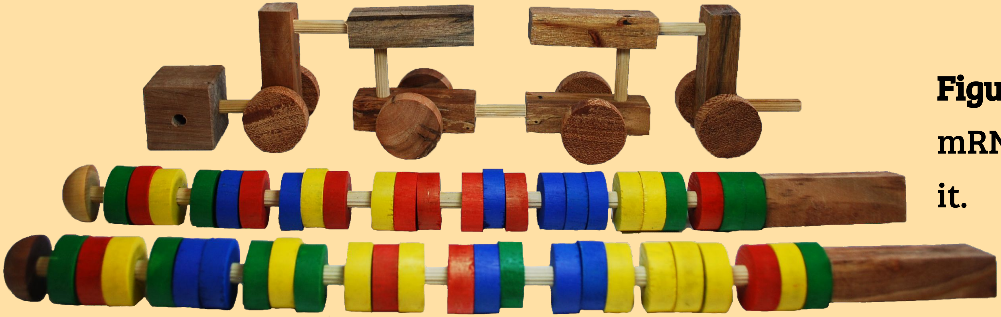


Figure 4. The "train" and two mRNA sequences that code for it.

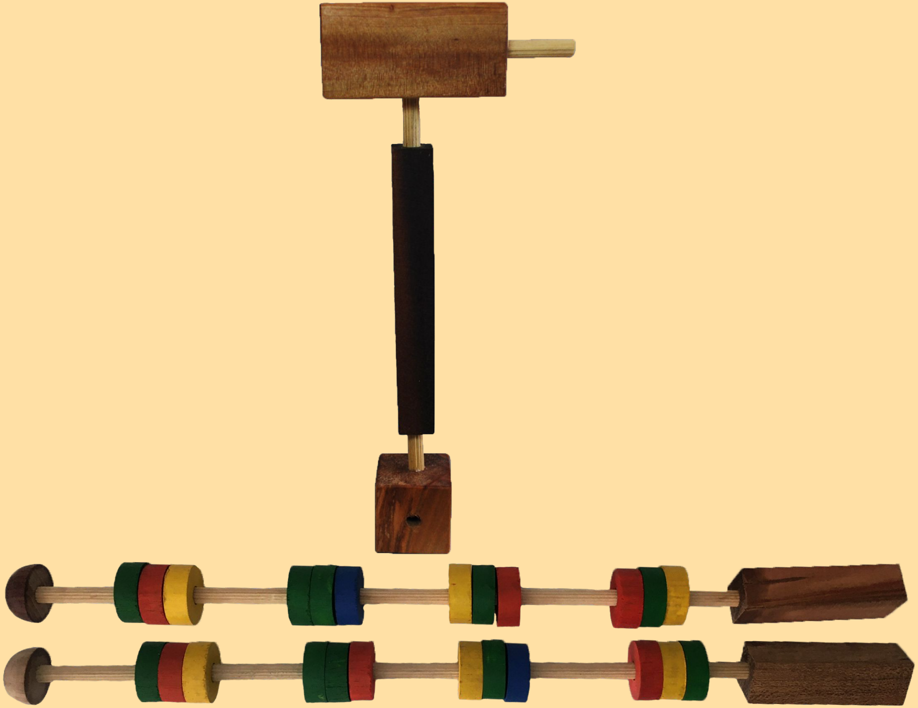


Figure 5. The "hammer" and two mRNA sequences that code for it.

Figure 6. The "track" and two mRNA sequences that code for it.

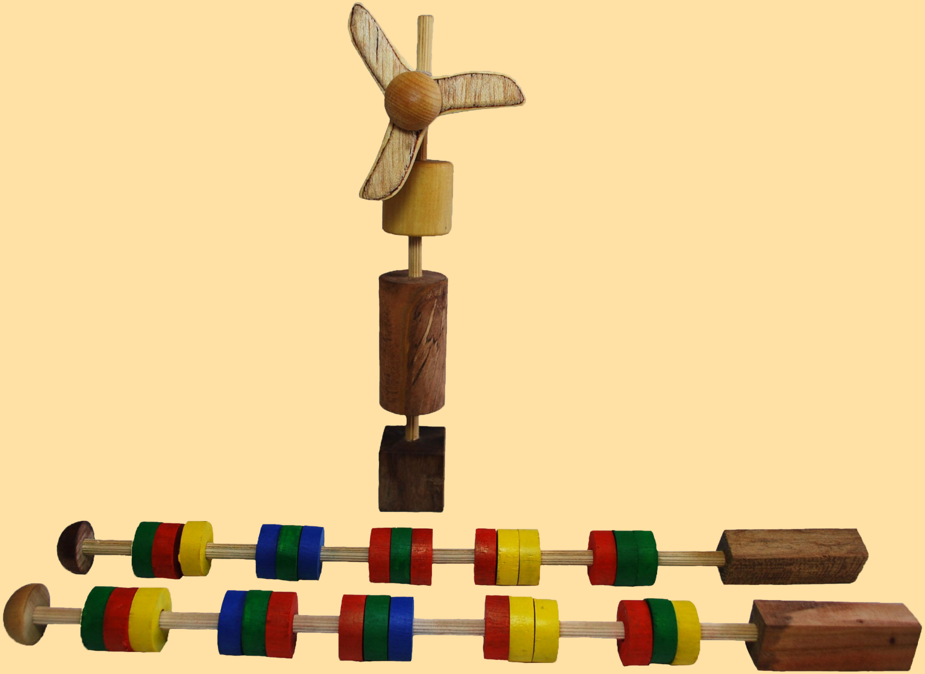


Figure 7. The "wind generator" and two mRNA sequences that code for it.

Option 6. Introduce mutations in codons that will lead to the substitution of amino acids in the protein (for example: a codon with the sequence blue, red and red determines the a piece that represents the amino acid leucine. Changing the blue piece for a green one, so that the codon becomes green, red and red, which determines the amino acid isoleucine in the same position where there previously was a leucine).

What to discuss: discuss with the students that, depending on the type of substitution (that is, which nitrogenous base has been changed) and where it happened, will determine the region of the protein where the alteration occurs, thus either impairing or not its function. You can even provoke the participants to imagine if it would be possible to improve the functioning of a particular object through the introduction of a mutation.

Option 7: Introduce mutations in codons that do not alter the amino acid to be incorporated into the protein. For example, a sequence that's green, blue and red determines the amino acid threonine; substitute it for a green, blue and blue, which also codes for the same amino acid in this same position.

What to discuss: Explain to your students that some mutations that happen in the DNA, specially those on the third position of the codon, don't imply an alteration in the amino acid that will be incorporated. These mutations are called "silent" or "synonymous" mutations. Here you can also discuss the redundancy of genetic code.

Option 8. You can now compare all of the mRNA sequences and/or the proteins assembled by the different groups in Option 1, for example, using photos taken with a mobile phone, and discuss the similarities and differences between the mRNA sequences and the proteins.

What to discuss: Could the proteins that are more similar to each other have the same function? Using the same approach used in Option 4, it's also possible to discuss phylogenetic issues, as for example: do more closely related organisms tend to have more similar proteins? If so, why?

Dear teacher, if you have any further suggestion on how to use this game, the Imagine Project will be very happy to hear you. We are always searching for new and attractive ways of instigating curiosity and making the learning process something more interactive and less abstract. Get in touch with us, make your suggestion and, who knows, you may see your idea being incorporated into the next version of this manual, which is available for free on the internet in the form of an Open Educational Resource.

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If you'd like to see more tips about the game Ima-gene, access Imagine Project's website (https://projetoimagine.ufsc.br/en/). There, the game's manual is available for free as an Open Educational Resource. But if you'd like to purchase an original set of the game from its own manufacturer, who participated in its conception, get in touch with Oficina do Aprendiz (https://oficinadoaprendiz.com.br/).

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