

2023



AP[®] Biology

Sample Student Responses and Scoring Commentary

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Free-Response Question 6

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Question 6: Analyze Data**4 points**

Housekeeping genes encode proteins involved in universally important processes such as transcription, translation, and glycolysis. Because these genes appear to be expressed in all cells at constant levels, the expression of housekeeping genes is often used as a control when comparing how the expression of other genes varies under different conditions.

Researchers studying the effect of pesticides on declining bee populations wanted to determine whether the expression of four housekeeping genes (*GAPDH*, *RPL32*, *RPS5*, and *TBP-AF*) was in fact constant in bees across different variables. The researchers collected samples of mRNA for each of the four genes and compared how their expression varied across the developmental stage of the bee, the sex of the bee, and the cell type from which the sample was taken. The mRNA from the samples was reverse transcribed to produce DNA copies of each gene. PCR was then used to amplify the DNA, and the Cq value was determined. The Cq value is the number of PCR cycles needed to produce a specified number of DNA copies (Figure 1). A high Cq value for a sample indicates the gene was expressed at a low level.

To analyze whether any of the examined variables affected expression of the housekeeping genes, researchers examined the range of Cq values for each gene in response to each variable. Genes with a wide range of Cq values were determined to be affected by the variable, while genes with a narrow range of Cq values were determined to be unaffected by the variable.

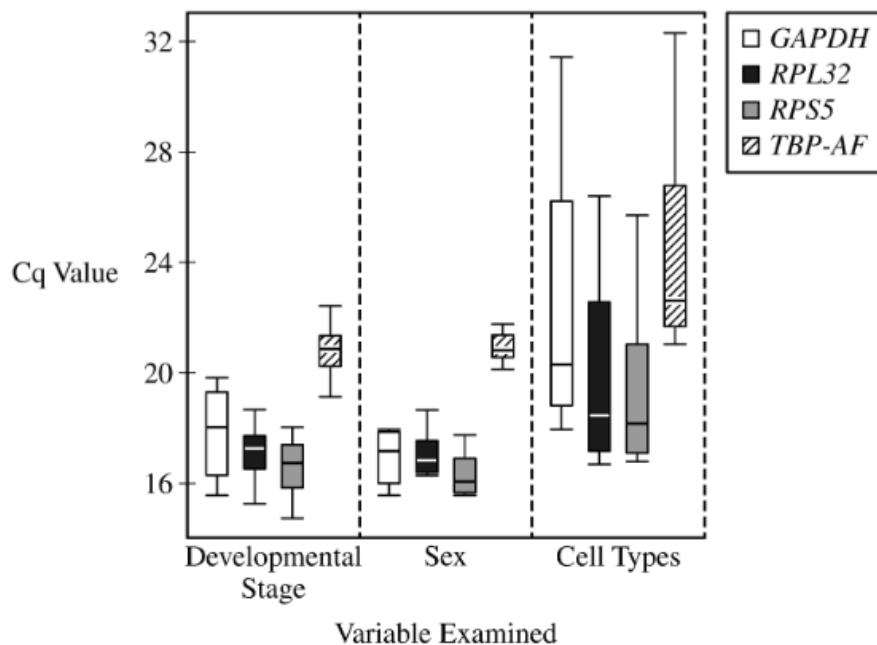


Figure 1. The effect of developmental stage, sex, and cell type on the Cq value of four housekeeping genes

(a)	Based on the data in <u>Figure 1</u> , identify the gene that had the lowest median Cq value when bees of different developmental stages were compared.	1 point
	<ul style="list-style-type: none">• <i>RPS5</i>	
(b)	The Cq value is inversely proportional to the amount of mRNA from that gene in the starting sample. Based on the data in <u>Figure 1</u> , identify the gene that has the lowest level of gene expression regardless of variable.	1 point
	<ul style="list-style-type: none">• <i>TBP-AF</i>	
(c)	The scientists investigated the effect of pesticides on the expression of other genes in one cell type of a group of bees containing males and females of the same developmental stage. They hypothesized that <i>TBP-AF</i> would serve as the best control gene for this experiment. Use the data to evaluate their hypothesis.	1 point
	<ul style="list-style-type: none">• Their hypothesis is supported because <i>TBP-AF</i> has the <u>smallest Cq range/most constant expression</u> (when comparing sexes).	
(d)	Explain how expression of a gene such as <i>GAPDH</i> can vary from one cell type to another within the same bee.	1 point
	<ul style="list-style-type: none">• Different cell types contain <u>different levels of/different</u> transcription factors, and therefore regulate the expression of genes in different ways.	

Total for question 6 4 points

BEGIN Question 6

Begin your response to **QUESTION 6** on this page. Do not skip lines.

- ~~_____~~
- a) The RP55 gene had the lowest C_q ~~value~~ value of all 4 genes ~~when~~ when developmental stages were compared.
- b) Regardless of variable, the TBP-AF gene had the highest C_q value and therefore the lowest level of gene expression.
- c) The hypothesis is accurate, because the TBP-AF gene has the smallest range of C_q values during the developmental stage, meaning that it is least affected by the variable.
- d) ~~The~~ Expression of a gene like GAPDH can vary from one cell type to another due to transcription factors. Cells that have the correct transcription factors will ~~be~~ translate and express the GAPDH gene.

BEGIN Question 6

Begin your response to QUESTION 6 on this page. Do not skip lines.

a) RPS5 gene

b) ~~RPS5~~ TBP-AF gene

c) the scientists' hypothesis is correct, because in the variation being tested (sex), TBP-AF had the narrowest range of q values, meaning it is relatively unaffected by variability in sex and will serve as a sufficient control for the experiment.

d) A gene like GAPDH is needed within certain cell groups, so it is expressed more in these cells. An example of this is glycolysis, which is more present in cells that ~~are~~ have many mitochondria, so the genes encoding the ~~genes~~ proteins involved in glycolysis will be expressed more.

BEGIN Question 6

Begin your response to QUESTION 6 on this page. Do not skip lines.

- a) The RPS5 gene had the lowest median C_q value of bees at different developmental stages.
- b) The TBP-AF gene had the lowest level of overall gene expression.
- c) Their hypothesis is likely true. The TBP-AF gene would serve as a good negative control in the experiment because it has low gene expression across all areas and a high C_q value across all areas according to the data in Figure 1.
- d) The expression of GAPDH can vary within one bee from one cell type to another because when looking at Figure 1, the range for GAPDH in the cell type variable is very large. This means that the C_q value and therefore gene expression has a wide range which creates variety in the GAPDH gene.

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Question 6

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 6 described housekeeping genes that tend to be expressed at constant levels in all cells. The stimulus also described an experiment designed to determine whether the expression of four specific housekeeping genes was indeed constant across different developmental stages, sexes, and cell types of bees. Gene expression was measured by collecting mRNA, performing reverse transcription, and then using PCR to amplify the DNA. This process results in a C_q value, defined as “the number of PCR cycles needed to produce a specified number of DNA copies.” Data from the experiment were presented in a box-and-whisker plot.

In part (a) students were asked to identify the gene that had the lowest median C_q value when comparing bees of different developmental stages (Skill 4.B).

Part (b) explained that the C_q value is inversely proportional to the amount of mRNA collected. Students were asked to identify the gene with the lowest level of gene expression (Skill 4.B; Learning Objectives [LOs] IST-1.N, IST-2.A from the AP Biology Course and Exam Description [CED]).

Part (c) described an investigation into the effect of pesticides on gene expression in male and female bees of the same developmental stage. Students were asked to use the data from the box-and-whisker plot to evaluate the scientists’ hypothesis about the best control gene for the investigation (Skills 4.B and 5.D).

In part (d) students were asked to explain how expression of a specific gene can vary in different cell types of the same bee (Skill 6D; LO IST-2.D).

Sample: 6A

Score: 4

The response earned 1 point in part (a) for identifying RPS5 as the gene with the lowest median C_q value. The response earned 1 point in part (b) for identifying TBP-AF as the gene with the lowest level of gene expression. The response earned 1 point in part (c) for correctly evaluating the hypothesis as being accurate because “the TBP-AF gene has the smallest range of C_q values.” The response earned 1 point in part (d) for explaining how different levels of gene expression in different cells are due to transcription factors, and “[c]ells that have the correct transcription factors will ... express the GAPDH gene.”

Sample: 6B

Score: 3

The response earned 1 point in part (a) for identifying RPS5 as the gene with the lowest median C_q value. The response earned 1 point in part (b) for identifying TBP-AF as the gene with the lowest level of gene expression. The response earned 1 point in part (c) for correctly evaluating the hypothesis as being supported because TBP-AF has the narrowest range of C_q values. The response did not earn a point in part (d) because it does not explain how different levels of/different transcription factors in different cell types lead to different levels of gene expression.

Sample: 6C

Score: 2

The response earned 1 point in part (a) for identifying RPS5 as the gene with the lowest median C_q value. The response earned 1 point in part (b) for identifying TBP-AF as the gene with the lowest level of gene expression. The response did not earn a point in part (c) because, although it does state the hypothesis is supported, it does not

correctly evaluate the hypothesis as being supported by TBP-AF having the smallest C_q range. The response did not earn a point in part (d) because it does not explain how different levels of/different transcription factors in different cell types lead to different levels of gene expression.