SUBMITTING ILLUMINATIONS FOR REVIEW

As educators, we are continually designing new methods and procedures to enhance learning. During this process, good ideas are frequently generated and tested, but the extent of such activities may not be adequate for a full manuscript. Nonetheless, the ideas may be quite beneficial in improving the teaching and learning of physiology. *Illuminations* is a column designed to facilitate the sharing of these ideas (illuminations). The format of submissions is quite simple: a succinct description of about one or two double-spaced pages (less title and authorship) of something you have used for the classroom, teaching, lab, conference room, etc. You may include one or two simple figures or references. Submit ideas for inclusion in *Illuminations* directly to the Associate Editor in charge, Stephen DiCarlo (sdicarlo@med.wayne.edu).

ANALOGY FOR EXPLAINING INTERMEDIATE METABOLISM

This Illumination describes an analogy for explaining intermediate metabolism by comparing glucose with the monthly paycheck. Intermediate metabolism is depicted in Fig. 1A and its analogy in Fig. 1B. The body’s major energy source is carbohydrates. Glucose (Fig. 1A) is the most important monosaccharide. Similarly, the major income for most people is a monthly paycheck (Fig. 1B). Glucose can be used in several different ways, but it must first be converted to acetyl-CoA, the most important intermediate metabolite.

Acetyl-CoA is the key molecule that allows an interchange between several biochemical pathways. In a similar way, a paycheck can be used in several ways, but it must be converted to currency, the key “metabolite” in our economy. Acetyl-CoA can enter the tricarboxylic acid (Krebs) cycle, generating NADH and FADH, which are used in oxidative phosphorylation to form ATP. Thus, to make energy, glucose is transformed into acetyl-CoA and traded for ATP. Similarly, a paycheck is transformed into currency, which “enters” into the shopping center and is ultimately traded for goods.

Because the body requires a minimum blood glucose concentration, we have developed ways to store excess glucose for future use. The first line of storage is glycogen production in the liver and muscle cells. After a meal, the excess glucose is stored as glycogen, to be released in the following hours. Similarly, most people receive their paychecks once a month but will need to store the money for use during the month. Depositing the paycheck into a bank account keeps the money safe and allows unrestricted access to it at any time (ATM machines). When glycogen is consumed, the other pathways must be activated to prevent a decrease in blood glucose concentration. In the same way, when money in the bank is reduced, people will activate other means to maintain currency in their wallet.

When food consumption is consistently higher than required, glycogen stores are saturated, and glucose is then stored as fat. For this purpose, acetyl-CoA is converted into fat for storage. When necessary, fat may release fatty acids that are oxidized to form acetyl-CoA by the β-oxidation pathway. In the analogy, when people have excess money, long-term savings is in order. This is a way to keep money safe for a long time; however, it is also more difficult to access it. An example is investments such a buying gold. When people gain weight, it is because food consumption is greater than energy expenditure, just as when people save money, it is because their income is greater than their expenses. To lose weight, the individual must decrease consumption (diet), increase expenditure (exercise), or both, just as the reduction in savings can be due to a decreased income, increased expenses, or both.

Note that, in Fig. 1A, another possibility for acetyl-CoA is to be converted into ketone bodies that might be released into the circulation to be used by other tissues for energy (especially by heart and kidney). Simi-
larly, we can purchase money orders to send currency to friends and family. Ethanol is another source of energy. During the metabolism of ethanol, NADH is accumulated and used to produce ATP. For every ethanol molecule that is metabolized, one glucose molecule is no longer necessary and thus will be stored. In the analogy, ethanol represents food stamps that are good only to purchase food. Sometimes, in addition to a paycheck, people receive food stamps. Although food stamps cannot be converted to currency, every time a stamp is used to buy food there is currency that is not spent and thus will be stored.

Finally, if it is necessary, proteins can be degraded to amino acid residues that are converted to acetyl-CoA, which in turn can be used to produce energy or glucose (gluconeogenesis). This is, however, not a good idea for the body (catabolism). In the analogy, proteins represent a house or business, the most solid way to store money for a long time. If some day your income is seriously reduced, selling your home or business will produce the money that is needed for living. As with proteins, however, on the long-term basis this is not a good idea.

Students enjoy this analogy, which produces a clear picture of intermediate metabolism. I found this analogy also useful for the general public to assist them in understanding the mechanisms by which people gain or lose weight and how different diets work.

GERARDO GAMBA  
Molecular Physiology Unit  
Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán  
Instituto de Investigaciones Biomédicas Universidad Nacional Autónoma de México  
Talpan 14000, Mexico City, Mexico  
E-mail: gamba@sni.conacyt.mx  
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RAPPING TO REVIEW: A NOVEL STRATEGY TO ENGAGE STUDENTS AND SUMMARIZE COURSE MATERIAL

Recent studies indicate that hip-hop can successfully be used as a tool in the K-6 classroom to improve literacy skills (1, 7). Although hip-hop is in its infancy, some educators are
using it as a mnemonic device to help students with math and history facts (8). The use of music as a way to stimulate and teach new material is based on the work of Howard Gardner, an educational psychologist best known for his theory of multiple intelligences (2). Gardner stresses the use of nontraditional teaching techniques to account for different learning styles (3). In fact, some science educators have used music to teach traditional lessons, such as biological classification (6). Furthermore, teachers may focus on a more specific area to provide greater depth and detail of the subject matter.

**Phys Is Supernatural**

TURN THIS UP A LITTLE LOUDER NOW
TURN THIS UP A LITTLE LOUDER NOW
TURN IT UP

LADIES AND GENTS YOU'RE TUNED TO THE SOUND OF A AND P 2
WHERE THE KIDNEYS AT?
WHERE THE LUNGS AT?

HERE IN PHYSIOLOGY NOTHING'S CHANGED
HOMEOSTASI S IS THE NAME OF THE GAME
FLUCTUATIONS THAT ARE OUT OF THE RANGE
ARE SENSED TO PREVENT DANGER
SITUATIONS THAT WOULD MAKE YOUR HEART
STOP
WOUL D MAKE ALL THE SYMPATHETIC NEURONS
START
FIRING TO SYNAPSES ON EVERY PART
WHERE RECEPTORS ARE FOR
Epi, ACh, AND NE
PUPILS DILATE, HELPS YOUR SEEN'
PRESSURE'S DROPPING, CO'S STOPPIN'
GOTTA GET THAT BLOOD FLOW HOPPIN'
BLOOD CELLS-WHITE, T CELLS FIGHT
WHAT HAPPENS DURING FIGHT OR FLIGHT?
THE SPLEEN IS SLY
AND RED CELLS DIE
AND LYSOZYMES COME OUT WHEN YOU CRY
OH, BP, BP, BP
NEGATIVE FEEDBACK
NO MATTER WHAT IT IS
BARORECEPTORS KEEP TRACK
WHEN IT'S GOING TOO HIGH
THE FIRING IS LOW
OH, DON'T WORRY ARTERY
NO ANEURYSM FOR YOU!
AND EACH MOMENT IN TIME
YOUR STOMACH KEEPS TRACK
OF THE LEVEL OF CHYME.
I AIN'T TOO MUCH OF A DORK TO SEE
THERE'S AMAZING STUFF TO LEARN IN PHYSIOLOGY.

WITH HOMEOSTASI S AIN'T NOTHING CHANGED
NEURONS KEEP FIRING UP TO YOUR BRAIN
KEEPING TABS ON YOUR PLEASURE AND PAIN
UNTIL THE SIGNALS START TO WANE
HYPOTHALAMUS SENDING SIGNALS
TO THE PITUITARY
CRH, TRH MAKIN' THYRO
THE ENDOCRINE SHOW WITH HORMONES—BUT THEY'RE SLOW!

POLYS STREAM IN, PHAGOCYTES CLEANIN'
WHITE CELLS COMING, YOU KEEP DREAMING
FEVER'S PASSING
FOOD'S MY PASSION
SINCE THOSE BAD BUGS GOT A BASHIN'
GORGE TONIGHT, TOO MUCH FAT, TOO MUCH
CARBS, TOO MUCH RICE.
MY GUT NOW HAS HCl, TOO HIGH
REVERSE PERISTALSIS, OUT IT FLIES!

VC, VC, VC
KEEP YOUR BREATHING ON TRACK
IF THE CO2'S HIGH
CHEMORECEPTORS BRING IT BACK
IF THE PH IS UP
THEN THE BREATHING IS LOW
OH, DON'T WORRY KIDNEYS
WE DIDN'T FORGET YOU!
CAUSE IF THE PH'S NOT FINE,
ACIDS IN THE URINE
ARE GONNA LEAVE ME BEHIND.
I AIN'T TOO MUCH OF A NERD TO SAY
PHYSIOLOGY IS FUN IN LOTS OF WAYS
WHERE THE KIDNEYS AT?
WHERE THE LUNGS AT?

HEY, B CELLS
MAKE THE BACTERIA DIE
JUST KNOW IN THE BODY
HOMEOSTASI S WANTS TO PREVAIL

BRAIN, GUT, FRONT AND DORSAL SIDE
PHYSIOLOGY IS SYSTEM-WIDE
HEART, LUNGS, HEAD, AND VENTRAL SIDE
HOMEOSTASI S LETS YOU MAKE IT FOR THE LONG RIDE

CAPILLARIES WOULD YOU EXCHANGE
EXCHANGE SOME OXYGEN FOR ME

Below are revised lyrics to Carlos Santana song “Since Supernatural” (4) as my template.

Few science educators incorporate music in their lessons. I was inspired by Professor Helen Davies, a University of Pennsylvania microbiology professor, who uses song to teach about infectious disease (5). Although she uses popular tunes such as Simon and Garfunkel’s “Sound of Silence” and the Beatles’ “Yesterday,” her tuneful teaching style has won her many awards, including the National Golden Apple for Teaching Excellence.

I L L U M I N A T I O N S
BRAIN, GUT, FRONT AND DORSAL SIDE
PHYSIOLOGY IS SYSTEM-WIDE
HEART, LUNGS, HEAD, AND VENTRAL SIDE
ARRANGED BY M. KNABB

MAUREEN KNABB
Department of Biology
West Chester University
West Chester PA 19383
E-mail: mknabb@wcupa.edu
10.1152/advan.00014.2003

This simplified model interprets the pacemaker potential as a hyperpolarization wave that is not able to reach the hypothetical resting membrane potential (calculated to be about \(-14 \text{ mV}\)), because the triggering potential of calcium/sodium channels \((-40 \text{ mV})\) initiates the next cycle. The continuous cycle of electrical activity in SA cells would then consist of four stages: depolarization (opening of calcium/sodium channels), repolarization with hyperpolarization (opening of several types of potassium channels), hyperpolarization recovery (cessation of potassium permeability), and triggering of depolarization without ever reaching the resting membrane potential. Although this is an oversimplified interpretation of SA potential generation, students who can understand and discuss it are better able to interpret resting and action membrane potentials.

The following text is given to medical students as reading material for discussion that is usually scheduled for the following week. The students can use their textbooks (1, 3) or other references (2, 4). In simplified characteristics of SA cells below, students are asked to calculate the hypothetical resting potential for the SA cells based on a Na/K permeability ratio of 0.58:1.00 and the following ion concentrations: extracellular Na\(^+\) = 142 meq/l and K\(^+\) = 142 meq/l (4).

Answer

\[
\text{EMF} = -61 \log(140 + (0.58 \times 14))/[4 + (0.58 \times 142)] = -14.3 \text{ mV}
\]

where EMF is electromotive force.

They are also expected to draw a graph similar to Fig. 1.

**Text for Study by Students**

A simplified interpretation of the SA potential generation. Please refer to your textbooks and other sources.

**Simple facts about membrane potentials.**

1) More permeable membranes have better defined membrane potentials that are less variable than potentials of less permeable membranes. The high permeability seems to anchor the membrane potential near the Nernst potential of that ion. The cost of stabilization is the high ion flux that must be compensated by more work of ion pumps.

2) Hyperpolarization can be described as a more pronounced negativity of the membrane potential after repolarization. The occurrence, quantity, and duration of the hyperpolarization wave necessarily reflects momentary membrane permeability for certain ions. Hyperpolarization is caused by the temporary relative increase in potassium permeability compared with the resting phase. If this increase in potassium permeability is small, the hyperpolarization wave will also be small. For example, if a certain membrane is almost exclusively permeable to K\(^+\) ions, it will have a membrane...
potential near the potassium Nernst potential. During repolarization, this membrane will not hyperpolarize, because additional opening of the potassium channels cannot move the potential any closer to the Nernst potential.

**Simplified characteristics of SA cells.** In SA cells, permeability for Na\(^+\) and K\(^+\) is similar, so the membrane potentials are between the Nernst potentials for potassium and sodium. Because the overall permeability is small, the membrane potential is also less stable. Calculate the resting potential if the Na/K permeability ratio is 0.58:1.00 and extracellular Na\(^+\) = 142 meq/l, K\(^+\) = 4; intracellular Na\(^+\) = 14 meq/l and K\(^+\) = 142 meq/l (4).

**Proposed hyperpolarization-based interpretation of SA potentials.** 1) During repolarization from the peak depolarization, slow K\(^+\) channels that are gradually activated during depolarization make the membrane much more permeable to potassium. So the membrane potential progressively becomes more negative, moving toward the potassium Nernst potential. This hyperpolarization wave is shaped by the opening and closing of different sets of K\(^+\) channels.

2) When all the K\(^+\) channels that were opened during depolarization are closed, the membrane potential will reach the resting potential that reflects the Na/K permeability ratio. In SA cells, the resting membrane potential is never reached, because it lies above the triggering potential of calcium/sodium channels.

3) A continuous cycle of electrical activity in SA cells consists of the following four stages: depolarization (opening of calcium/sodium channels), repolarization with hyperpolarization (opening of several types of potassium channels), hyperpolarization recovery (cessation of potassium permeability), and triggering of depolarization without ever reaching the resting membrane potentials.
triggering of depolarization without ever reaching the resting membrane potentials.

Activities for Students

1) Use figures of SA potentials from your textbook and mark the calculated level of the hypothetical resting membrane potential of SA-nodal cells.

2) Does this make sense to you?

3) Draw a graph of two SA action potentials. Label the vertical axis in mV (+ and −) and the horizontal axis in seconds.

4) List pros and cons for the proposed model.

5) Discuss the model with your classmates.

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References


SVEN KURBEL
Osijek Medical Faculty
Dept. of Physiology
3100 Osijek, Croatia
Email: sven@jware.hr
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