The Use of DATA BASED QUESTIONS (DBQs) To Help Students in Advanced Placement Biology Develop Critical Thinking Skills

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Introduction

The Advanced Placement Biology course was radically revised beginning in the 2012-13 school year. One of the goals of the College Board in making the revision was to increase the ability of students to analyze real world science data. That data may be presented in the form of tables, graphs, written descriptions and models. In addition, it requires students to consider the statistical significance of the data by examining the Standard Error of the Mean (SEM), considering error bars, or doing a chi square analysis. The students are expected to use mathematical analysis in their studies. That includes, but is not limited to examining Hardy-Weinberg equilibria, population growth (exponential and logarithmic), and studies of water potential.

In order to meet the new demands, I designed a set of 74 Data Based Activities which include questions in various formats. The intent is to challenge the students to "think" about the discoveries made by scientists: What was the basis of their experimental design, what factors did they control for, what is the independent and dependent variable, what statistical tools were used to analyze their data, what model accounts for the results of their experiment(s), what conclusions were the scientists justified in making and how do those conclusions affect the way scientists view a particular phenomenon.

The activities cover the following areas of biology: Biochemistry, Molecular Genetics, Classical Genetics, Cell Biology, Energetics: Photosynthesis and Cell Respiration, Animal, Physiology, Plant Physiology, Evolution (including taxonomy), Development, and Environmental Science (including Ethology). I am providing four examples, along with sample answers (in red), to give a sense of how these DBQs address the issues described above.

My AP Biology class is usually taught frontally (except for lab) and I take a Socratic approach, using many questions that the students must contemplate and respond to and that guides students from point to point. However, the weakness of this system is that only one student gets to verbally respond to any given question. Yes, my hope is that ALL of the students are thinking about the question and trying to come up with an answer, but I have no way of knowing for sure if that is happening. The DBQs are used in class or assigned for homework, and so the students must be "thinking" to come up with their answer. They must ALL write out their answers and so they must all think.

The first activity (see SAMPE 1 below) supports the cell unit. The students have learned about the general function of the endoplasmic reticulum. Here they have an opportunity to apply what they have learned and to analyze data related to how this cell structure affects the recommended dosage of a drug. It is based on an article in the magazine "Science" (see bibliographic information at the end of the activity).

SAMPLE 1

The smooth endoplasmic reticulum (SER) has a number of enzymes which metabolize alcohol and other drugs such as the a tranquilizer called meprobamate. (This drug was introduced in the 1950s, but has been mostly replaced by other tranquilizers) The graph[1] shown in figure 1 shows how long it takes to clear 50% of the drug from an experimental group that had been consuming ethanol for a period of one month and a control group which was not consuming ethanol.

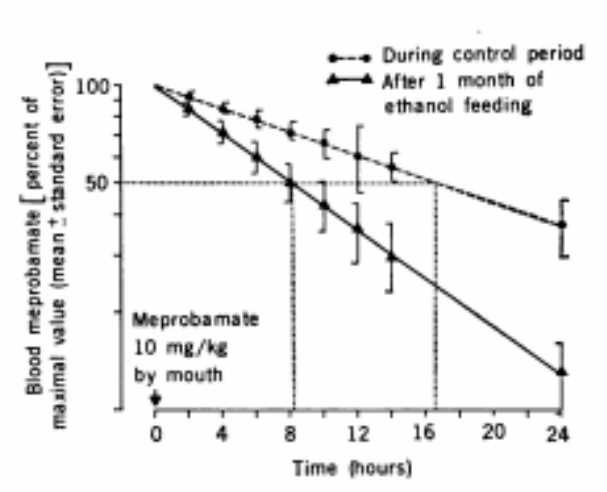


Figure 1

Q1. Compare how much did the time it takes for the body to clear the drug in alcohol consumers and alcohol non-consumers. View the error bars on the graph. Is your conclusion statistically supported? Explain

It took a little of 8 hours to clear 50% of the drug in those feeding on alcohol compared to over 16 hours in the control group. The fact that the error bars of the early readings does NOT overlap with the error bars at 8 and 16 hours for the experimental and control respectively shows that the stated conclusion is statistically supported.

It has been observed that alcohol consumption increases the amount of SER in liver cells, and that the SER are also responsible for detoxifying and removing various drugs. There are other drugs (including certain narcotics) which also increase the amount of SER found in cells.

Q2. Why is this information important for pharmaceutical companies who must insure that the proper dosages of drugs are given to patients? Explain.

The recommended dosage of the drug would depend on whether or not the patient had been consuming alcohol. Since the SER increases in amount as the result of alcohol consumption and since the SER has enzymes which detoxify by breaking down drugs, the recommended dosage hinges on whether or not the patient consumes alcohol.

Q3. How do these finding explain why drug addicts feel the need for increasing amounts of their illicit drugs to obtain the desired effects of those drugs?

Drug addicts build up more SER, so the effect of the drugs that they are taking is diminished. To overcome the diminished positive feelings that the addict senses, the addict will feel the need to increase the amount of illicit drugs being taken.

Q4. What is the general role of the SER? From an evolutionary standpoint, why would it be an advantage to have the ability to metabolize alcohol? (Did early mammals, including humans drink alcohol??)

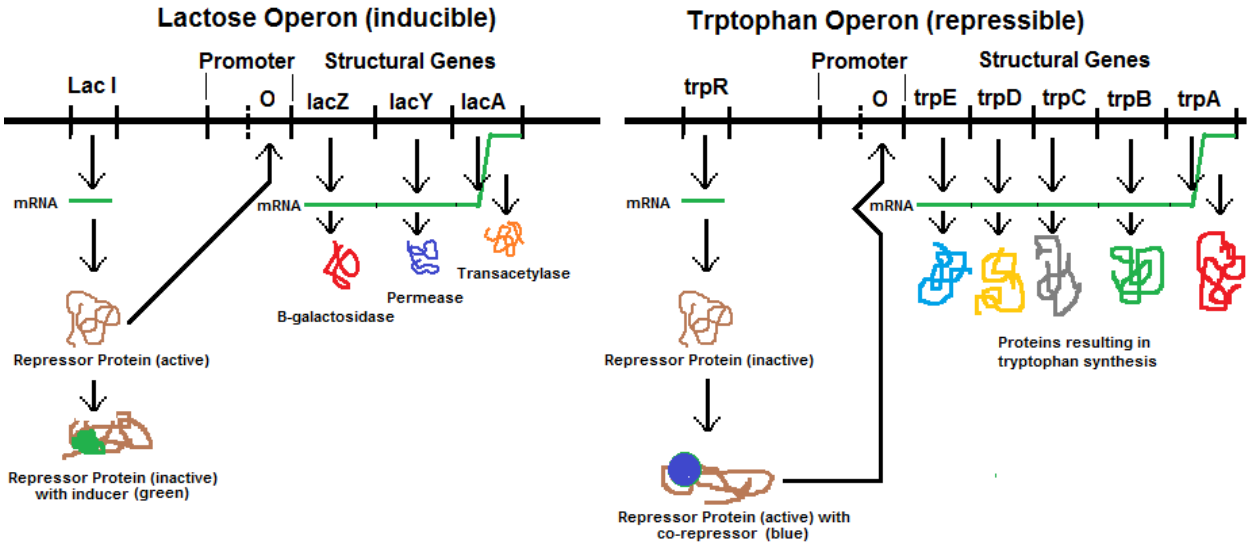
Prior to refrigeration, it was more common to be eating partially fermented food. The alcohol being consumed was removed by enzymes embedded in the membranes of the SER.

Endnotes:

1) E Rubin and C. Lieber. Alcoholism, Alcohol, and Drugs. Science. 1971; 172: 1097-1102.

The second activity (see SAMPLE 2 on the following page) involves modeling how the expression of genes is controlled in bacteria. The students must differentiate between two models; one which supports a catabolic (breakdown) chemical pathway, and the other which supports an anabolic (build up) chemical pathway. At first they seem extremely similar, but when looked into carefully, the key difference become apparent. Although this activity demands that students make some important distinctions, I would still like to collect data from the original experiments so show how the two scientists originally worked out these pathways.

The operon model first proposed by Jacob and Monod in 1961 exemplifies the control of gene expression in bacteria. The lactose operon shown on the left is inducible and the tryptophan operon shown on the right is repressible.



Q1. Explain why natural selection would favor inducible operons when the genes they control code for proteins in catabolic pathways, while natural selection would favor repressible operons when the genes they control code for proteins in anabolic pathways. Note, for example that β-galactosidase (lactose operon) hydrolyzes lactose while the proteins in the trypophan operon are necessary for tryptophan (an amino acid) synthesis.

Catabolic pathways are "breakdown" pathways. An organism would generally need to break up a substance when that substance (often a nutrient) becomes available. So, making the repressor is always being carried out, but the repressor is generally shut down (made inactive) by the inducer which is generally some form of the nutrient. If the nutrient IS available, some of it binds to the repressor and shuts down the repressor….thus allowing for the production of mRNA which codes for the proteins that metabolize the available nutrient.

Anabolic pathways, on the other hand are "build up" pathways. So, if a bacterial cell needs to build up a substance it must turn on the genes which code for the enzymes that build up that substance. Such genes are generally turned on because the repressor can't act by itself...but rather only when a corepressor attaches to it. The corepressor is some form of the product. So if there is enough product, some of it binds to the repressor to form a repressor-copressor complex. That complex attaches to the operator, thus shutting down the expression of the genes which code for the enzymes that make the product…which makes sense, because there is now enough product already made.

Q2. Explain the role of the following:

RNA Polymerase (both operons)

The enzyme that makes RNA when there is no repressor attached to the operator.

Promotor Region of the DNA (both operons)

The section of DNA adjacent to the structural genes that the RNA polymerase recognizes.

Operator Region of the DNA (both operons)

The section of DNA adjacent to the promoter to which a repressor (in an inducible Operon) or a respressor-corepressor complex (in a repressible operon) attaches to.

Repressor (inducible operon)

The substance which attaches to the operator, thus shutting down gene expression.

Inducer (inducible operon)

The substance which attaches to a repressor, thus preventing it from attaching to The operator.

Corepressor (repressible operon)

The substance which attaches to a repressor, thus allowing it to attach to an operator.

The third activity (See SAMPLE 3 on the following page) involves having the students mathematically explore a chromosome mapping question mathematically. The students have to determine the order of three imaginary genes on a chromosome and the distance (relative distance measured in map units) between the genes.

SAMPE 3

Imaginary genes R, B and D are linked on the same "arm" of the same chromosome.

R=round head is dominant over r=square head
B=brown belly is dominant over b=white belly
D=dark eyes is dominant over d=light eyes

The following cross is made: RrBbDd X rrbbdd. For the triple heterozygote parent the three dominant alleles are on the same chromosome. However, the order of the three alleles is not known.

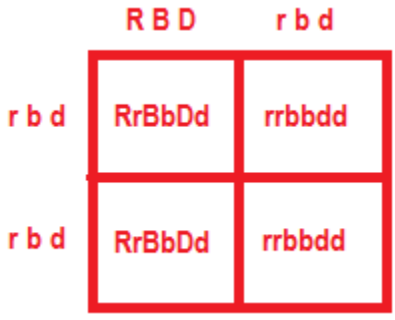
The cross, repeated many times results in the following offspring:

373	round head, brown belly, dark eyes
361	square head, white belly light eyes
89	square head, brown belly, light eyes
94	round head, white belly, dark eyes
28	square head, brown belly, dark eyes
35	round head, white belly, light eyes
9	round head, brown belly, light eyes
11	square head, white belly, dark eyes

Q1. What is the order of the genes on the chromosome, RBD or RDB or BRD. What are the map distances between the alleles?

Note that the cross is between a triple heterozygote (whose phenotype shows all three dominant traits) and a triple homozygous recessive (whose phenotype shows all three recessive traits).

Now examine the 8 classes of offspring. The first two categories (373 and 361) are called parental because their phenotypes are the same as the parents. That is what we expect if there is no crossing over. Consider the punnet square shown to the right. If there is no crossing over, then the offspring will be the same as the parents….hence they are called parental. Since crossing over usually does not occur, they would be in the highest frequency..

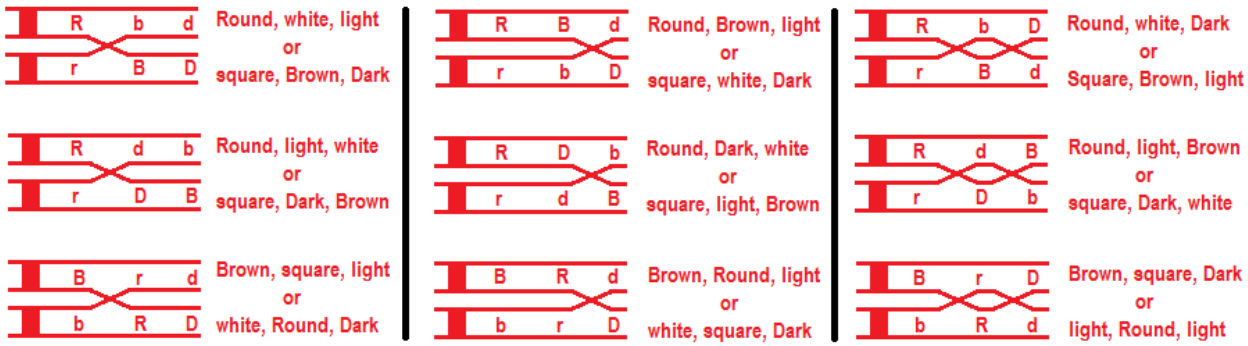


The next four "classes" of offspring (89, 94, 28 and 35) are single crossovers…that is crossovers between the first two alleles and then crossovers between the second two alleles. But the question is….what is the order of the alleles.

Also note the last two categories (9 and 11) are most rare…they are double crossovers.

Since you are asked to choose from three possible gene orders (RBD, RDB and BRD), let's consider which one would match our results. Note that the triple homozygote recessive parent will only produce rbd or rdb or brd gametes. What type of games might the heterozygous parent produce?

You were given 3 possible gene orders RBD (first row), RDB (second row) and BRD (third row). We are just considering the product of the chromatids involved in the crossover event. Also, we can assume that the heterozygote parent could only produce rbd, rdb or brd gametes. That being the case, to the right of each chromosome are the possible phenotypes of the offspring resulting from the single or double crossovers.



Note that only the middle row is consistent with the 2 single crossover categories and the 1 double crossover categories. Hence, the order of the genes is RDB (or rdb)

*Note: See middle row, NOT middle column.

Order of Alleles ___RDB_____

Map distance: Between R and B 20.3+8.3=28.6 MU (MU=map units)
Between B and D [(89+94+9+11)/1000]x100=(203/1000)x100 or 20.3 MU
Between R and D [(35+28+9+11)/1000]x100=(83/1000) x 100=8.3 MU

Q2. Which of the following offspring were NOT the product of a crossover event? 373, 361 Single crossover event? 89,94. 28. 35 Double crossover event? 9. 11

Q3. In the space below, draw the crossover event(s) that leads to offspring that WERE the product of at least one chromosomal crossover.
Shown in the middle row of crossover diagrams above.

The fourth activity (see SAMPLE 4 on the next page) involves data (see figure 1) and a model (see figure 2) that supports an explanation for what controls flowing in plants. This is particularly interesting because the data is based on two 2013 articles. Scientists studying plants have had such a hard time understanding how flowering is controlled in plants. Such a common process and yet the control mechanism have eluded scientists for decades. This data suggests that we are on the cusp of finally understanding how it is regulated.

SAMPLE 4

Researchers have been working for many years trying to determine what causes flowering in plants. There are a number of environmental cues that are involved, but bridging the environmental cue to the flowering event has been elusive. According to a recent study,[1] there is a correlation in the level of sucrose in a plant and the level of a sugar phosphate called trehalose-6-phosphase (T6P) in the leaf (see figure 1).

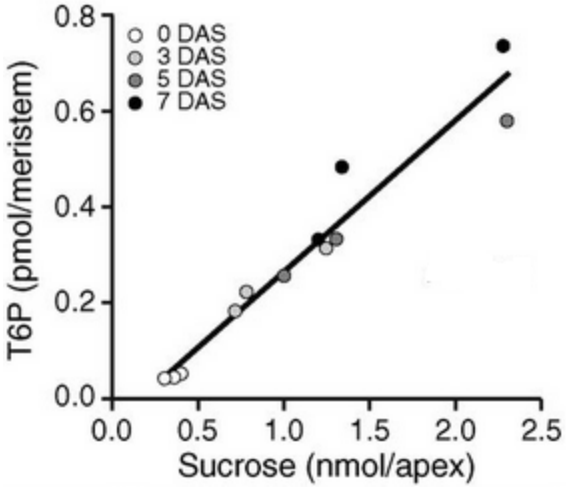


Figure 1

Q1. Based on the graph (see figure 1), describe the relationship between sucrose and T6P levels.

As the sucrose level increases, the T6P level increases.

When the level of T6P rises in the leaf, it also contributes to the production of a protein called flowering locus T (known as FT). FT has been shown to trigger flowering. It is produced in leaves and travels through the phloem to the shoot apical meristem where it triggers flowering.

Q2. Based on the information above what is the relationship between sucrose levels in the leaf and the level of FT produced and released by the leaf?

As sucrose levels increase T6P levels increase and when T6P levels increase, FT levels increase.

Q3. The timing of flowering in plants may be controlled by multiple cues. One of them may be the level of sucrose. Based on your understanding of energetics, what is the evolutionary advantage of the relationship that you described in Q2?

This would ensure that flowers are produced when the plant is actively photosynthesizing, and thus making the organic products needed to support flowers and subsequent seeds and fruit that develop. Successful flowering is crucial to successful reproduction in flowering plants.

Q4. T6P also seems to work in the stem apical meristerm (SAM) which is the part of the plant from which a flower grows. There are microRNAs in the SAM that inhibit flowering. What affect would you suggest that T6P has on the levels of those microRNAs?

These microRNAs may play a role in RNA interference (RNAi). T6P may cause flowering by lowering the levels of the microRNAs.

T6P is found in low quantities in the organisms that it affects and yet it plays important roles in those organisms. It seems to be involved in overcoming several "checkpoints" other than just signaling flowering (see figure 2). Note that it is also involved in controlling yeast cell division and a fungus that grows on rice plants. The key enzyme in the synthesis of T6P is called trehalose-6-phosphate synthase 1 (TPS1).

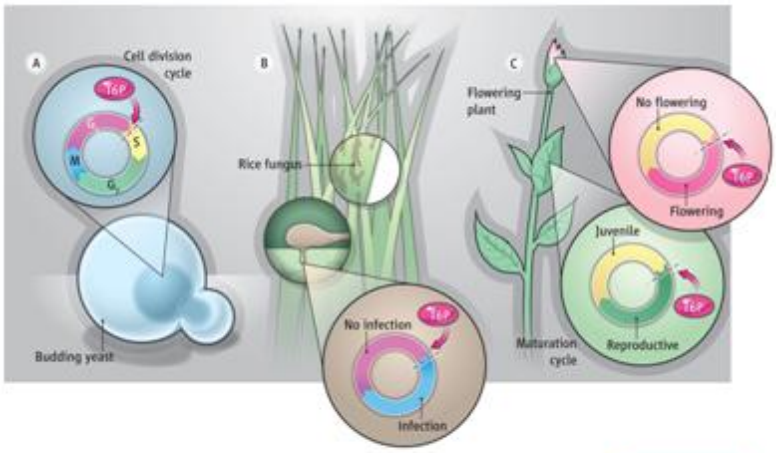


Figure 2[2]

Q5. What does the role of T6P in making "developmental transition decisions" suggest about evolution and TPS1?

TPS1 seems to be found in fungi, plants and animals suggesting common ancestry going far back in time. It may well be that it has been involved as an energy checkpoint for cell reproduction in those organisms and thus signaled such events when there was in fact a source of energy to support those events.

Endnotes

1) V. Wahl et al. *Regulation of Flowering by Trehalose-6-Phosphate Signaling in Arabidopsis thaliana*. Science 2013; 339: 704-707.
2) J Danielson and W Frommer. *Jack of All Trades, Master of Flowering.* Science 2013; 339: 659-660.

Conclusion:

One of the questions that I would like to tackle is to determine to what extent these activities are helping my students become better "thinkers". It is a difficult question to tackle because I cannot practically set up a control group (ie, a group that is NOT exposed to my exercises). One possibility would be to do a before and after test, but that is complicated by the lack of "content" the students have before the course starts. If the before and after test showed improvement, it would not be obvious whether it was due to the DBQs or the new content the students were exposed to. If a different school allowed it, I could give a before and after test to their students who are NOT using my activity. By comparing students with equivalent scores on the "before" test with the same students taking the "after" test, I would have a basis for

comparison. There too, however, those students would have been exposed to different learning experiences. Perhaps by designing test questions on material which neither school has encountered, a meaningful comparison could be made.

Another possibility is to score the students over the course of the year to see to what extent, if any, they have improved. But that too raises the question of whether or not it is the content which is affecting the quality of their answers.

Perhaps the use of student questionnaires could be used to access the effect of these activities on student learning.

Over the course of the summer and next year (2014-15) I would like to add to the 74 activities that I have designed so far. For some areas of the course I have too few activities and I would also like to integrate more of the activities into my actual lessons. My early informal impression is that these activities have been effective in helping students to analyze data, to think about experimental design, to visualize models which explain various phenomena and to get a sense of whether or not data is statistically significant. I am also considering whether or not to attempt to publish the material; hence I do not yet want to put all of my activities online.

Overall, I like the idea of professional development being a centerpiece of what educators do…a must for the staff of SAR. The extent to which the process is formalized is questionable, but educators can never be satisfied with the status quo. I feel that the staff should be both encouraged and supported (financially and in terms of class coverage) to attend professional conferences. Overall, I enjoyed and continue to enjoy this project.

Bob Goodman

Sources:

1. **E Rubin and C. Lieber. Alcoholism, Alcohol, and Drugs. Science. 1971; 172: 1097-1102.**
2. V. Wahl et al. *Regulation of Flowering by Trehalose-6-Phosphate Signaling in Arabidopsis thaliana.* Science 2013; 339: 704-707.
3. J Danielson and W Frommer. *Jack of All Trades, Master of Flowering.* Science 2013; 339: 659-660.