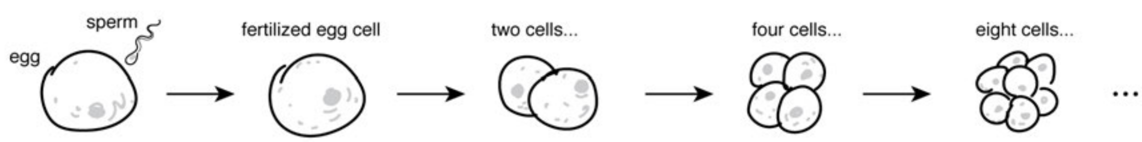
Teacher Tune-up

Quick Content Refresher for Busy Professionals

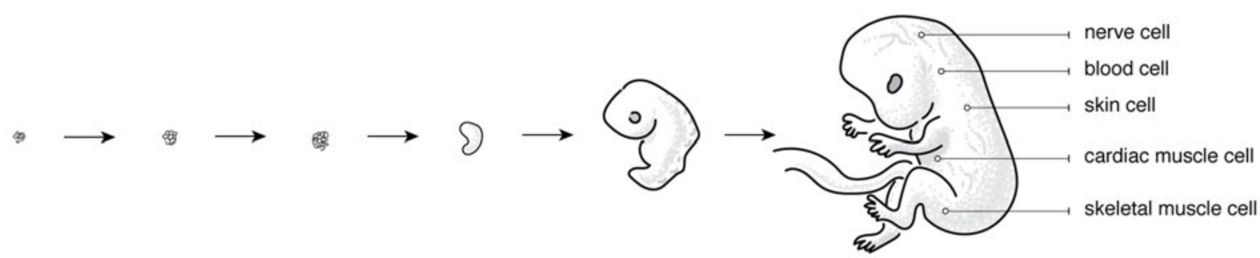
How do cells with the same DNA become different?

There are about 200 kinds of cells in the human body, all exhibiting different structures and behaviors. And yet these cells all have exactly the same DNA. How does this variety of form and function arise from such genetic sameness? If DNA is like an instruction manual that cells follow, so that they know what to be and do, then how can cells with the same instruction manual end up being and doing different things?

Here's a lightning-fast review of every human individual's genetic origin story: the DNA in every cell of one's body is a copy of the complete set assembled when a sperm fertilizes an egg. Those sex cells are exceptions to the rule: through a special kind of cell division called meiosis, sex cells wind up with uniquely shuffled chromosomes, and they have only a half set each, enabling them to compose a complete set when combined. From that point on (except when it's time for the new individual to produce some new sex cells), cell division consists of mitosis: division that produces genetically identical cells.



Divide, divide, divide… copy, copy, copy… Each cell is a genetic clone of the original fertilized egg (called a zygote). But eventually…

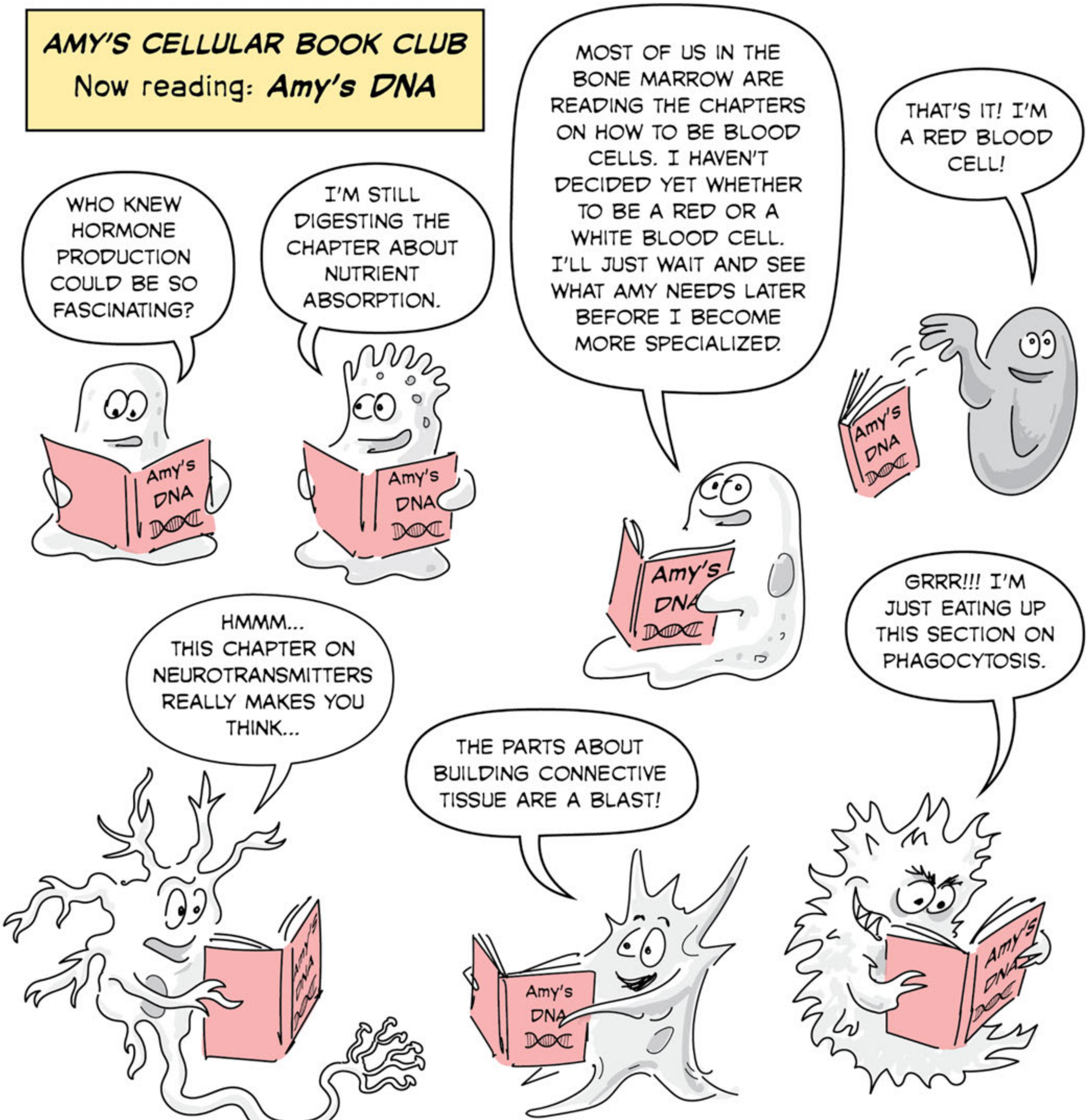


Many different kinds of cells differentiate as the embryo develops. All with the same DNA.

The trick here is genetic *expression.* A cell does not just put all of its DNA into play at once, like some mad pianist running their fingers up and down the entire length of a keyboard. Instead, a cell plays different tunes depending on the chemical signals it receives. It selects certain appropriate sections of DNA—certain genes—depending on circumstances.

Initially, the circumstances of a few identical cells derived from a dividing zygote are pretty darn similar. But soon, they begin having slightly different experiences. For example, cells at the center of the clump and cells on its periphery are exposed to different concentrations of chemical signals from their neighbors, and from their environment. A few small differences like this lead to some initial differentiation in gene expression, and quickly the differences start to cascade. Primitive structures emerge: the clump becomes a hollow ball with a wall of epithelial cells; that ball develops into a form with some basic structural orientation (top and bottom, front and back) and three distinct layers of tissue (ectoderm, mesoderm, and endoderm) that will give rise to increasingly diverse cell lineages. Every distinction provides more opportunities for different cells to receive different signals, and differentiation feeds on itself, generating ever more astonishing multicellular variety and organization.

All the cells in this evermore complex, decentralized, cooperative multicellular community are reading from the same DNA book of instructions. But they are reading different chapters, and they change their bookmarks from time to time as their nuclei receive signals from their own intracellular soup, from their fellow cells near and far in the body, or from the environment outside the body. By reading and acting on specially selected sections of their DNA, cells develop different structures and do different jobs.



What about stem cells?

Cells that have not yet specialized are called stem cells. When the body needs to repair itself or grow, stem cells can become specialists. In general, once a stem cell specializes, it (and any cells that come from it) cannot go backwards and become less specialized again. There are degrees of specialization, and adult stem cells are generally more professionally committed, so to speak, than embryonic stem cells; they've been to college, but not yet graduate school, and have an intermediate level of flexibility about their ultimate career. Cell specialization is pretty much a one-way street. So until they get a signal that they need to specialize, stem cells just wait quietly, or else divide to produce extra stem cells for later.

Do red blood cells lack DNA?

Red blood cells in humans and other mammals are unusual in that they do not have a nucleus. The stem cells they come from have nuclei, but when the stem cells change to red blood cells, they get rid of their nuclei to make room for more hemoglobin (the chemical that allows red blood cells to carry oxygen from the lungs to the rest of the body). Without a nucleus full of DNA instructions, red blood cells cannot reproduce themselves by dividing. As they wear out, they must be replaced from stem cells. This replacement is happening all the time: every second, about two million of your red blood cells die, and another two million red blood cells are produced from stem cells to replace them!