Developing Learning Progressions in Undergraduate Physiology (LeaP UP)

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Expert thinking in a discipline is principle-based while novices rely on superficial features

We will focus on 2 key principles in physiology: **Flux** (movement) and **Mass Balance** (amount)

$$Flux \propto \frac{Gradient}{Resistance}$$

Ohm's Law

$V = IR$

I = Current
V = Voltage
R = Resistance

Fick's Law of Diffusion

$R = \frac{DA\Delta C}{d}$

R = rate of diffusion
ΔC = concentration gradient
D = diffusion constant
A = area over which diffusion occurs
d = distance over which diffusion occurs

Poiseuille's Law of Fluid Flow

$Q = \frac{\pi P r^4}{8\eta l}$

Q = flow rate
P = pressure gradient
η = viscosity of fluid
l = length of tubing
r = radius of the tubing

	Flux Examples	Gradient	Resistance
Diffusion	**Nerve, Muscle, Plant signaling:** diffusion of ions to generate action potential	ion electrochemical	membrane & channels
	Nerve: diffusion of Acetylcholine (Ach) across synaptic cleft	Ach chemical	extracellular fluid
	Muscles: movement Ca++ out of the sarcoplasmic reticulum	Ca++ chemical	SR membrane &
	CV: Movement of nutrients between blood & cells	nutrient chemical	membrane
	Respiratory: diffusion of gases across respiratory membrane, capillary-cell interface	partial pressure	thickness of membrane
	Transpiration: Diffusion of water vapor out of leaf air spaces	partial pressure	stomatal conductance
	Transpiration: K+ entering guard cell during stomatal opening	K+ electrochemical	membranes & channels
	Photosynthesis: Diffusion of CO_2 into leaves	partial pressure	stomatal conductance
	Photosynthesis: Movement of H+ through ATP synthase	H+ chemical	membrane & synthase
	Growth: Diffusion of water into cells during expansion	water potential	membrane & aquaporins
	Growth: Diffusion of auxin during Polar Auxin Transport	IAA^- & IAAH chemical	membrane & PINs
	Plant Defense: Diffusion of volatiles from one leaf to another	partial pressure	air density
Bulk Flow	**CV:** movement of blood in the circulatory system	hydrostatic pressure	diameter of vessels
	Respiratory: Movement of air into/out of lungs during ventilation	atmospheric pressure	bronchial tree diameter
	Transpiration: Movement of xylem sap through the trachearies	hydrostatic pressure	diameter of elements
	Sugar transport: Movement of phloem sap in sieve tubes	hydrostatic pressure	diameter of elements

1. Deconstruct the principle to create frameworks for principle-based reasoning

Flow Down Gradients

I. Flow is the movement of "stuff" from one point in a system to another point in the system.

II. Flow occurs because of the existence of an energy gradient between two points in the system.
- **A.** Concentration gradients cause molecules and ions in solution to move.
- **B.** Electrical potential gradients cause ions in solution to move.
- **C.** Pressure gradients between two points in a system cause substances to move.

III. The magnitude of the flow is a direct function of the magnitude of the energy gradient that is present; the larger the gradient, the greater the flow.

IV. More than one gradient may determine the magnitude and direction of the flow.

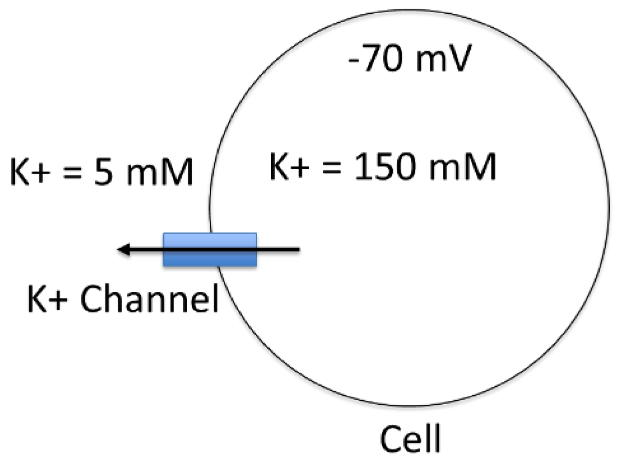
V. There is resistance or opposition to flow in all systems.
- A. Resistance and flow are reciprocally related.
- B. Some resistances are variable and can be actively controlled.

Adapted from Michael, J., & McFarland, J. (2011). The core principles ("big ideas") of physiology: results of faculty surveys. *Advances in physiology education*,*35*(4), 336-341.

2. Investigate students current understanding of the principles

a. Create a set of interview tasks

b. Conduct student interviews



"What can we change to cause net movement of K+ INTO the cell?"

3. Create a learning progression (LP) with five levels based on student responses using grounded theory.

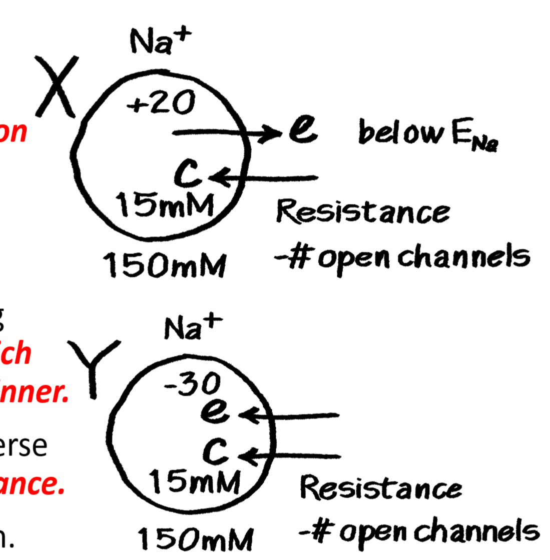
Level Descriptions
Level 5 Principle-based reasoning with full consideration of the interacting components **Flux:** Student constrains their explanations or predictions of movement of a substance by identifying and integrating the impact of all gradients (e.g. electrical & chemical) and all variation in resistance.
Level 4 Principle-based reasoning using individual components **Flux:** Student constrains their explanations or predictions of movement of a substance by using the gradients (e.g., electrical & chemical) and variation in resistance independently but not integrating them.
Level 3 Incorporating principles as just another fact in storytelling **Flux:** Student uses gradients or resistance as another factual element in their "steps story" of a physiological process. They do not constrain their explanation, "their story", by applying the principle.
Level 2 Storytelling without mechanistic understanding and no use of principles **Flux:** Student tells a story that only includes the steps of a process and does not include the underlying mechanism or principle (e.g., steps in generation of an action potential).
Level 1 Teleological and anthropomorphic reasoning **Flux:** Student describes phenomena occurring because the organism "wants" or "needs" to perform a physiological function.

4. Create teaching tools to help students move up Learning Progression

a. Flux Thought Organizer

When a question or problem is about the direction or rate of movement of something, do the following:

1. Identify what the something is. ***Draw a diagram of the situation (e.g., cell and surroundings with all relevant values).***
2. Figure out the direction(s) of the driving force(s) acting on the something. ***Add a labeled arrow for each driving force.***
3. If there is more than one driving force acting on the something determine the relative sizes of the driving forces. ***Indicate which arrow is the stronger force by making one thicker and one thinner.***
4. Figure out the resistances to movement of the something (inverse of the conductance). ***Make a note about any sources of resistance.***
5. Then, use this information to help answer the specific question. (Note: if the problem states something is moving in contradiction flux, then active transport (primary or secondary) is involved.)



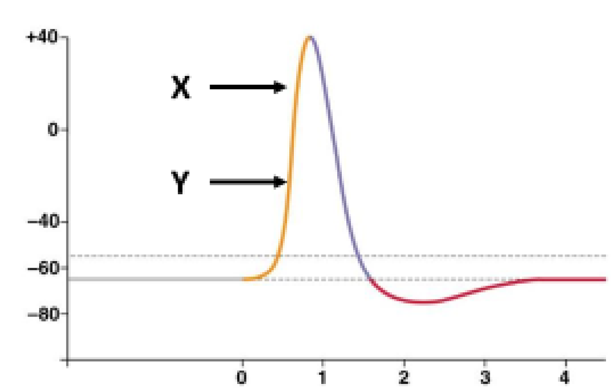
b. In-class activities (Clicker Questions)

Do Na+ ions continue to rush into the cell at point 'X' as compared to point 'Y'? Why or why not?

A. No, because at 'X', Na+ would be moving against its electrical gradient

B. Yes, at 'Y' along their electrochemical gradient, and at 'X' with their chemical gradient but against their electrical gradient

C. Yes, because at both at 'X' and 'Y' they are moving along their electrochemical gradient



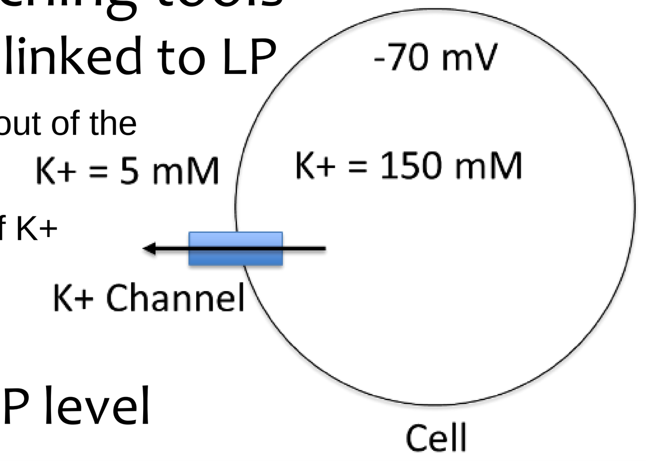
5. Assess effectiveness of teaching tools

a. Create written assessments linked to LP

In the figure, there is net movement of K+ ions out of the cell (as indicated by arrow).

What can we change to cause net movement of K+ INTO the cell?

The reason for my answer is



b. Generate a rubric to assign LP level

	Description	Student Exemplars
5	The interaction of the conc. gradient **AND** electrical forces determine ion movement.	*Lower the membrane potential below -91 mV, increase the concentration of K+ outside the cell, or decrease the K+ concentration inside the cell. The concentration gradient and/or the electric gradient must be changed so that the **driving force into the cell (caused by the electric gradient) is greater than the driving force out of the cell (via the concentration gradient).***
4	The electrical force **OR** conc. gradient can impact ion movement.	*Make the inside of the cell more negative and add more potassium ions to the outside of the cell.* *The negative charge of the inside of the cell will attract the positively charged potassium ions creating a stronger electrical gradient.* *The addition of potassium to the outside will create a concentration gradient that makes the ions flow in.*
3	The conc. gradient is the **ONLY** thing that impacts ion movement.	*By making the ion **concentration greater outside the cell than inside**, there will be a gradient that will result in a net movement of ions into the cell.*

6. Develop computer scoring of written answers so assessments can be easily scored

Used **AACR** Confirmatory Analysis to develop predictive model of human scoring.

Computer Prediction	Human Scoring 3	4	5
3	**194**	14	5
4	8	**133**	42
5	1	17	**69**

Kappa 0.72
Accuracy 0.82
Accuracy 95% CI 0.783 - 0.853

7. Create a teaching taxonomy to assess fidelity of implementation of teaching methods

Taxonomy of Teaching with General Models			
STUDENTS		daily	cumulative in course
# times students practiced with using GM	frequency		
amount of time students practiced in class	intensity		
# times students used GM in their explanations of instructor posed question	intensity		
# homework question addressing GM concepts	intensity		
FACULTY			
# times instructor used GM question prompt	frequency		
# times instructor used the GM words	frequency		
order in which instructor introduced GM			

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