2026 Mitosisphere $(p+q)^2 = 1$

ANSWER KEY

60 MCQ, 32 MTF / 120 minutes

Input answers into the provided form. Scratch paper and a non-graphing, non-programmable calculator of any kind is allowed . There are 60 multiple choice single select questions, and 33 MTF questions. Multiple choice questions are all valued at 1 point. There will be partial credit for MTF questions on a 0/0/0.4/1.2/2 scale.

Best of Luck!

Part A (60 MCQ)

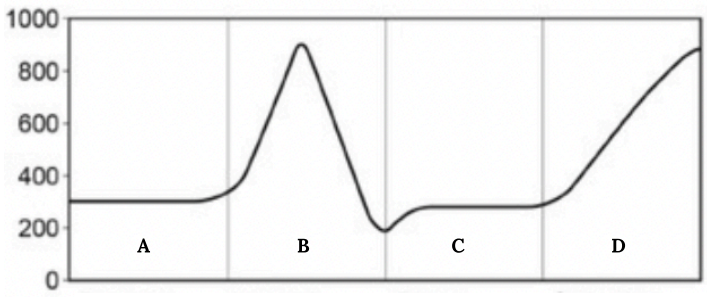
Anatomy & Physiology (15 questions)

1. “It’s not what it looks like, I swear!” Garry said.
“Don’t worry, Garry, I also eat rabbit poop. But you're doing it wrong,” replied Loseph.
“What?”
“You can’t eat the pellets, you’ve gotta eat the soft stuff.”

Why did Loseph tell Garry to “eat the soft stuff” instead of the pellets?

A. The pellets don’t have any nutrients; the soft stuff does.
B. Loseph is trying to kill Garry, the soft stuff is toxic.
C. The pellets contain too much insoluble fiber; the soft stuff is easily digested.
D. The soft stuff carries beneficial symbiotic bacteria
E. The pellets will block Garry’s pyloric sphincter, not allowing food to enter the small intestine.

2. The following graph depicts filtrate osmolarity as a function of length along the nephron.



Which of the following statements is FALSE?

A. Region C corresponds to the distal tubule.
B. NaCl is reabsorbed along the second half of region B.
C. Ingestion of Furosemide, a loop diuretic, would result in a greater peak in region B.
D. Aldosterone would not significantly affect region A
E. The part of the nephron depicted by the boundary of regions B and C is closely associated with both the afferent and efferent arterioles.

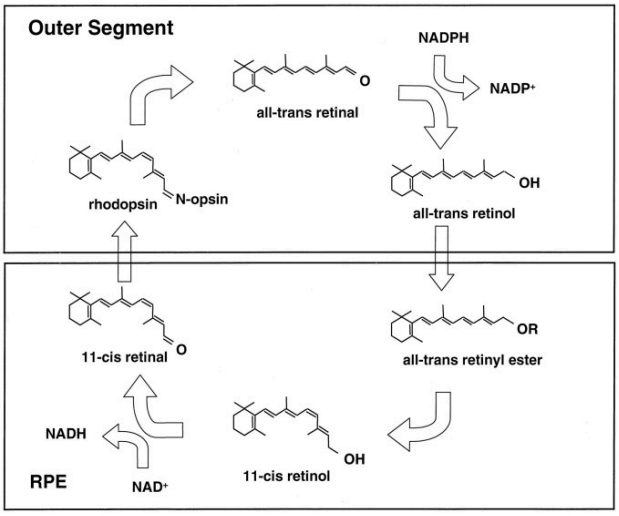
3. Arrange the following steps of sea urchin egg development and fertilization in the order they occur:

I. Spreading wave of Ca2+
II. Sharp increase in metabolism
III. Completion of meiosis
IV. Fusion of sperm and egg nuclei
V. Depolarization of egg

A) III, V, I, II, IV

B) V, I, II, IV, III
C) V, IV, II, I, III
D) I, V, II, III, IV
E) I, V, II, IV, III

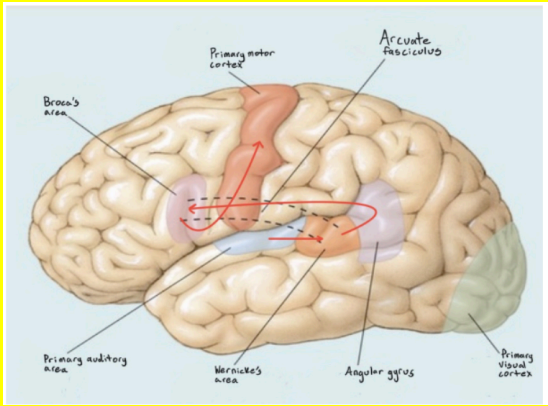
4. Based on your knowledge of the visual cycle and the image below, which of the following statements is FALSE?



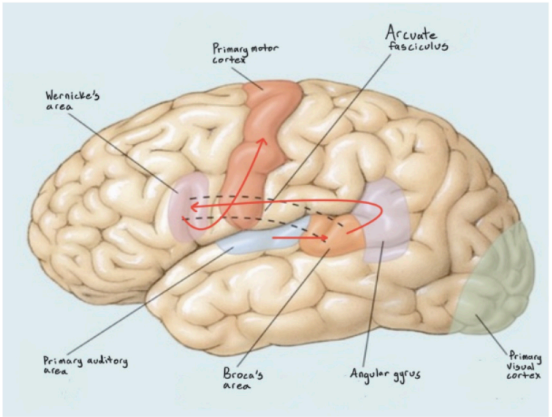
A) Photoreceptor discs are found in the outer segment of photoreceptors.
B) Conversion of 11-cis retinol to all trans acidifies the retinal pigment epithelium.
C) Retinal isomerase is likely membrane-localized
D) Rhodopsin absorbs light best at 400-600nm.
E) There exists a fundamentally similar cycle within cones.

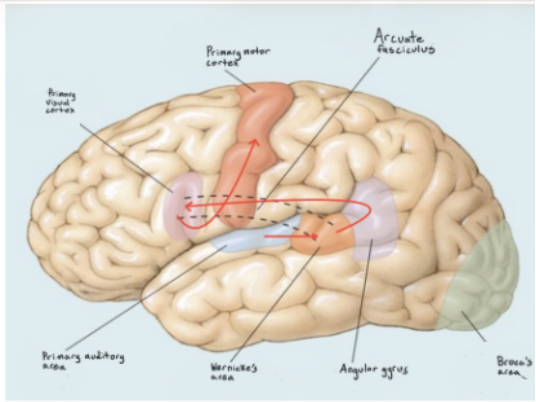
5. You would like to prevent Raymond from speaking a heard word. Which choice correctly maps the brain pathway for this action.

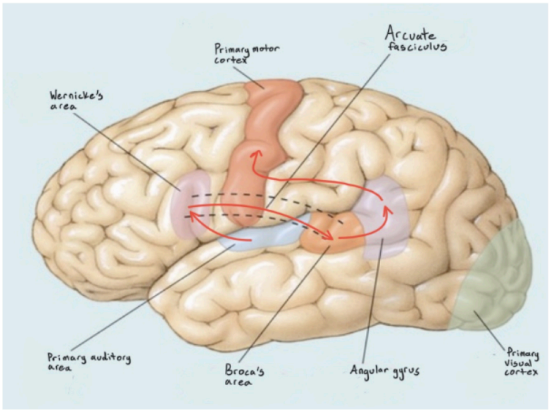
A.

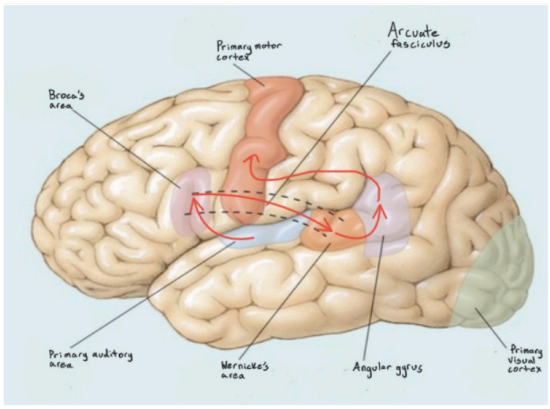


B.



C. 

D. 

E. 

6. Anish is studying gastrointestinal hormones and their actions. Which of the following pairs are incorrect?

A) Gastrin; stimulates mucosal growth
B) Cholecystokinin; stimulates growth of exocrine pancreas
C) Secretin; inhibits growth of exocrine pancreas
D) Motilin; stimulates intestinal motility
E) Glucose-dependent insulinotropic peptide; stimulates insulin release

7. Renal regulation of substances X, Y & Z are provided below. Which of the following choices correctly identifies which substances would be most effective in measuring GFR and total renal plasma flow, respectively?

- Substance X: Neither secreted nor reabsorbed
- Substance Y: Strongly secreted
- Substance Z: Strongly reabsorbed

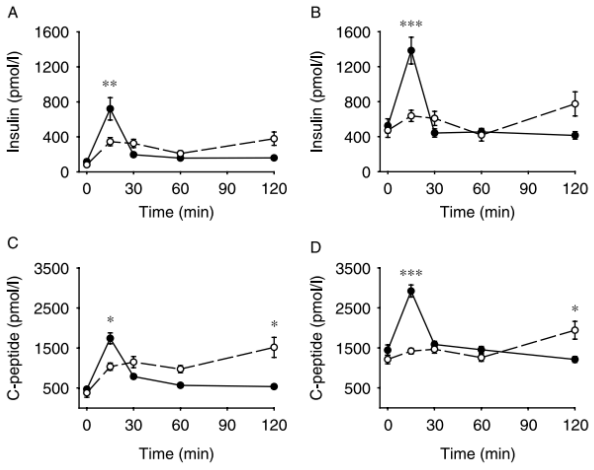
A) X, X
B) Y, Z

C) Z, X
D) X, Y
E) Z, Y

8. Which of the following statements is TRUE about thyroid hormone and its actions?

A) It's derived from tryptophan.
B) Increased thyroid hormone decreases plasma triglycerides and increases free fatty acids.
C) Thyroid hormone doesn't increase cholesterol loss in feces.
D) A relative vitamin deficiency might happen when someone has low thyroid hormone
E) Thyroid hormone decreases BMR.

9. Shown below are plasma levels of insulin and C-peptide before and after oral administration of glucose at 25 mg and the corresponding results from i.v. glucose infusion in anesthetized female mice fed normal diet or high-fat diet.



Which of the following choices identifies the graphs that correspond to high fat diet, and the lines that correspond to oral administration, respectively?

A) A & C, dark lines
B) B & D, dark lines
C) A & C, light lines
D) B & D, light lines
E) B & C, light lines

10. Countercurrent exchange in fish gills is cool. Which of the following statements is TRUE regarding this mechanism?

A) Water flows perpendicular to the lamellae to maximize oxygen unloading into the capillaries.
B) Two gill filaments extend from each gill arch; one carries oxygenated blood, the other carries deoxygenated blood.
C) This system evolved from pharyngeal slits in all vertebrates
D) Continuous active pumping up water over the gills increases blood pH.
E) Decreasing the number of lamellae per gill arch would increase oxygen unloading per lamella.

11. Jerry recently became vegan; however, he's also an extremely picky eater which has led him to accumulate some nutrient deficiencies. He's noticed red and itchy skin, but for some reason can't remember what he's been eating to cause this nutrient deficiency. Furthermore, he's been making quite a few unpleasant trips to the bathroom, which happen to be very watery.

Which of the following is Jerry most likely deficient in?

A) Pantothenic acid
B) Glutamine
C) Tryptophan
D) Tocopherol
E) Magnesium

12. Oh gosh, after walking in on Uddip with another guy, Ajay promptly kicked him in the testis and ran to his car. Fortunately for Uddip, he wasn't planning on having any kids. However, the unfortunate consequence of testicular torsion has temporarily cut off blood supply to his testis. Which of the following is NOT a consequence of Uddip's unfaithful endeavors?

A) Atrophy of the testis
B) Nausea and vomiting
C) Testicular necrosis
D) Inflammation of the rete testis
E) Reduced fertility

13. Which of the following statements regarding brain organization in different animals is FALSE?

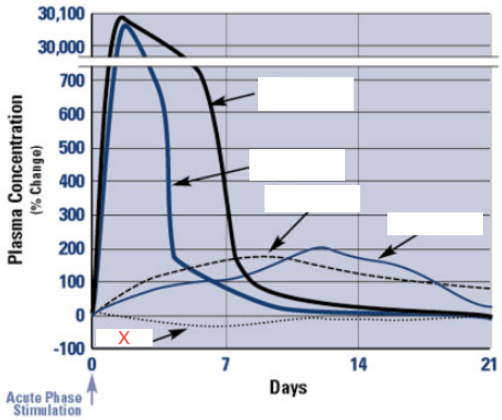
A) Crocodilians have relatively large olfactory bulbs
B) Birds have relatively large forebrains
C) Lampreys have relatively small cerebellums
D) Sharks fishes have relatively large midbrains
E) Birds have relatively large cerebellums

14. Identify all of the following adaptations that deep divers have evolved for proper oxygen regulation:

I. High myoglobin content
II. High plasma volume
III. Ventricular shunt from pulmonary circulation
IV. Thick subcutaneous layer of fat

A) I, II
B) I, II, III
C) I, III, IV
D) I, II, IV
E) I, II, III, IV

15. The acute phase response (APR) is the body's rapid, systemic reaction to infection, injury, or inflammation. It involves fever, alteration of blood protein concentrations, and altered metabolism. Shown below is a graph of relative levels of different proteins and cytokines in circulation following activation of this response.



Which of the following does the red X correspond to?

A) IL-1

B) Transferrin
C) C reactive protein (CRP)
D) Hepcidin
E) Complement factor 3 (C3)

Genetics & Evolution (12 questions)

16. In the parthenogenetic desert grassland whiptail lizard species, *Aspidoscelis uniparens*, all individuals are female. However, two individuals often form mate pairs in which one female adopts "male-like" behavior, such as mounting. This mounting behavior has been seen to increase the reproductive success of *Aspidoscelis uniparens* by increasing the likelihood of ovulation. In the context of evolution, which of the following terms best describes this behavior?

A. Exaptation
B. Biological spandrel
C. Directional selection
D. Fixed action pattern
E. Mate choice copying

17. In a cross between two heterozygous individuals for 4 unlinked genes, A_1, A_2,..., how many offspring must be produced to be 95% certain that there will be an individual homozygous recessive for all genes?

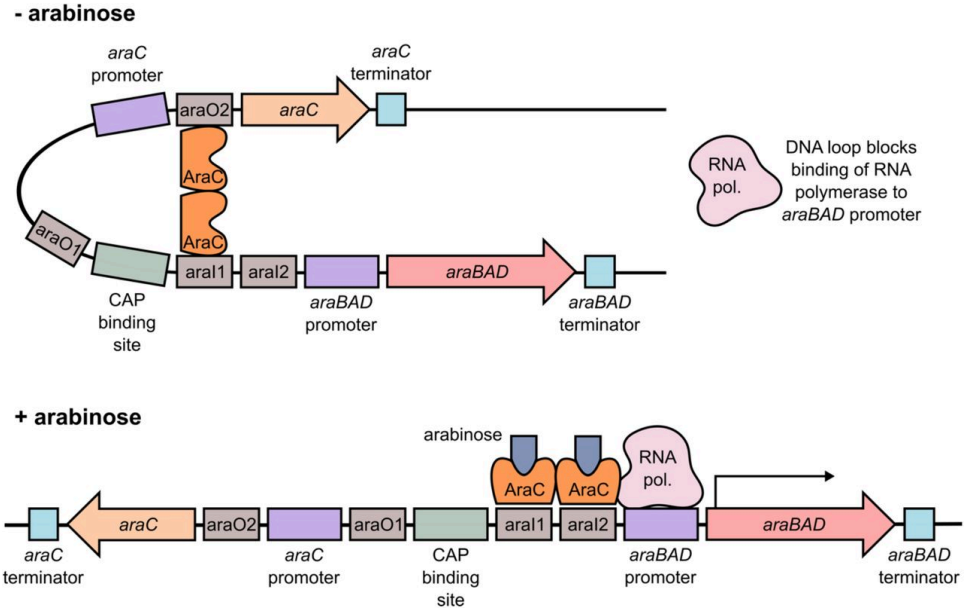
A) 243
B) 256
C) 269
D) 565
E) 765

18. Recombination hotspots are chromosomal loci so named for their increased frequency of crossing over. Which of the following statements is/ are true regarding recombination hotspots?

I. A hotspot between two genes would increase the observed map distance between the two.
II. Centromeres are considered recombination hotspots.
III. Consider three genes A, B, & C, arranged in that order from left to right. A hotspot between genes A & B would decrease the observed map distance between A & C.

A) I only
B) II only
C) I, III
D) I, II
E) I, II, III

19. The arabinose (ara) operon regulates the expression of 3 structural (protein coding genes): araB, araA, & araD. Whether or not the ara operon is transcribed is determined via dual positive and negative regulation. Arabinose represses further synthesis at high concentrations, while low glucose levels promote arabinose synthesis.



Based on the information and image above, which of the following statements regarding the ara operon is TRUE?

A) A WT strain of *E. coli* grown in the presence of glucose and arabinose would transcribe araB, araA, & araD.
B) A loss-of-function mutation in the araC DNA-binding motif would lead to constitutive expression of the ara operon.
C) A partial diploid created by crossing araB+/araA+/araD+/araC- with araB-/araA-/araD-/araC+ would transcribe ara.
D) A mutant with loss-of-function mutations in the araC binding motif would exhibit upregulated expression of the ara operon.
E) Constitutive cAMP phosphodiesterase activity would promote transcription of the ara operon.

20. Which of the following chromatin modifications would you NOT expect to decrease the expression of a gene?

A) H3K27me3 of the promoter.
B) Hyperactive histone methyltransferase activity.
C) Selective inhibition of methionine adenosyltransferase (MAT).
D) Hyperactive histone deacetylase activity.
E) Introduction of miRNAs specific to the gene of interest.

21. In bloopers, 4 genes W, X, Y, & Z all additively affect bloopy length. Bloopy length can range from 8 to 40. In a certain population of bloopers, the frequency of the dominant alleles for W, X, Y, and Z is 0.5, 0.6, 0.7, and 0.8, respectively. Assuming each dominant allele confers 4 points of bloopy length, and that the population of bloopers is in Hardy-Weinberg equilibrium, what percentage of bloopers would you expect to have a bloopy length of 40?

A) 0.14%
B) 1.2%
C) 2.8%
D) 5.6%
E) 16.8%

22. In a dihybrid cross, you notice a ratio of roughly 13 WT to 3 mutant offspring. Which of the following best explains the observed ratio?

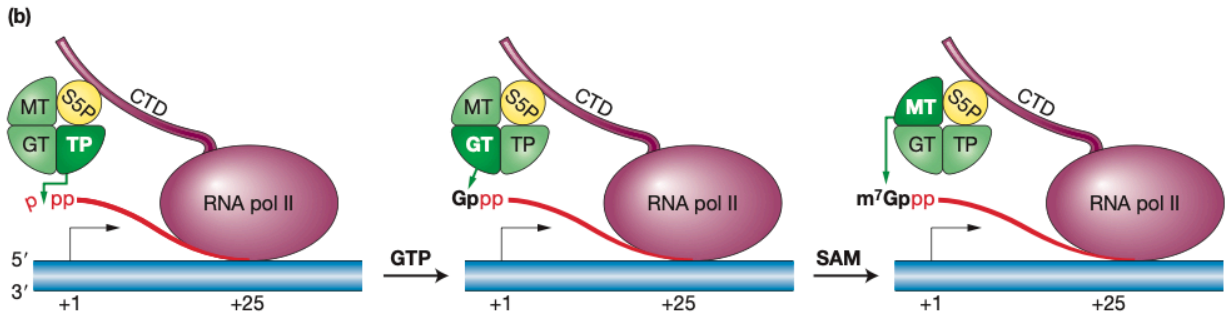
A) One dominant allele of one gene is sufficient to override the expression of another gene.
B) The two GOIs act at different steps along a biosynthetic pathway.
C) A mutant allele of one of the genes reverses the effect of a mutant allele in the other gene.
D) Both genes are required in their WT to confer a WT phenotype.
E) The genes are redundant; only 1 WT copy of either allele is required to confer a WT phenotype.

23. The restriction enzyme r67 recognizes the sequence 5'-GCAT-3'. In a 0.2kbp plasmid with a G+C content of 60%, how many fragments are expected to be generated by treatment with r67?

A) 1 (circular)
B) 1 (linear)
C) 2

D) 3
E) 4

24. Shown below is a three-step enzymatic process. Which of the following statements regarding the image below is false?

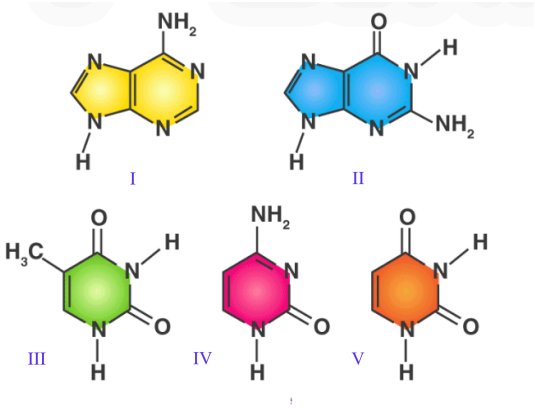


A) Inhibition of any one of these steps would result in decreased mRNA translation.
B) This process occurs cotranscriptionally in bacteria.
C) In eukaryotes, inhibition of this process would result in decreased export through NPCs.
D) This process requires adequate levels of methionine in the cell.
E) This process only occurs for mRNAs synthesized by RNA pol II.

25. Which of the following modes of selection maintains the most genetic diversity within a population?

A) No Selection
B) Disruptive
C) Directional
D) Stabilizing
E) Artificial

26. One of the inherent benefits of utilizing uracil as opposed to thymine in DNA is that it may be recognized in the case of mutations. This is because it allows for the recognition of spontaneously deaminated cytosine residues. Which of the following choices correctly describes this spontaneous deamination?



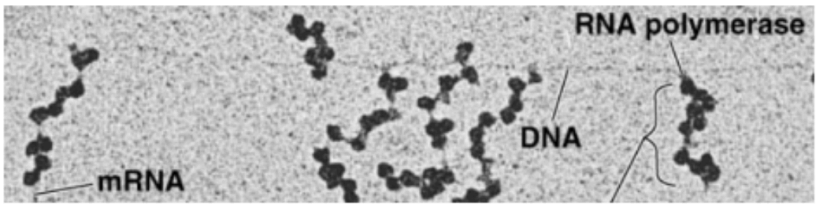
A) I->V
B) II->V
C) IV->V
D) III->IV
E) V->III

27. In a population of Suzuklers, there exists a rare X-linked recessive synthetically lethal trait called Xookle. A newly married couple with 1 healthy son and 1 healthy daughter is considering whether they should have another child. The husband has an aunt who recently attempted to have a child, but miscarried due to Xookle. The wife's mom is known to be a carrier for Xookle. What is the probability that if the couple decides to have a child, they will survive? (i.e., not be Xookled).

A) 75%
B) 80%
C) 83%
D) 87.5%
E) 92%

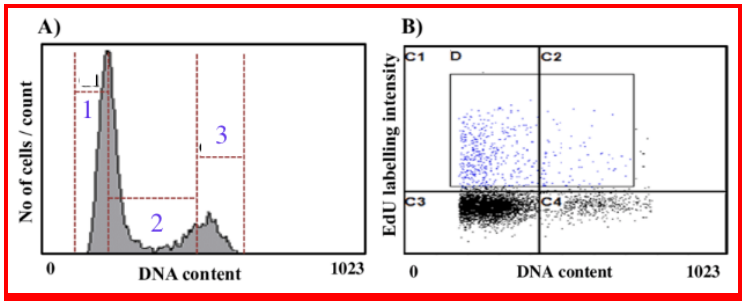
Cell Biology (12 questions)

28. Which is most likely TRUE about the organism from which this electron micrograph was taken? Select one.



A) The dense circles are likely 80S ribonucleoprotein complexes.
B) This organism may produce polycistronic mRNA.
C) The RNA polymerase is likely RNA polymerase II if the produced mRNA is destined to make an enzyme for glycolysis.
D) This organism likely does not possess a primosome.
E) E. Impossible to know.

29. Flow cytometry was performed on a range of dividing cells all at various points along the cell cycle. Given the data below, which of the following statements is true?



A) Zone 1 corresponds to cells in G2/M
B) Zone 3 corresponds to when the uracil content of the cell is the highest
C) Chromatin is the most condensed in cells of region C2
D) Region C3 in figure B. corresponds to regions 3 of figure A.
E) Inhibiting microtubule polymerization would result in a greater fraction of cells in region 1.

30. Kian is interested in understanding how constitutive PI3K activation leads to the development of colon cancer. You know that normally, growth factors such as EGFR induce receptor dimerization, causing recruitment of PI3K to the membrane. PI3K then converts PIP2 to PIP3, which recruits AKT to the membrane. Phosphorylation of AKT at threonine 308 (T308) and serine 374 (S473) is carried out by PDK1 and mTORC2, respectively. Phosphorylation of either T308 *or* S473 leads to partial activity of AKT; however, full activity requires phosphorylation at both sites. Which of the following procedures would you advise Kian to perform on WT cells to investigate the mutations seen in colon cancer?

A) Site-directed mutagenesis of both T308 and S473 to isoleucine residues.
B) Site-directed mutagenesis of both T308 and S473 to aspartate residues.
C) CRISPRi directed knockouts of both T308 and S473.
D) CRISPRi directed knockouts of T308 and S473 individually.
E) Introduction of alternative target for PI3K phosphorylation.

31. Unlike hemoglobin seen in mammals, hemocyanin is a free floating respiratory pigment. Furthermore, it's extremely large, with 96+ subunits, and has a copper center rather than an iron center. Similar to hemoglobin though, hemocyanin does exhibit positive cooperativity. Which of the following statements regarding hemocyanin is FALSE?

A) Hemocyanin shows a sigmoidal curve for oxygen saturation versus partial pressure of oxygen.
B) Hemocyanin is free floating due to its large size.
C) Hemocyanin is ideal for lower oxygen concentrations than hemoglobin.
D) Hemocyanin both loads and unloads oxygen more readily than hemoglobin
E) Animals that carry hemocyanin do not have blood types (Like A,B,O)

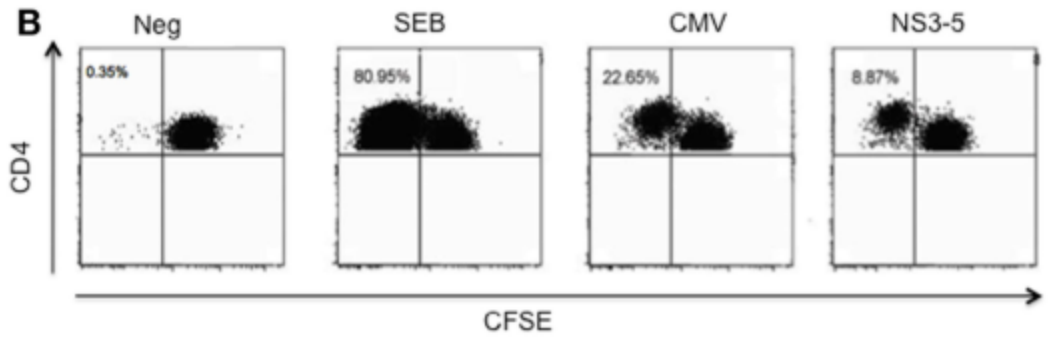
32. Which of the following amino acid substitutions would be most disruptive to the tertiary structure of hexokinase?

A) Cysteine to methionine
B) Leucine to isoleucine
C) Glutamine to arginine
D) Arginine to leucine
E) Serine to tyrosine

33. Which of the following techniques would be best suited for determining the location of an enhancer for a promoter whose location is already known?

A) Fluorescence in situ hybridization
B) EMSA
C) Co-immunoprecipitation
D) Micro-C
E) FRET

34. Naive CD4 T cells were labeled with CFSE, a fluorescent marker. They were then divided into 3 cultures and treated with either SEB, CMV, or NS3-5. FACS plots of CD4 versus CFSE are shown below.



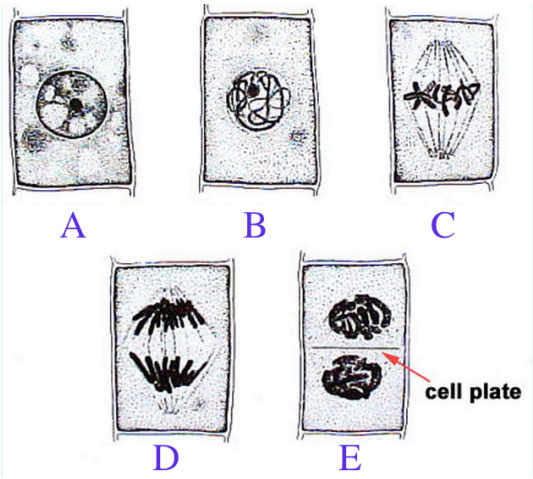
Which of the following statements is FALSE?

A) Observed results may be attributed to clonal expansion.
B) Assuming both cultures started with an equal number of cells, there are more cells in the SEB-treated culture than in the NS3-5-treated culture.
C) CFSE content per cell is highest in SEB-treated cells.
D) Simultaneous treatment with SEB and corticosteroids may result in a FACS plot more similar to that of CMV treatment than SEV treatment alone.
E) CD4 expression is independent of SEB treatment.

35. Which of the following statements regarding the citric acid cycle is FALSE?

A) Carbon dioxide is only released at one step along the pathway.
B) Acetyl-CoA adds its carbons to a 4-carbon intermediate.
C) Each turn generates one GTP through substrate-level phosphorylation.
D) The cycle occurs in the mitochondrial matrix.
E) Enzymes of the citric acid cycle are not exclusive to the cycle.

36. Shown below cells is a longitudinal section in the growing root-tip of an onion.



Which of the following cells likely has the highest MPF activity?

A) A
B) B
C) C
D) D
E) E

37. Which of the following events does NOT occur/ is not true during prophase?

A) Fragmentation of nuclear envelope
B) Chromatin fiber condensation
C) Formation of mitotic spindle
D) Sister chromatids are held together by cohesins
E) Astral microtubules extend from centrosomes

38. Which of the following amino acids contains the fewest nitrogens?

A) Arginine
B) Lysine
C) Asparagine
D) Methionine
E) Histidine

39. Which of the following statements of a non-reducing gel is most accurate?

A) Their primary constituent is agarose
B) They are unsuitable for determining molecular weight of a protein
C) They are suitable for determining 3D conformation of a native proteins configuration
D) In order to visualize bands, ethidium bromide is commonly utilized.
E) They preserve primary and secondary structure, but fail to preserve tertiary or quaternary structure.

Plant Biology (9 questions)

40. Which of the following statements regarding auxin transport is FALSE?

A. Auxin transport is polar, moving basipetally

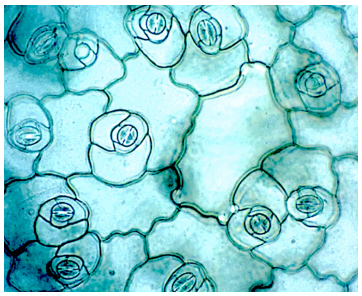
B. PIN proteins are primarily found in the xylem parenchyma
C. If sunlight was coming from the east, a paraheliotropic (sun avoiding) plant would have a greater auxin concentration towards the west than a diaheliotropic (sun tracking) plant.
D. Raising auxin levels too high may induce senescence
E. Inhibiting auxin transport would have a similar effect as inhibiting proton pumps

41. While light is necessary for photosynthesis, too much light can be harmful. As such, many plants have evolved different features in order to minimize excess light exposure. Which of the following adaptations to excess light exposure may also reduce photosynthetic yield?

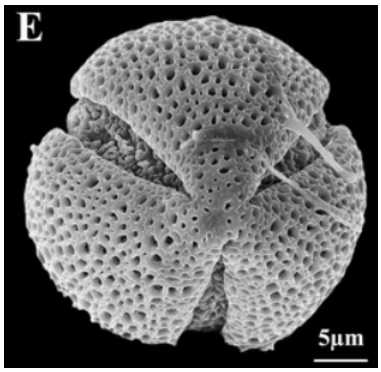
I. Trichomes
II. Lateral chloroplast movement
III. Thick cuticle
IV. Crypts

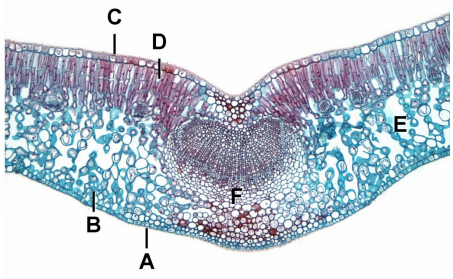
A. II only
B. I, II
C. II, IV
D. I, III, IV
E. I, II, III, IV

42. Which of the following could NOT come from a eudicot?

A. 
B. 

C. 

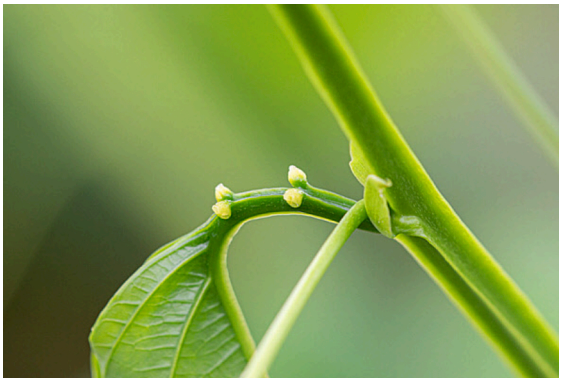
D. 

E. 

43. In which of the following plant phyla would you expect the greatest increase in ethylene concentration during the fall?

A. Coniferophyta
B. Anthophyta
C. Anthocerophyta
D. Bryophyta
E. Gnetophyta

44. While inspecting his favorite passionflower, Grayson notices some round yellow structures on it. Curious what they are, he takes the following picture to send to his friend Greycen, an avid botanist. Greycen quickly recognizes them and tells Grayson that the primary function of these yellow structures is to:



A. Produce pollen
B. Deter insects
C. Grow into new leaves
D. Attract pollinators
E. Protect from harmful UV rays

45. In an attempt to figure out which wavelengths of light are responsible for different plant responses, you look at an action spectra for different responses as a function of wavelength. Which of the following results would you likely NOT observe?

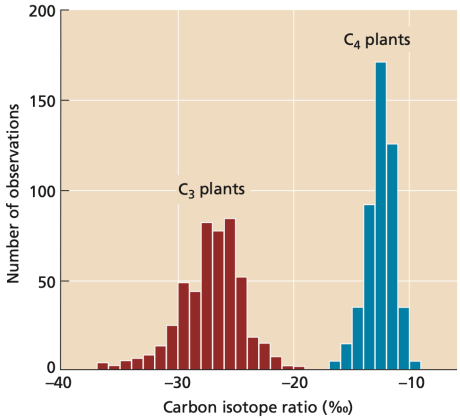
A. Maximal coleoptile bending at ~480nm
B. Maximal flowering at ~660nm
C. Nothing at ~550nm
D. Maximal cytokinin production at ~480nm
E. Maximal branching at ~730nm

46. Evil scientist Doseph Jong was just rejected by the guy of his dreams after buying him flowers. Naturally, he has decided that this is no fault of his own but rather the flowers. As such, he has synthesized *Compound* X^{TM}, a proton pump inhibitor, which he plans on dumping on any flowering plant that he comes across. Which of the following functions would *Compound* X^{TM} least disrupt?

A) Translocation of photosynthates
B) Elongation of internodes
C) Hypersensitive response
D) Cellulose cross-linking
E) Stomatal opening

47. The $^{13}C/^{12}C$ ratio R can be used to define the carbon isotope ratio $\delta^{13}C$ ‰ = $[R_{sample}/R_{standard}*-1] * 1000$. Taking our standard to be the carbon ratio of atmospheric

carbon dioxide, and our sample to be different plant tissues, a frequency histogram for observed carbon isotope ratios in C_3 and C_4 plant taxa from around the world was generated.



Based on the figure, which of the following statements is FALSE?

A. Plants preferentially take up carbon dioxide with ^{12}C
B. C_3 plants are more discriminatory in their assimilation of carbon isotopes
C. Sugar samples from maize would contain a greater fraction of ^{13}C than a rice plant
D. Global warming can be expected to increase the abundance of ^{13}C in human tissues
E. A faster speed of diffusion may account for isotope discrimination

48. The Bowen ratio is defined as the ratio of sensible heat loss (heat lost due to difference in temperature with surrounding air) to latent heat loss (heat dissipated by evapotranspiration). In which of the following plant families would you expect to find the greatest Bowen ratio?

A. Bromeliaceae
B. Poaceae
C. Ranunculaceae
D. Solanaceae
E. Rhizophoraceae

Ecology (6 questions)

49. According to the island equilibrium model, which of the following best describes relative levels of immigration and extinction above the equilibrium number of species (Q)?

A) Immigration > extinction

B) Immigration < extinction
C) Immigration = extinction
D) Depends on relative fitness of different species
E) Depends on size of island and proximity to mainland

50. Which of the following biomes would you expect to best follow the intermediate disturbance hypothesis?

A) Boreal forest
B) Tundra
C) Tropical rainforest
D) Shrubland
E) Peatland

51. In a mark-recapture experiment, Jerry labels 75 pigeons red and comes back a month later. To your surprise, only 3 out of 300 pigeons that you find when you return are labeled red. Which of the following best describes how Jerry should interpret this data?

A) He should realize his estimate will be far too large due to migration.
B) He should realize his estimate will be far too little due to migration.
C) He should realize his estimate will be reasonably accurate and the population size is roughly 7,500.
gg pigeons don't migrate L
D) He should realize his estimate will be accurate and the population size is roughly 68,000.
E) He should realize his estimate will be too little due to pigeons dying off over the last month.

52. Which of the following scenarios provides an example of a foundation species?

A) A beaver that builds dams to filter water.
B) Shrimp that keep the zooplankton population of a marine ecosystem in check so as to maintain an adequate amount of phytoplankton.
C) A tree that provides a habitat for nearby squirrels and insects.
D) Zooxanthellae algae that form mutualistic interactions with coral to help them survive.
E) Lichen and moss that colonize a piece of land that got covered by lava from a volcanic eruption 200 years ago.

53. A population of *M.itosisphere* individuals strangely has 250 males and 780 females. Which of the following gives the effective population size of the population, rounded to the nearest whole number?

A) 815
B) 1030
C) 757
D) 796
E) 910

54. A population of desert jackrabbits inhabits an isolated basin. Researchers recorded the population size over time after a wet year increased vegetation. Population size over six years is given in the table below.

Year	Population Size
0	120
1	190
2	280
3	360
4	410
5	430
6	438

Which of the following choices is closest to the maximal intrinsic rate of growth in this population between any two given years?

A) 0.64
B) 0.76
C) 0.79
D) 0.80
E) 0.83

Ethology (3 questions)

55. When urban birds see humans wearing funny hats or masks, they fly away. But, after seeing the same humans with the same hats repeatedly, they'll just ignore them—even if the hats are really bright or weird-looking. Which of the following best explains this?

A) Acclimization
B) Adaptation
C) Sensitization
D) Habituation
E) Two of the above

56. Which of the following groups of animals would you expect the lowest certainty of paternity?

A) Frog
B) Albatross
C) Threespine stickleback
D) Prairie vole
E) Beaver

57. Oh no! Because you failed your math exam, your friendly neighborhood fraud Naoya spins the block on you and punches you in the face, like he does every time you fail a test. Which of the following correctly describes the type of operant conditioning this displays?

A) Negative Punishment
B) Positive Punishment
C) Negative Reinforcement
D) Positive Reinforcement
E) None of the above

Biosystematics (3 questions)

58. Which of the following statements are true regarding freshwater flatworms?

I. They primarily reproduce asexually
II. They possess protonephridia well adapted to the excretion of metabolic wastes
III. They possess an open circulatory system

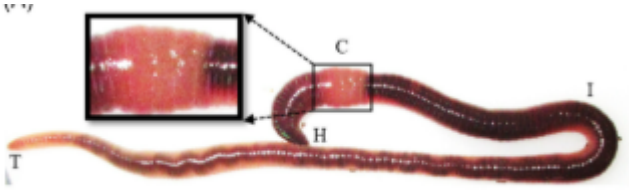
A. I only
B. II only

C. I & II
D. I & III
E. I, II, & III

59. Although nothing can quite match his deep love for Lampreys, Ajay takes interest in all marine invertebrates. While scuba-diving, he observes an echinoderm that strangely reminds him of kelp. It sits anchored to its substrate via a holdfast and has a long stalk that possesses long and flexible arms. To which of the following clades does this echinoderm most likely belong?

A. Asteroidea
B. Ophiuroidea
C. Echinoidea
D. Crinoidea
E. Holothuroidea

60. While scavenging, Anish comes across the following worm and observes a strange structure. Unsure of what type of worm he is dealing with, as well as the function of this structure, he turns to his friend Sunigoon. He confidently tells Anish that this worm is part of the phylum ___, and this structure mainly functions in ___.



A. Annelida, digestion
B. Annelida, reproduction
C. Nematoda, digestion
D. Nematoda, reproduction
E. Nemertea, digestion

Part B (33 MTF)

Animal Anatomy & Physiology (6 questions)

1. In contrast to squamates, crocodilians have a four-chambered heart with a complete septum. The two aortic arteries reconnect shortly after exiting the heart, connected by the Foramen of Panizza. Crocodilians may open or close this shunt, depending on metabolic needs.

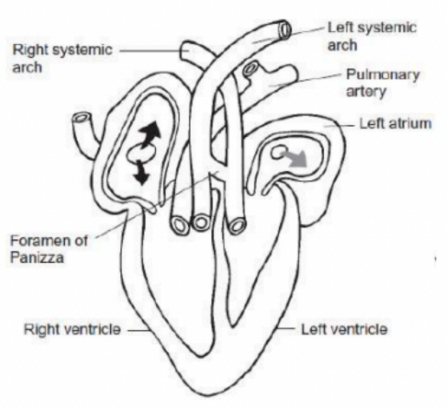
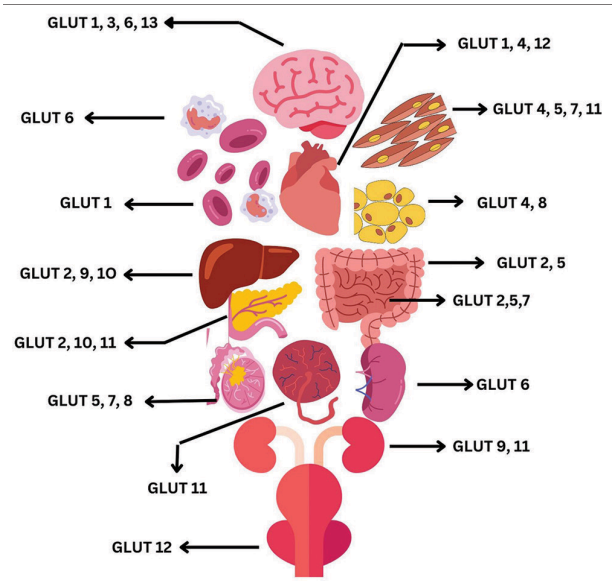


Fig 1. *Not enough pixels to go around*

Identify whether the following statements are true or false:

I. The Foramen of Panizza is closed while submerged underwater for extended periods.
II. The presence of the Foramen of Panizza indicates that crocodilians are more closely related to birds than lizards.
III. During a fight-or-flight response, the Foramen Panizza is closed to maximize blood flow to the lungs.
IV. While submerged underwater, the foramen of Panizza of crocodilians shunts blood in the same direction as the foramen ovale in a human fetus.

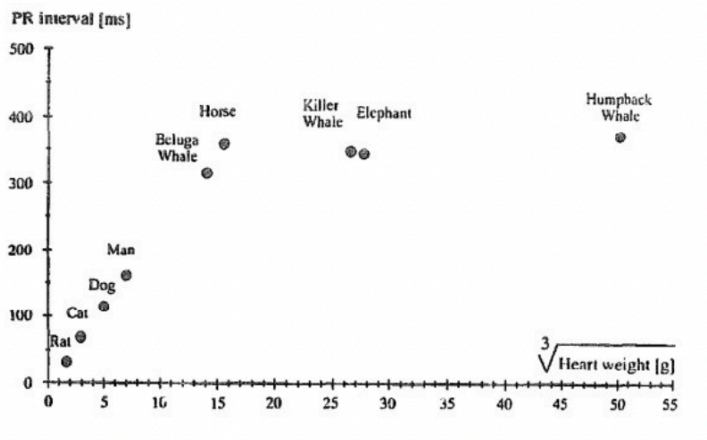
2. Different organs throughout the body possess different classes of glucose transporters depending on their metabolic requirements.



Identify whether the following statements are true or false:

I. GLUT1 has a lower K_M than GLUT4
II. GLUT6 is insulin-independent
III. During periods of starvation, GLUT2 insertion is stimulated
IV. Following a meal, GLUT1 will transport a lower fraction of total blood glucose

3. In many species, the timing of electrical conduction does not scale with body size, but remains virtually unchanged (barely double that of the human), suggesting that there is some mechanically optimal conduction rate that needs to be maintained for the cardiac cycle to work.

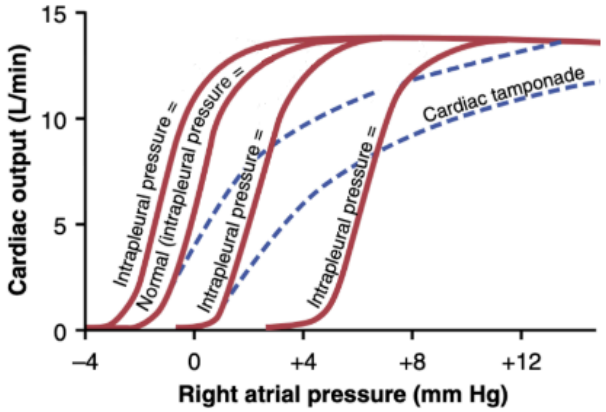


Based on your knowledge of the cardiac cycle and the figure above, identify whether the following statements are true or false:

I. In smaller mammals, the PR interval appears to scale linearly with heart weight.
II. Humpback whales likely have a much slower conduction velocity than horses
III. Sympathetic stimulation of the SA node in a humpback whale would result in a PR interval more similar to that of a Beluga whale.
IV. Human infant PR intervals are shorter than human adult PR intervals.

4. You are studying how various pressures affect cardiac output in rodents. In an anesthetized rodent, right atrial pressure in reference to the atmosphere (RAP), pericardial pressure (PP), intrapleural pressure (IPP), and cardiac output (CO) are measured. Autonomic reflexes are inhibited pharmacologically while blood volume, myocardial contractility, and systemic vascular resistance are held constant. You then sequentially perform the following on the rodent, allowing for a steady state after each.

1. Switch from unconscious respiration to constant +6 mm Hg positive-pressure breathing.
2. Perform a median sternotomy.
3. Inject saline into the pericardium.
4. Switch respiration to -6 mm Hg negative-pressure breathing (a miniature iron lung has been developed).

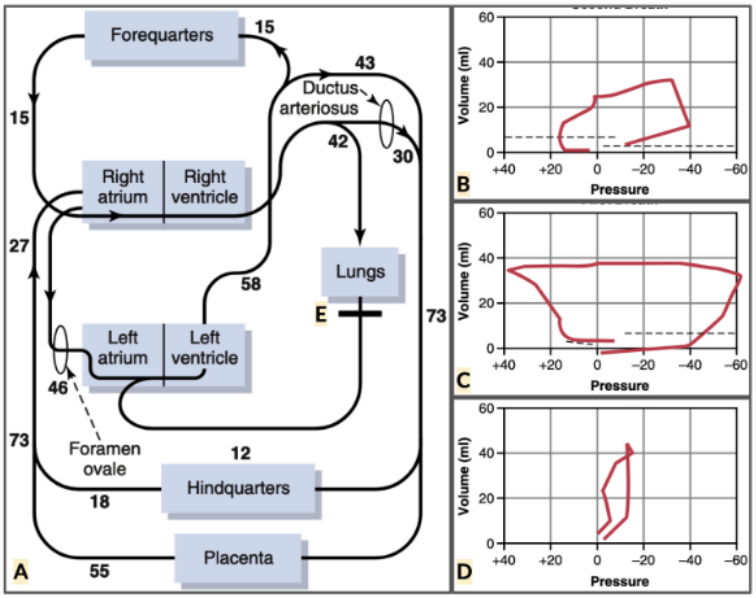


Cardiac output curves at different levels of intrapleural pressure and different degrees of cardiac tamponade.

Following each step, you obtain a CO vs. RAP curve (shown above) by transiently altering venous return. Mark the following statements as either TRUE or FALSE.

I. After performing the above steps in order, you will observe a right-shifted (compared to baseline), left-shifted (compared to step 1), right-shifted (compared to step 2), and finally left-shifted (compared to step 3) RAP vs. CO curve.
II. The curvature shifts in steps 1 and 2 can be explained by adaptive alterations in myocardial contractility.
III. In step 4, venous return increases, increasing total blood flow back to the heart.
IV. If instead we measured RAP with respect to pericardial pressure, the apparent rightward shifts caused by changes in external pressure would be mostly eliminated.
V. Just like a tension pneumothorax, step 2 will cause hypotension and jugular venous distension.

5. Consider the following diagrams. The left image (A) depicts the fetal circulatory system, showing the relative distributions of blood flows to the different vascular areas. The numerals represent the percentage of the total output from both sides of the heart flowing through each particular area. The right image (B-D) diagrams the lungs' pressure-volume curves of a neonate at various times.



Anish is studying how various neonatal/fetal defects can impact respiratory physiology. Particularly, he notes the following defects:

- A patent foramen ovale (PFO) is a heart condition where a small flap-like opening between the heart's atria doesn't close after birth.
- A patent ductus arteriosus (PDA) is a heart defect where the ductus arteriosus, a normal fetal blood vessel connecting the aorta and pulmonary artery, fails to close shortly after birth.

Furthermore, Anish is studying the effects of a blockage at point E on image A.

Identify whether the following statements are TRUE or FALSE:

I. If a PDA occurs while the obstruction at point E is present, the transition from the pressure-volume curve seen in B/C toward the curve in D will be delayed following birth.

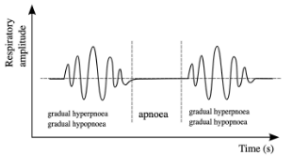
II. A PFO will compensate for the obstruction at point E by allowing oxygenated blood to recirculate, accelerating the maturation of lung compliance.

III. Given a patient with an obstruction solely at point E, pulmonary blood flow will decrease while right ventricular afterload increases; the lung's pressure-volume curves will not change.

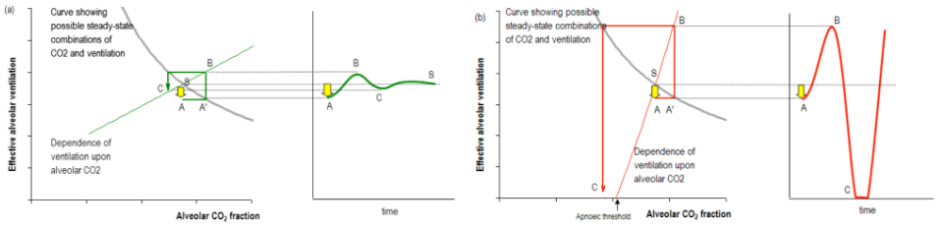
IV. If BOTH a PDA and PFO are present in addition to the obstruction at point E, pulmonary venous return will increase and move the lung's pressure-volume curve closer to image D.

V. The pulmonary patterns observed in B-D reflect lower pulmonary blood flow in the fetus, so a condition that reduces pulmonary perfusion after birth will result in neonate-like pressure-volume curves.

6. A cohort of patients with advanced systolic heart failure exhibit Cheyne–Stokes respiration during sleep (shown below). The SSBSG performs various tests on the patients to better understand respiratory physiology.



Cheyne–Stokes respiration: alveolar ventilation vs. time



I. If central chemoreceptor sensitivity to CO2 is increased, the steady state will be shifted leftward and placed in a region where perturbations don't decay.

II. Given that total CO2 production is equal to VCO2, at the peak of hyperpnea during Cheyne-Stokes respiration, if alveolar ventilation doubles compared to the mean steady-state value, end-tidal CO2 will fall to about half its steady-state value.

III. The crescendo–decrescendo envelope observed can be explained because if the linearized gain of the ventilatory response around the steady state exceeds the inverse slope of the CO2 production hyperbola by a factor greater than 1, any small perturbation of alveolar ventilation will grow exponentially to a point.

IV. If low-flow oxygen is administered, disregarding the action of peripheral chemoreceptors, oscillations will remain; this suggests that hypoxic drive is not a prominent oscillator.

V. During the apneic phase, there is 0 functional alveolar ventilation.

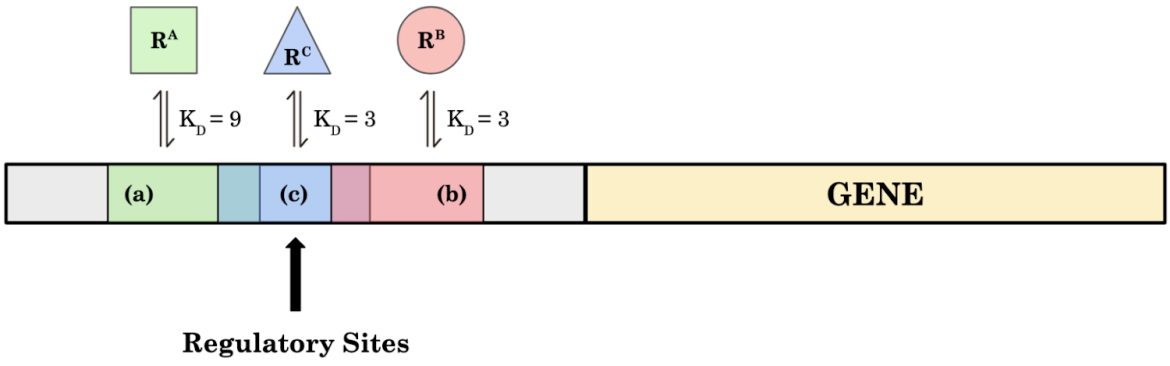
Genetics & Evolution (7 questions)

7. Aryan is studying genetics with Anish. They're studying two loci, X/x and Y/y, in a diploid organism. X and Y are on the same chromosome at an unknown distance apart. An individual heterozygous for both genes is crossed with an individual who is homozygous recessive for both genes. Unfortunately, the linkage phase (i.e., cis or trans) of the heterozygous individual is not known. Thus, XY/xy or Xy/xY are possible. Anish determines the phenotypic frequencies of offspring such that $p_1 \geq p_2 \geq p_3 \geq p_4$ and $p_1 + p_2 + p_3 + p_4 = 1$ (assume a sufficiently large number of trials). Determine whether the following statements are either TRUE or FALSE.

I. $p_1 = p_2$.
II. Discovering that the linkage phase is cis will decrease the recombination frequency r.
III. $p_3 + p_4 = r$.
IV. Parental haplotypes will be the most frequent.

8. Consider a floral pigment synthesized from a colorless precursor in a three-step enzymatic pathway. Pigment intensity depends on the flux through the pathway, which is determined by the rate-limiting enzyme.

The regulatory gene R encodes a transcription factor that upregulates a gene that's spliced into the three enzymes for the synthesis pathway. R has three alleles, A, B, and C, whose protein products compete for binding. Sites (a), (b), and (c) have strong, weak, and moderate up-regulation, respectively, when bound to their specific protein (note sites of overlap). High or intermediate expression of all three enzymes results in a dark purple and lavender color, respectively. Low expression of any enzyme will result in a white flower. In addition, a second gene, S, determines promoter accessibility, with recessive S causing a 5-fold increase in K_D for (a). Assume phenotype depends on the maximally activated regulatory site.



I. The probability of obtaining lavender flowers exceeds the probability of obtaining either white or dark purple flowers.

II. Among F1 progeny possessing at least one copy of the A allele at R, the presence of a recessive S phenotype reduces the probability of dark purple flowers by ∞.
III. There exists a genotype among the offspring in which dominance at the R locus is not observable.
IV. Given that an offspring has genotype $R^{C}R^{-}Ss$ (- means unknown allele), the probability of it being lavender is 1/3.

9. In a large population of diploid Raymonds, ClashAddition is a disease controlled by an autosomal locus that has alleles A and a. Mutation from A to a happens at a rate u per generation, while mutation from a to A happens at a rate v per generation. You may assume an infinitely large population and random mating. It's also known that AA and Aa genotypes confer a fitness of 1, while aa confers a fitness of 1-s (aa is fully recessive and deleterious). Mutation is weak but nonzero, and the system reaches a mutation-selection balance.

- p = **frequency of A**
- q = **frequency of a**
- $\hat{q}$ = **equilibrium frequency of a**

Note that in the absence of selection:

$$\Delta q = up - vq \text{ and } \hat{q}_{\text{mutation only}} = \frac{u}{u+v}$$

Identify whether the following statements are true or false:

I. If s = 0 after the population has reached mutation-selection equilibrium, the allele frequency will initially change towards an increasing q.
II. If v = u, the equilibrium allele frequency is $\hat{q} = 1/2$
III. If mutation is halted after equilibrium is reached, the frequency of a will decrease faster when it is rare than when it is common.
IV. If s ≪ u, the equilibrium allele frequency approaches the mutation-only equilibrium.

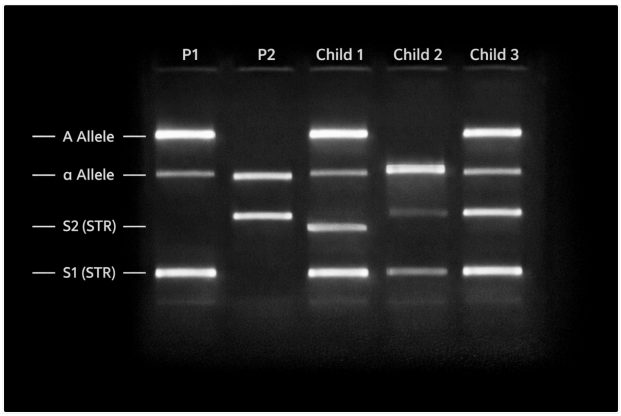
10. A haploid colony of S. *cerevisiae* mutants, all mutated for a single gene responsible for the production of yellow pigment, appears phenotypically white. The colony was then subjected to intense UV radiation, plated on minimal media, and grown. Additionally, one colony of WT yeast and one colony of yellow-pigment mutants without additional UV radiation were plated and grown.



Using the information and image above, identify whether the following statements are TRUE or FALSE:

I. The mutated allele is important for the growth of S. *Ceriviseae*.
II. The majority of the yellow colonies in the UV-treated plate exhibit the WT phenotype due to reversion of their original mutation
III. If a yellow colony from the UV-treated plate is crossed with a WT and allowed to sporulate, the presence of the original mutant in some of the progeny of this cross would indicate that the UV-treated yellow colony's original mutation was NOT reverted.
IV. If a yellow colony from the UV-treated plate is crossed with a WT and allowed to sporulate, the presence of only WT progeny could indicate the yellow colony is a double mutant in two closely linked genes.

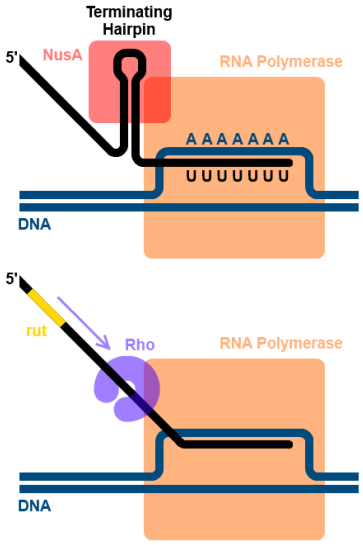
11. A couple (P1 & P2) had three children and gel electrophoresis was performed on gene A. This gene's homozygous recessive form is known to cause pink eyebrows with 70% penetrance. Gene A is also known to be linked to an STR, S, which comes in two isoforms: S1 & S2.



Identify whether the following statements are TRUE or FALSE:

I. If this disease is X-linked, child 2 must be male.
II. If this disease is autosomal, a non-disjunction must have occurred in P1.
III. Assuming an autosomal recessive pattern of inheritance, if child 3 has a child with a pink-eyebrowed individual, their child has a 35% of having pink eyebrows.
IV. S2 is linked to the a allele, while S1 is linked to the A allele.

12. Bacterial transcription termination may occur through one of two mechanisms: Rho-dependent or Rho-independent.



- In Rho-dependent termination, Rho recognizes a 50-90 nucleotide long sequence rich in C nucleotides and poor in G nucleotides called the rut-site. After binding,

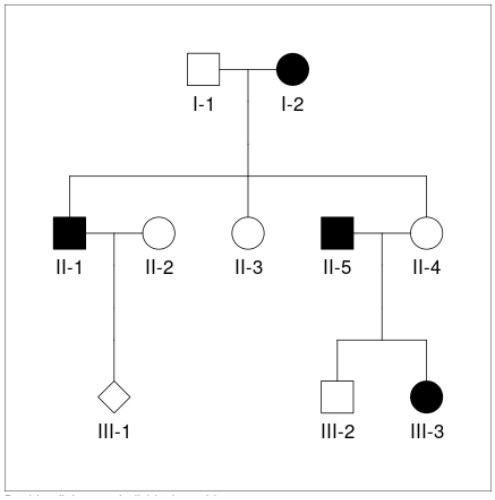
Rho moves towards the paused fork, unwinds the RNA-DNA hybrid, and causes RNA dissociation.

- In Rho-independent termination, a GC-rich sequence followed by an A-rich sequence is transcribed. The GC-rich sequence is self-complementary, forming a terminating hairpin.

Identify whether the following statements are TRUE or FALSE:

I. The relatively low abundance of G nucleotides in the Rho-dependent mechanism mainly serves to lower the number of hydrogen bonds in the RNA-DNA hybrid behind the replication fork.
II. The high variability in nucleotide count of the rut site (50-90 nt) indicates this site is likely not very well conserved.
III. The high A count following the terminating hairpin serves to increase ease of RNA polymerase release.
IV. Transcription termination in eukaryotes relies on similar mechanisms

13. A certain gene is known to confer stubby fingers in its recessive form. In the general population, 2% of individuals are known to have stubby fingers. Assuming Hardy-Weinberg equilibrium, and based on the pedigree below, identify whether the following statements are TRUE or FALSE:



I. This pedigree is consistent with an autosomal recessive pattern of inheritance
II. Assuming X-linked inheritance, the probability that III-1 is a male with stubby fingers is 6.07%
III. If stubby fingers was X-linked dominant, the frequency of the mutant allele is lower than if it were X-linked recessive

IV. If stubby fingers are X-linked recessive and III-2 mates with a random normal-fingered individual, the probability that their child is an affected son is 6.19%

Cell Biology (6 questions)

14. mRNA samples from 3 different breast cancer subtypes— Luminal A, Basal-like, & HER2—were reverse-transcribed into cDNA, amplified, and placed onto a microarray plate (1). Principal component analysis (PCA) on transcriptomes across all 3 subtypes was then performed (2). Expression of different receptors across different subtypes (3).

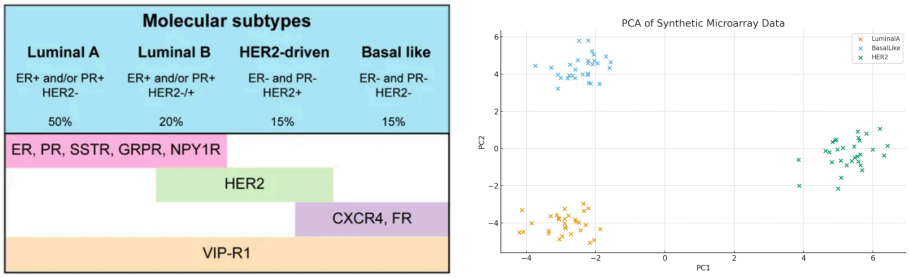


Fig. 2 *Principal Component Analysis is a technique to simplify complex data by reducing dimensions, transforming variables into new, uncorrelated ones called principal components (PCs) that capture the most variance in the dataset

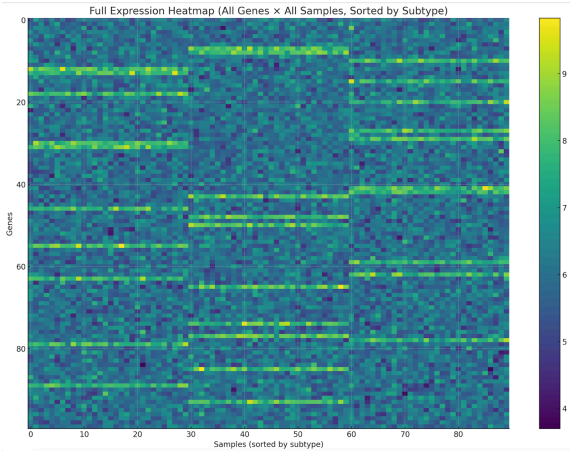


Fig 1. ER: estrogen receptor, PR: Progesterone receptor, HER2: Human epidermal growth factor receptor

Based on the data provided, indicate whether the following statements are true or false:

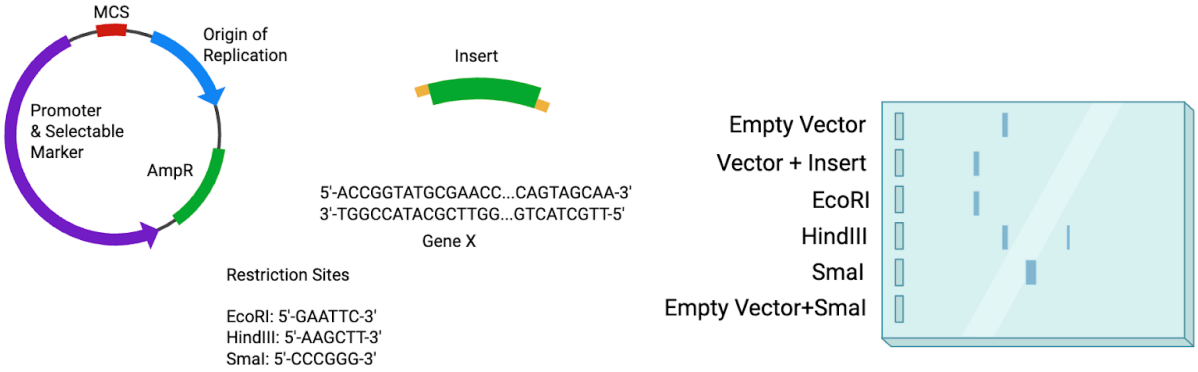
I. Tamoxifen (a selective estrogen receptor modulator/SERM) treatment would be more effective in treating the HER2 subtype than luminal A subtype.

II. PC1 in figure 2 is more indicative of HER2 expression, while PC2 is more indicative of ER & PR expression.

III. The left column of figure 1 may correspond to the luminal A subtype.

IV. A much greater number of genes are overexpressed in HER2 than in basal-like subtypes.

15. Ajay has recently designed an insert of gene X for cloning . However, he has unfortunately forgotten what primers, as well as which restriction endonuclease(s) he utilized to do this. Shown below is the empty plasmid, as well as the sequence of gene X. The top strand (5'-ACC...CAA-3') is the sense strand. Additionally, various restriction sites, as well as restriction digests of the empty vector, vector + insert, and various restriction digests of the vector with the insert were performed and are shown at right. Unfortunately, Ajay also forgot to load the bottom well, so no bands are shown.



Note that the top 2 wells are circular (non-linearized) forms of the vector.

Utilizing the data above, identify whether the following statements are true or false:

I. By including a promoter within the insert, the amount of successful transformations (i.e., yeast that may transcribe gene X) can be expected to double.
II. SmaI and HindIII are both suitable restriction enzymes for cloning, while EcoRI is not.
III. The forward primer used for insertion may have been 3'-CCCAAGCTTATGCGAACC-5'
IV. If Ajay remembered to load the bottom well and there was a single band that migrated further than the empty vector alone, then there exists a SmaI site within both the insert and the empty vector.

16. Identify whether the following statements regarding respiration are true or false:

I. Glycolysis and alcohol fermentation release carbon dioxide, while lactic acid fermentation does not.

II. NADP+ and NAD+ can be expected to be found at much greater concentrations within the stroma than the thylakoid lumen.
III. A mutation in the alcohol dehydrogenase gene of beer-brewing yeast would result in excess buildup of NADH.
IV. Rapidly removing the ethanol from the media that beer-brewing yeast are growing in would allow for a higher yeast concentration than would be normally expected.

17. Shikimate is produced via the shikamate pathway (Fig. 2). Shikamate is converted into chorismate, which acts as a branch point for aromatic amino acid biosynthesis. Shikamate itself is also a highly useful pharmaceutical product, and strategies for producing shikamate through bacterial hosts have been utilized. One previous approach has been KOs of pyruvate kinase, the phosphotransferase system (PTS), and redirection of carbon flux from pyruvate to PEP by PEP synthase expression. However, these approaches often cause growth defects that are difficult to recover. As such, alternative methods for producing shikamate remain an active area of study.

Utilizing Corynebacterium *glutamicum* (*C. glutamicum*) as a host for shikamate production, scientists performed transformations utilizing various plasmids across various C. *glutamicum* mutants with knockouts across different genes. Information regarding strains and plasmids are shown in the table below.

Strain SA-2 carried a Ser361Phe (S361F) point mutation of the 6-phosphogluconate dehydrogenase gene. This mutation is known to cause increased L-lysine production due to enhancement of NADPH supply (Ohnishi et al., 2005). Shikimic acid production titers in SA-7 strains were conducted under 2 sources of carbon: solely glucose (CGGXII) & CGXIIY media, which included a 100-fold higher concentration of tryptophan, tyrosine, & phenylalanine (Figure 4).

Sato, Naoki, et al.

Strain/plasmid	**Genotype**
ATCC13032	WT
SA-1	ATCC13032 + ΔcglMRR, Δqsu, ΔqsuB, ΔnagD, ΔaroK
SA-2	SA-1 + gnd^{S361F}
SA-7	SA-2 + $aroG^{gtg->atg}$, Δcg2392 +aroK:P_{H36}aroB, pta:P_{H36}-aroG
PCC-P_{H36}-aroG	pCCS containing aroG under H36 promoter
PCC-P_{H36}-aroB	pCCS containing aroB under H36 promoter
PCC-P_{H36}-qsuC	pCCS containing qsuC under H36 promoter

PCC-P_{H36}-aroE1	pCCS containing aroE1 under H36 promoter
PCC-P_{H36}-aroE3	pCCS containing aroE3 under H36 promoter

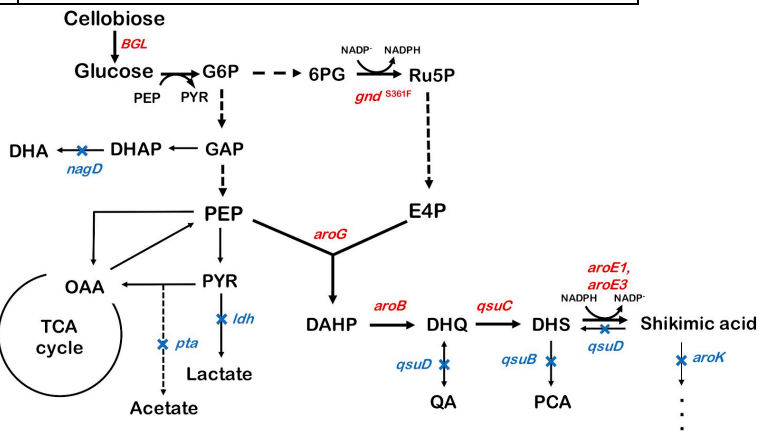
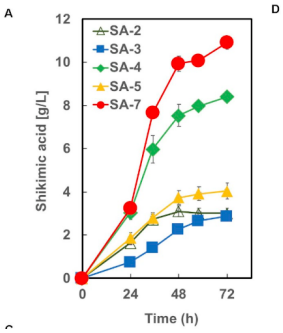
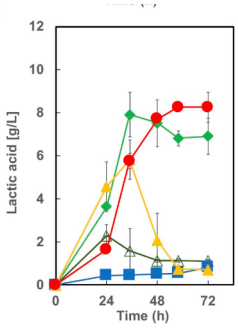
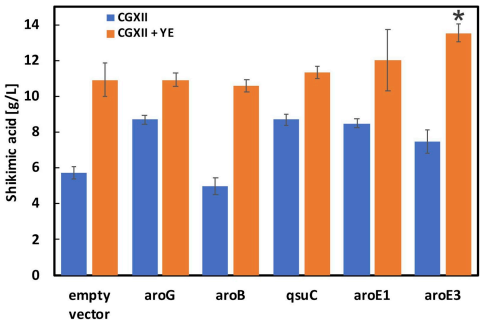


Fig. 2: Shikamate pathway





(Fig. 3) Culture profiles of SA-7 and its derived strains. (A) Shikimic acid production (D) lactic acid accumulation.



(Fig 4) blue (CGXII): just glucose; orange: CGXIIY

Using the data above, identify whether the following statements are true or false:

I. SA-4 may have a knockout in lactate dehydrogenase (ldh).
II. It can be expected that strains SA-2 & SA-3 exhibited higher rates of cell growth than SA-4 & SA-7.
III. The data in fig 4. suggests that via aromatic amino acids exert strong negative feedback on shikamic acid synthesis.
IV. AroG knockout C. *glutamicum* strains would likely exhibit WT growth on CGXII.
V. Knockout of aroK in SA-1 was restored through transformation with a plasmid.

You should've skipped this ._.

18. Shinya Yamanaka won the Nobel Prize in Physiology or Medicine in 2012 for his research into stem cell physiology. He discovered that through the introduction of four master regulatory genes, c-Myc, Klf4, Sox2, & Oct3/4, differentiated fibroblasts could be “undifferentiated” into induced pluripotent stem cells (iPSCs). Identify whether the following statements are true or false:

I. The 4 Yamanaka factors (c-Myc, Klf4, Sox2, & Oct3/4) are sufficient for fibroblast de-differentiation.
II. The 4 Yamanaka factors (c-Myc, Klf4, Sox2, & Oct3/4) are necessary for fibroblast de-differentiation.
III. Shinya Yamanaka's findings could not be extrapolated to cells that were further differentiated than fibroblasts such as myoblasts or cardiomycetes.
IV. iPSCs would be suitable for treating diabetes mellitus type 1 & 2.

19. The enzyme DER-ASE is a transferase which catalyzes the addition of a DER group onto its substrates. A solution is prepared with DER-ASE among various other substrates, [LARRY], [BIO], and [MSJ]. Rapid conversion of substrate into the products [ONLY-LARRY-OFFENDER], [ONLY-BIO-RENDER], and [MSJ-ATTENDER] is observed.

Another solution of just [MSJ] and DER-ASE, with [MSJ] >> [DER-ASE] was also prepared. A double-reciprocal plot of ENDER-ASE conversion of [MSJ] into [MSJ-ATTENDER] for this second solution is shown below (Figure 1).

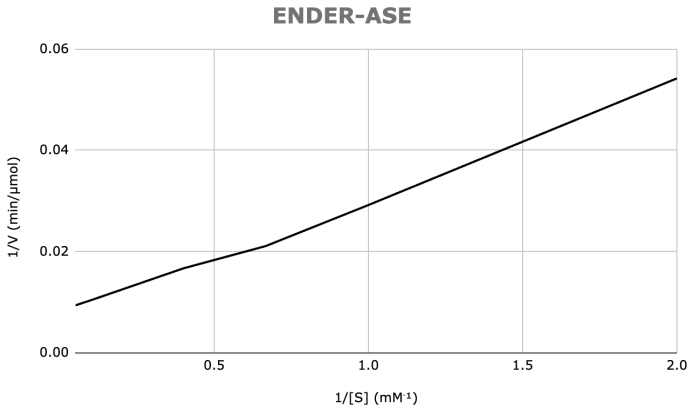


Fig. 1

**For the following questions, assume ENDER-ASE is a multi-substrate enzyme with equal affinity for all of its substrates.*

Identify whether the following statements are true or false:

I. If a double-reciprocal plot of ENDERASE conversion of [MSJ] into [MSJ-ATTENDER] was generated for the first solution, it would have a steeper slope.
II. If a double-reciprocal plot of ENDERASE conversion of *all* of its substrates into product was generated for the first solution, it would be nearly identical to the graph in fig. 1.

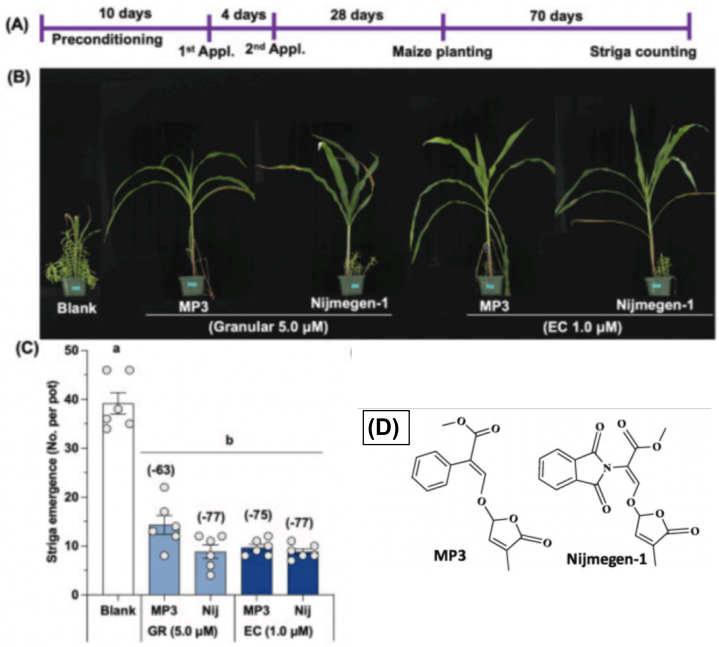
III. If [BIO] and [MSJ] are both substrates of ENDER-ASE, but [LARRY] is an uncompetitive inhibitor, then the apparent K_M of ENDER-ASE in a solution with just [BIO] & [MSJ] would be lower than a solution with [BIO], [MSJ], & [LARRY].

IV. If [BIO] and [MSJ] are both substrates of ENDER-ASE, but [LARRY] is a competitive inhibitor, then [BIO], [MSJ], and [LARRY] likely all have similar structures.

Plant Biology (5 questions)

20. Infesting about two-thirds of the area devoted to cereal crops, *Striga* may be the greatest obstacle to food production in Africa. *Striga* is an obligate root parasitic which often infects the roots of crops such as maize, sorghum, and rice. *Striga* seeds often lie dormant in soil for years, germinating only when a suitable host nearby has begun growth. The signal for *Striga* germination is exudation of strigolactones from host roots.

In order to combat *Striga*, the granular (GR) and liquid formulation (EC) of MP3 and Nijmegen-1 (at 1.0 or 5.0 μM) were applied two times in *Striga*-infested pots to induce germination for four weeks. Striga emergence was counted 70 days after sowing of maize. Maize height was also taken. Chemical structure of MP3 and Nijmegen-1.

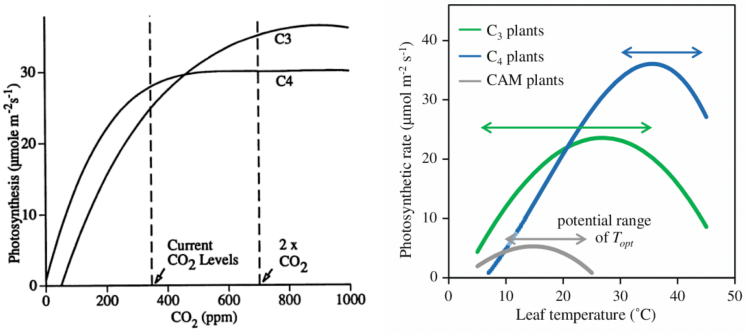


A: *timeline*; B: *maize growth under granular & liquid formulation*; C: *Striga emergence*; D: MP3 & *Nijmegen-1 chemical structure.*

Identify if the following statements are true or false:

I. MP3 functions as a strigolactone analog.
II. Nijmegen-1 is likely a cholesterol derivative.
III. Granular formation of MP3 was more effective than liquid formulation in inducing increased maize height
IV. Decreased emergence of *Striga* is likely due to the induction of precocious germination.

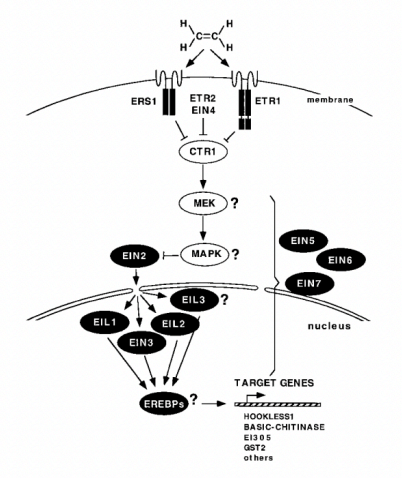
21. Since the late 1800s, global carbon and temperature have both steadily risen. This has affected both the distribution and function of C3 and C4 plants globally.



Based on the data above, identify whether the following statements are true or false:

I. At current carbon dioxide levels, maize would likely outperform rice photosynthetically.
II. C4 plants are likely to show greater increases in photosynthesis due to increased temperatures than C3 plants.
III. C3 plants are likely to show greater increases in photosynthesis due to increased carbon dioxide levels than C4 plants.
IV. Assuming global carbon and temperatures continue to rise, C3 plants will certainly outperform C4 plants.

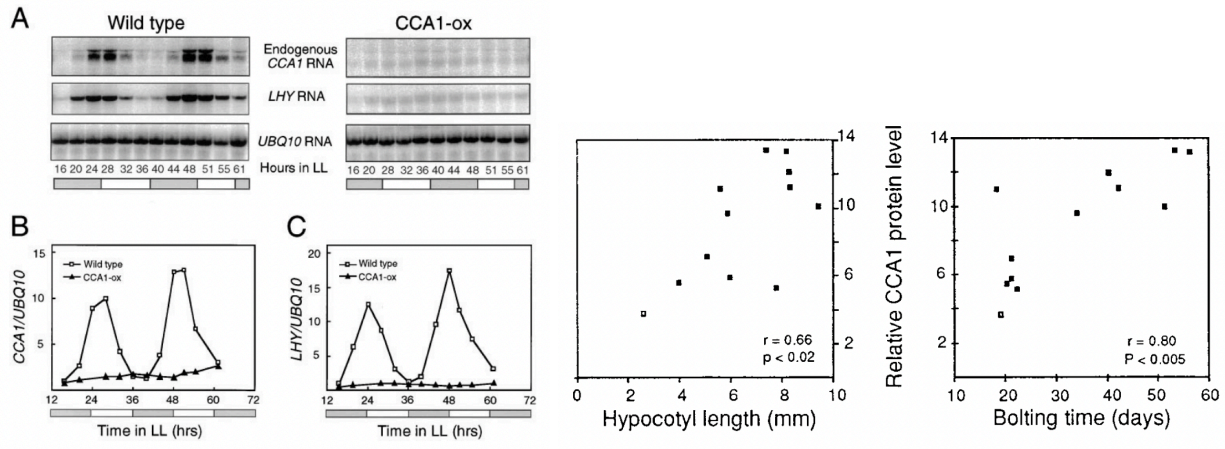
22. Three different mutants in the response pathway for ethylene are being studied. Strain W has a loss-of-function in MAPK, strain X has a loss-of-function mutation in EIN2, & strain Z has a loss-of-function mutation in CTR1. The pathway is shown below.

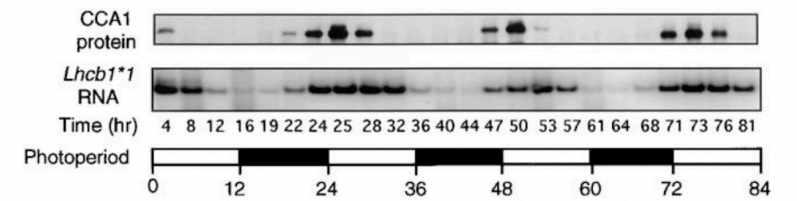


Based on the figure above, identify whether the following statements are true or false

I. A cross between strain X and strain W would not exhibit the triple response
II. If a deciduous tree's leaves all exhibited the same mutation as strain Z, this tree would phenotypically be more similar to an evergreen.
III. If a plant exhibiting the same mutation as strain X were submerged in waterlogged water, it would be more susceptible to drowning
IV. Assuming MAPK and EIN2 don't impact other pathways, a double mutant with mutations X AND Z would be phenotypically identical to Strain X.

23. The circadian clock-associated 1 (CCA1) gene encodes for a transcription factor that helps regulate rhythmic gene expression by binding to promoters for genes such as Lchb, which is necessary for phytochrome responsiveness. CCA1 is also known to act in concert with LHY to regulate circadian rhythms. In order to study the regulation and expression of these clock genes, qRT-PCR on CCA1 and LHY was performed in WT and constitutive CCA1 expressing mutants (CCA1-ox) (fig 1). Temporal expression of CCA1 protein in WT was also monitored via affinity-purified anti-CCA1 antibodies (fig 2). Finally, hypocotyl length and time to bolting were monitored in 11 CCA-ox lines (dark boxes) as well as 1 WT line (open box) (fig 3).





Identify whether the following statements are true or false

I. Constitutive expression of CCA1 inhibits transcription of the *LHY* gene.
II. CCA1 and LHY periodically alternate expression.
III. Overexpression of LHY may cause increased hypocotyl length and decreased time to flowering (bolting).
IV. Lchb1*1 RNA may act as an activator of CCA1 expression.

24. Over time, plants have evolved a wide variety of adaptations to adapt to their changing environments. Identify whether the following statements are true or false:

I. As plants have gotten more complex, the gametophyte generation has monotonically decreased in size.
II. The evolution of lignification in gnetophytes is what allowed plants to begin growing large and tall.
III. The retention of flagellated sperm in some gymnosperms, such as Ginkgophyta and Cycadophyta, indicates that these phyla are more basal than conifers such as redwoods and pines
IV. A homosporous plant is likely more basal than a heterosporous plant.

Ecology (4 questions)

25. Tropical forests are some of the oldest and most diverse ecosystems on Earth. Identify whether the following statements regarding tropical forests are TRUE or FALSE:

I. Tropical rainforests often have evergreens, while tropical dry forests often have deciduous trees.
II. Epiphytes such as bromeliads are more common in tropical dry forests than tropical rain forests.
III. Tropical rainforests have little seasonal variation in temperature, while tropical dry forests show great variation.
IV. Tropical forest soils are extremely rich in nutrients.

26. The granular poison frog (*Oophaga granulifera*) is a species of frog native to Costa Rica. Its bright aposematic coloration has been evolutionarily advantageous in warning potential predators from ingesting poison that makes them sick and vomit. Furthermore, male granular poison frog spends the majority of its time and energy defending its calling site with predominantly vocal warning signals. If an encroaching male approaches too closely, a fight could ensue.



Identify whether the following statements are true or false:

I. Aposematic coloration in *Oophaga granulifera* is an example of positive frequency dependent selection.
II. Intraspecific competition between males of *Oophaga granulifera* has likely driven the evolution of aposematism.
III. If a mutation in *Oophaga granulifera* causes their poison to become relatively harmless, selection for cryptic coloration rather than aposematic coloration would likely result
IV. If a mutation in *Oophaga granulifera* causes their poison to become deadly, selection for cryptic coloration rather than aposematic coloration would likely result.

27. The Lotka-Volterra model for predatory-prey may be used to describe the dynamics of biological systems in which two species interact, one as a predator and the other as prey. In a certain ecosystem, foxes prey on rabbits. Equations for the model as well as initial conditions are shown below; a graph of relative species oscillations is also shown.

$$\frac{dx}{dt} = \alpha x - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$

Prey growth	0.1
predation	0.02
Predator death	0.3
Predator efficiency	0.01
Initial prey	40
Initial predator	9
Time steps	200

Figure 1. Lotka-volterra equations; figure 2. Initial conditions

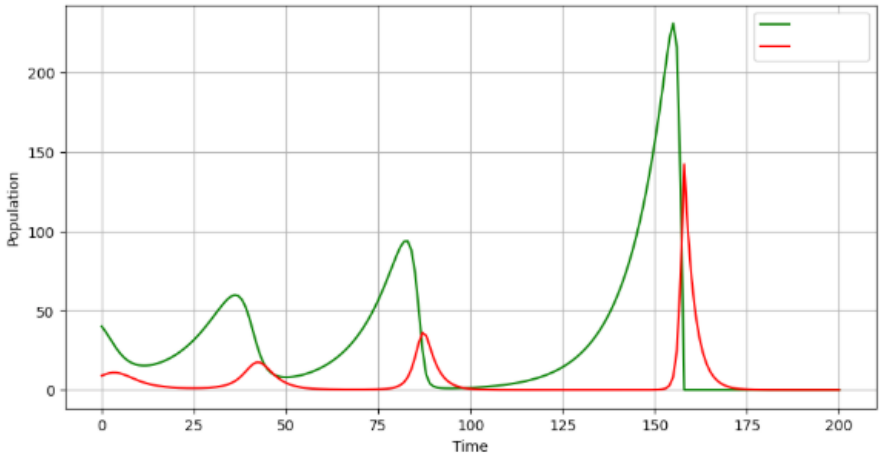


Figure 3. Species versus time

Identify whether the following statements are TRUE or FALSE:

I. The green line represents foxes.
II. Given a sufficient number of time steps, foxes will drive the rabbits to extinction.
III. In figures 1 and 2, alpha and beta correspond to prey growth and predator efficiency, respectively.
IV. This model suggests a bottom up regulation of species abundance

28. Different nutrients are more or less available in different ecosystems. Identify whether the following statements are TRUE or FALSE:

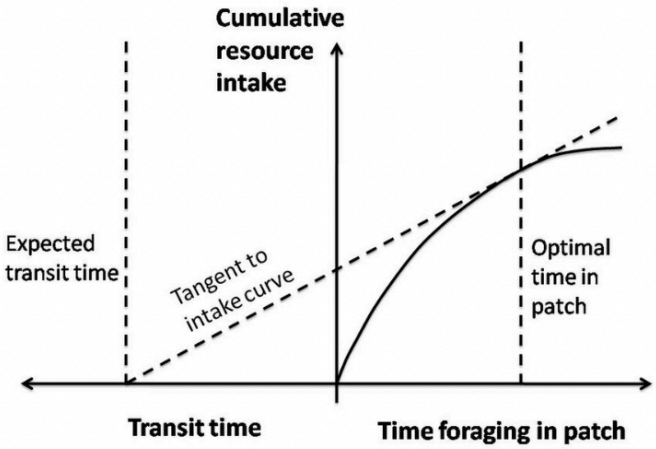
I. Globally, nitrogen and phosphorus are the two most limiting resources.
II. In older ecosystems, nitrogen tends to be more limiting than phosphorus.

III. In marine environments, nitrogen tends to be the most limiting.
IV. Eutrophication may be considered a beneficial disturbance long-term in nutrient depleted waters.

Ethology (2 questions)

29. The marginal value theorem (MVT) is a model used to describe optimal foraging in a system with resources localized to discrete patches. It states that the resource consumer should leave the patch it's currently in when the marginal capture rate drops to the average capture rate for that habitat.

In this model, the optimal time spent in a patch is given by the tangent to the resource intake curve that departs from the expected transit time value.



Identify whether the following statements are true or false:

I. This model assumes that resource intake within a patch stays constant with time.
II. The MVT could be used to model a lizard basking on a rock to soak up the sun
III. If this model were used to model root branching, low nitrate conditions would result in a tangent line with a steeper slope than high nitrate conditions.
IV. If this model were used to model mate territoriality, males of semelparous species would spend more time defending their mates than males of iteroparous species.

30. Mating systems may be monogamous or polygamous. Identify whether the following statements regarding monogamy and polygamy are TRUE or FALSE:

I. Monogamy is more common in larger species.
II. Polygamy maximizes effective population size.

III. Polyandry is more common than polygyny.
IV. Polygyny is associated with a higher certainty of paternity than polyandry

Biosystematics (2 questions)

31. Environmental DNA (eDNA) was extracted from various ponds and lakes using a set of universal PCR primers (MiBird) and amplified. Analyses of water samples from zoo cages of birds with known species composition suggested such primers in conjunction with NGS could successfully detect avian species in water samples.

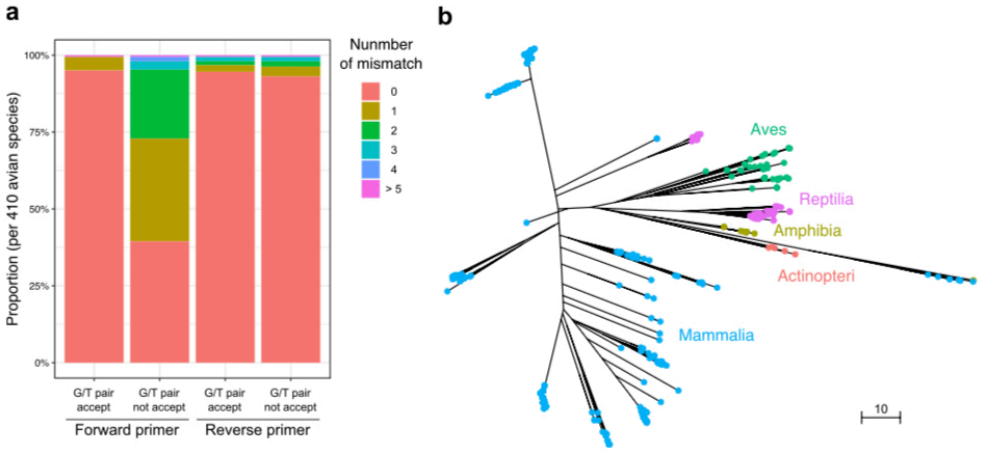


Figure 1. *In silico* evaluations of MiBird-U primers. Binding capacity of MiBird-U primers (**a**). y-axis represents the proportion of avian species that showed 0, 1, 2, 3, 4, or >5 mismatches (indicated by different colours) with MiBird-U F/R primers. The total number of avian species evaluated was 410. The phylogenetic tree was constructed for species that can be amplified using MiBird-U primers (**b**). A total of 2,000 sequences were retrieved from the database to construct the phylogenetic tree. Different classes are represented by filled circles with different colours. Lengths of branches correspond to the differences in sequences. Bar indicates edit distance.

Based on the information and figure, identify if the following statements are true or false:

I. Trees constructed utilizing MiBird primers are largely inaccurate in representing true phylogenetic relations
II. Forward and reverse primers showed similar numbers of mismatches
III. Reptilia and Aves showed a similar number of pairwise differences with mammalia
IV. Researchers constructing these trees should be weary of DNA contamination from other aquatic organisms such as diatoms and phytoplankton

32. Traits that are present in different species but have evolved independently are called homoplasies. Traits that are present in different species due to shared ancestry are called

homologies. Identify whether the following four choices are examples of homoplasies (True) or homologies (False):

I. Four chambered heart of birds and orangutans
II. Closed circulatory system of octopuses and mammals
III. Acoelomatous body plan of flatworms and ctenophores
IV. Dioecy in Gingko and Kiwis

Congratulations!