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Tips & Tools

Teaching the Central Dogma of Molecular Biology using Jewelry †

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INTRODUCTION

The central dogma of molecular biology, which describes the transfer of information from DNA to RNA to peptide, is a key concept in biology. All fields of biology, and especially microbiology, have undergone a molecular revolution and now rely on DNA-based techniques in research. These techniques exploit the information-carrying capacity of DNA, and are used to study form and function of all types of organisms. All students should understand the core concepts of the structure and function of DNA and the molecular basis of heredity—content that is currently listed in the National Science Education Standards (NSES) (2) for levels 5–8 and 9–12.

"Cracking the Code" is an activity developed to demonstrate the processes of transcription and translation. (See Appendix 1 for teacher instructions and student handouts.) This hands-on activity helps students understand the relationship between form (base pairing) and function (information storage and transfer) of nucleic acids. In this activity, students go through the processes of transcription and translation of a DNA molecule to create jewelry; a beaded bracelet or necklace is used as a tactile representation of a chain of amino acids. To determine the correct order of "amino acid" beads, students must first decode a strand of DNA using complementary base pairing rules. The decoding is a two-step process that illustrates transcription (the copying of DNA to RNA) and translation (using tRNAs to match the genetic code to the correct amino acid). This teaches the relationship between structure (base pairs) and function (information storage and transfer) in nucleic acids.

This activity is suitable for students in grades 5 to 10. As an extension, this activity can be used as a platform to illustrate genetic mutations and their effects. This activity conforms to NSES Life Sciences content standards, outlined in Table 1.

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†Supplementary materials available at http://jmbe.asm.org

PROCEDURE

An analogy for teaching the central dogma of molecular biology

Prior to starting the activity, it is important that the students are given a description of the central dogma. An analogy that works particularly well to illustrate the concepts is the chef analogy. This metaphor, used by *Nova ScienceNow* to describe the action of RNAi (1), describes the genome as a recipe book locked in a high tower (nucleus). It has all the information for creating a delicious meal, but unfortunately is locked up—it can't be taken in or out. Fortunately, there's a tower scribe (= RNA polymerase) that can read the book, and make copies of the recipes (= messenger RNA). These copies can leave the tower, and are picked up by the little chefs below (= ribosomes). These chefs can then read the recipes (= mRNA), and use raw ingredients (= amino acids) to create a meal (= peptides and proteins). You can find an animation of this metaphor here: http://www.pbs.org/wgbh/nova/body/rnai-explained.html.

This recipe book analogy can also be extended to describe the organization of DNA. We can think of the genome as a book and all the letters in the book are individual nucleotides. These nucleotides are organized into codons (= words), genes (= paragraphs or recipes), and chromosomes (= chapters).

Another extension is to use the recipe book analogy to describe cell differentiation and gene regulation. All the cells in an organism have the same genome (= recipe book), but it is through turning on and off different genes (= recipes) that we get different cells doing different jobs.

As an analogy, the set of recipes you would use to prepare a Thanksgiving meal will be very different from the recipes you would use for a 4th of July summer barbeque. All the recipes (= genes) are present in the same book (= genome or genotype), but by using different subsets we get different meals (= phenotypes).

Activity

Step-by-step instructions are provided in the Supplemental Materials. Materials needed for this activity are minimal; the main items are 20 different colors or styles of beads representing 20 amino acids and a cord to string

TABLE 1.
National Science Education Standards addressed through this activity.

NSES Standard C	NSES Concepts	"Cracking the Code" Concepts
Life Science (5-8): Structure and function in living systems	"Living systems at all levels of organization demonstrate the complementary nature of structure and function."	DNA is an information molecule; structure of DNA; bases and base pairing.
Life Science (5-8): Reproduction and heredity	"Hereditary information is contained in genes… each gene carries a single unit of information."	The information in DNA is organized as genes; Genes can be copied; A single gene is translated into a single protein product.
Life Science (9-12): The cell	1. "Cells have particular structures that underlie their functions…[including] the storage of genetic material." 2. "Most cell functions involve chemical reactions." 3. "Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires."	1. Genetic material (DNA) is in every cell, and has all the information needed to make that cell or organism. 2. RNA polymerase and ribosomes are enzymes that catalyze the polymerization of RNA and peptides, respectively. 3. Central dogma of molecular biology: DNA is transcribed to RNA then translated to protein.
Life Science (9-12): Molecular basis of heredity	1. "In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA… The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded … and replicated." 2. "Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms."	1. DNA is an information molecule; structure of DNA; bases and base pairing; replication mechanisms. 2. This activity can be used to show the effects of DNA or RNA mutations on the resulting peptides. Silent, missense, and nonsense mutations can be demonstrated and discussed.

them on. The other materials are available electronically in the supplemental information and can be printed and cut out. The instructor prepares strips of DNA code and blank RNA strands. Students begin the activity by acting as an RNA polymerase: they decode a strand of DNA using complementary base pairing rules writing down complimentary bases on the RNA strand (Fig. 1(A)). Once the RNA strand is complete, the students then act as ribosomes: they use the tRNA playing cards to identify which amino acids are coded by each codon (Fig. 1(B)). Once students correctly match a tRNA card to a codon, that card will indicate which amino acid bead to add to their bracelet (Fig. 1(C)).

Tips

- In the Supplementary Material, there are DNA sequences for human lactase and keratin, two common proteins. However, consider using a different DNA code, perhaps for something that you discussed in class, so it is relevant to the students.
- Have the students work in groups to do the decoding, but have them each make their own bracelet. This speeds up the search for the correct tRNA and they can work together to check their work for errors.
- If time is an issue, presort the tRNA cards according to the first letter to speed up searching.

Extension

For older students (grades 9–12), this activity is a valuable platform for illustrating the effects of genetic mutations. Bases can be altered in the DNA or RNA to show what happens to the resulting peptide sequence. Use this to explain mutations that are silent (have no effect on amino acid sequence), missense (resulting in a change in amino acid), and nonsense (resulting in a premature stop codon and truncated peptide).

CONCLUSION

This activity has been presented to several middle school groups, approximately 80 students total. Reactions were largely positive: the students liked the problem-solving

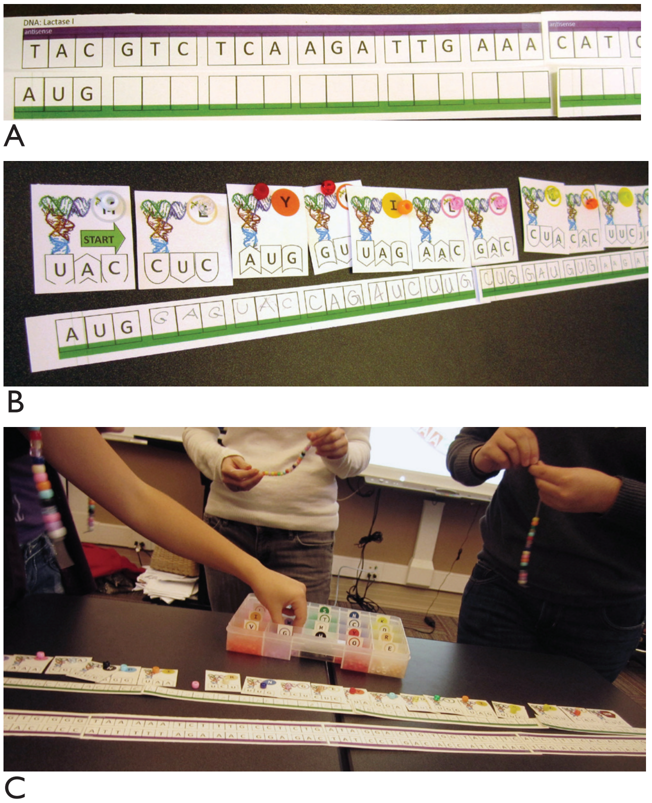

FIGURE 1. Students string "amino acid" beads to make "protein" bracelets: (A) DNA code (purple backbone) is transcribed into mRNA (green) using base pairing rules; (B) RNA is translated to amino acids using tRNA playing cards; (C) the correct amino acids, as determined by the tRNA cards, are strung together to make a bracelet.

approach and the hands-on nature of the activity. They enjoyed being able to take home their bracelets. Feedback from educators has also been positive: several commented how easy it would be to implement this in the classroom. One teacher commented that the tactile nature of the activity would work well in an inclusion classroom.

In summary, this hands-on activity is relatively simple to implement and effective in illustrating the concepts of transcription and translation.

SUPPLEMENTAL MATERIALS

Appendix 1: "Cracking the Code" Teacher Instructions and Student Handouts

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