

An Activity to Demonstrate the Genetic Code, Gene Duplication, and Divergence

By *Nora Egan Demers*

Gene expression is a central tenant that is taught in introductory biology courses. Many students seem to confuse the connection between transcription and translation and are unaware of the wobble and redundancy of the genetic code. Furthermore, evolution is elegantly demonstrated by gene duplication and divergence. This activity provides a way for students to practice using the genetic code and, as a result, to realize the redundancy of the genetic code by practicing “reverse translation” and understand why it’s physiologically impossible. Evolution by gene duplication and divergence is demonstrated with very short peptide sequences that have a great deal of homology, yet have diverged in their function.

The role of an educator is changing from one who is the purveyor of knowledge and information to one who is a facilitator of students gaining and interpreting knowledge while awash in a sea of information. Online resources have changed the way that we obtain information and learn about our world. I encourage students to learn how to use the internet to acquire biological information and better understand the process of science by looking for competing and corroborating information. In this activity, students are encouraged to use the internet to find information, and Wikipedia is often the first return on a search of the terms. Although the

use of Wikipedia is not recommended as the sole source of information, it is relatively reliable as an encyclopedia for basic scientific information (Giles 2005) and is a readily accessible resource.

Questions this activity helps students to answer

- How does the genetic code provide instructions for a protein?
- What is redundant about the genetic code?
- What does the “wobble” in the genetic code refer to?
- What does gene duplication mean?
- What does gene divergence mean?
- What are some examples of gene duplication and divergence in humans?
- What are the differences in function brought about by slight changes in the primary structure of proteins?

Preparation

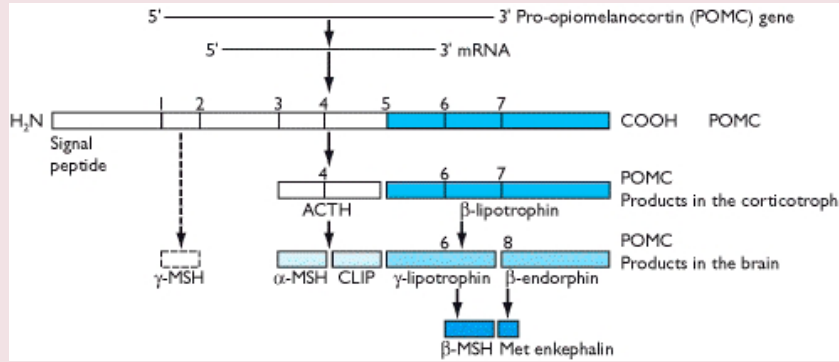
The instructor may want to introduce or reinforce this active-learning strategy with concepts presented through lecture before or after this activity; be familiar with the genetic code, including the redundancy and wobble aspects; and do some background reading on pro-opiomelanocortin (POMC; see Figure 1), a precursor polypeptide with 241 amino acid residues, and its derivatives that

include alpha-, beta-, and gamma-melanocyte stimulating hormone (MSH). The melanocyte stimulating hormones play roles in appetite and immunity.

Gene duplication is believed to play an important role in evolution. The duplicated gene does not have the same selective pressures to maintain its structure and can diverge (mutate) from its original structure and function. This divergence may provide a selective advantage to an organism. This is elegantly visible by examining the POMC genes and gene products. POMC is located on chromosome 2 in humans. The preprotein POMC is differentially cleaved in a variety of tissues, including the pituitary, hypothalamus, placenta, and epithelium. There are up to 10 different biologically active peptides produced. The polypeptides play roles in pain, immunity, and appetite. In some organisms, the entire POMC gene has been duplicated and a variety of divergent proteins and expression have resulted.

Alpha-melanocyte stimulating hormone (α -MSH) stimulates synthesis and distribution of melanin (a pigment that darkens skin) in melanocytes. It also has anti-inflammatory effects in all animal models tested, with specific receptors on neutrophils (Catania et al. 1996).

Beta-MSH (β -MSH) is present in hypothalamic nuclei that regulate feeding, and its concentrations

FIGURE 1**Pro-opiomelanocortin and its cleavage products (Nussey and Whitehead 2001). Reprinted with permission.**

- β-melanocyte stimulating hormone (asp-glu-gly-pro-tyr-lys-met-glu-his-phe-arg-trp-gly-ser-pro-pro-lys-asp)
- gamma-melanocyte stimulating hormone (tyr-val-met-gly-his-phe-arg-trp-asp-arg-phe)

Class discussion and debriefing

When each student or group of students has sufficiently worked through the worksheet (this activity will probably take 15–45 minutes to complete successfully), debrief the entire class on the activity and highlight the important concepts that were demonstrated. First, discuss how the genetic code is redundant (i.e., there is more than one codon that codes for most amino acids). The wobble in the third base of the codon is clearly shown as students

alter with nutritional state. Harrold, Widdowson, and Williams (2003) suggested that “β-MSH rather than α-MSH is the key ligand that regulates feeding, and that inhibition of tonic release of β-MSH is one mechanism contributing to hunger in under-feeding” (p. 397). It is an 18-amino-acid polypeptide that has also been shown to regulate skin pigmentation and steroid production. Gamma-MSH (γ-MSH) stimulates adrenal steroidogenesis and has a regulatory role in the cardiovascular and the renal systems (National Library of Medicine 2009).

Materials**Students**

Each student or team of students will need the following materials:

- pencil or pen
- textbook containing the genetic code
- access to the internet

Instructors

Instructors should prepare worksheets for each of three small polypeptides (α-MSH, β-MSH, and γ-MSH). A model for one worksheet

is provided in Figure 2. Each worksheet will contain one of the following sequences:

- α-melanocyte stimulating hormone (ser-tyr-ser-met-glu-his-phe-arg-trp-gly-lys-pro-val)

FIGURE 2**Worksheet provided to students.****Genetic code, gene expression, duplication, and divergence**

For this exercise, each of you will be given one of three different worksheets containing an amino acid sequence of a very short protein. Answer each question to the best of your ability.

Questions

Below is the amino acid sequence for β-melanocyte stimulating hormone:

Asp-glu-gly-pro-tyr-lys-met-glu-his-phe-arg-trp-gly-ser-pro-pro-lys-asp

1. Use this sequence to determine a potential mRNA sequence that it could have been translated from.
2. Now, check the mRNA sequence that you proposed with that of someone who has the same protein. Are they identical (redundancy)? In what location (which base of the codon) is there most often a difference (wobble)?
3. Use your mRNA sequence to show the DNA sequence that it was transcribed from. What is the term for this (reverse transcription)?
4. Look online to find out about this peptide—its function and other related proteins. It has roles in appetite and immunity.
5. Compare your protein’s primary sequence to that of α-melanocyte stimulating hormone and γ-melanocyte stimulating hormone.
6. Structurally, how similar are the sequences to each other? Functionally, what are the similarities and differences between these polypeptides?
7. Use this information to explain what is meant by gene duplication and divergence.

FAVORITE DEMONSTRATION

compare their different potential mRNA sequences with each other. You should next align the amino acid sequences of the melanocyte-stimulating hormones together to show how they are similar in the majority of their primary protein structure. Then have students provide the information they learned about POMC as a preprotein and discuss the varying roles of these polypeptides. Help them develop the concepts of gene duplication and divergence and their role in evolution.

Method of evaluation

Students could provide the worksheet they complete during the activity in their portfolio or as a home-

work assignment that can be turned in for grading. Alternatively, this activity can simply be integrated into a lecture on gene expression, and assessment would consist of testing for comprehension and ability to use the genetic code and ability to articulate what is meant by gene duplication and divergence. ■

References

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