2022

AP® CollegeBoard

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

Researchers are studying the use of RNA vaccines to protect individuals against certain diseases. To develop the vaccines, particular cells are first removed from an individual. Then mRNAs coding for specific proteins from a pathogen are introduced into the cells. The altered cells are injected back into the individual, where the cells make the proteins encoded by the introduced mRNAs. The individual then produces an immune response to the proteins that will help to protect the individual from developing a disease if exposed to the pathogen in the future.

When introduced into cells, the mRNAs used for vaccines must be stable so that they are not degraded before the encoded proteins are produced. Researchers developed several modified caps that they hypothesized might make the introduced mRNAs more stable than mRNAs with the normal GTP cap. To test the effect of the modified caps, the researchers produced mRNAs that differed only in their cap structure (no cap, the normal cap, or modified caps I, II, or III). They introduced the same amount of each mRNA to different groups of cells and measured the amount of time required for half of the mRNAs to degrade (mRNA half-life) and the total amount of protein translated from the mRNAs (Table 1).

TABLE 1. EFFECT OF mRNA CAP STRUCTURE ON mRNA HALF-LIFE AND PROTEIN TRANSLATED FROM THE INTRODUCED mRNA

5′ Cap Structure	mRNA Half-Life $\pm 2\mathrm{SE}_{\bar{X}}$ (hours after introduction into cells)	Total Amount of Protein Translated from mRNA $\pm 2\mathrm{SE}_{\bar{X}}$ (relative to amount in normal cap)
No cap	1.41 ± 0.02	0.011 ± 0.000
Normal GTP cap	16.10 ± 1.83	1.000 ± 0.007
Modified cap I	15.50 ± 1.57	4.777 ± 0.042
Modified cap II	27.00 ± 2.85	13.094 ± 0.307
Modified cap III	18.09 ± 0.81	6.570 ± 0.075

(a) Based on the data, **identify** which cap structure is most likely to protect the end of the mRNAs from degradation. — **1 point**

- Modified cap II

(b) Based on the data for the mRNAs with modified caps, **describe** the relationship between the mRNA half-life and the total amount of protein produced. — **1 point**

Accept one of the following:

- A longer mRNA half-life is associated with more protein.
- There is a positive correlation/relationship.

(c) After examining the data on mRNA half-lives and the amount of protein produced, the researchers hypothesized that each mRNA molecule with modified cap I was translated more frequently than was each mRNA molecule with the normal GTP cap. **Evaluate** their hypothesis by comparing the data in Table 1. — **1 point**

- The data support their hypothesis because the half-lives of the two mRNAs are the same, but the amount of protein produced from the mRNA with modified cap I is more than (four times as much as) that produced from the mRNA with the normal cap.

(d)	Introduction of mRNAs into cells allows the cells to produce foreign proteins that they might not normally produce. **Explain** why the production of a foreign protein may be more likely from the introduction of mRNA than DNA into cells. Accept one of the following: • Protein production from the DNA requires (transcription) factors to initiate transcription. • Protein production from the mRNA does not depend on (correct posttranscriptional) processing of the pre-mRNA. • The cells may be unable to transcribe the DNA (while mRNA can be directly translated).	**1 point**
	Total for question 6	**4 points**

BEGIN Question 6

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

a) Modified cap II increased the mRNA half life the most and protected the end of the mRNAs from degradation.

b) The greater the mRNA half life, the more protein was translated from the mRNA. Modified cap I is a curious outlier, producing almost 5x as much protein despite degrading in a similar (statistically identical) period of time as the normal GTP cap.

c) The mRNA molecules with the modified cap I degraded in a statistically identical period of time as the mRNA molecules with the normal cap. However, the greatest amount of protein translated from the modified cap I mRNA molecules was greater than that translated from the normal GTP cap molecules. Given that the same amount of mRNA was added to each cell, this suggests that the researchers' hypothesis was correct.

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Additional page for answering Question 6

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

d) Proteins are produced directly from mRNA. If DNA coding for a specific protein was introduced to a cell, for the protein to be produced, first mRNA must be created. Not only does introducing mRNA reduce the complexity of the operation, but also controls during the transcription and translation process increase the likelihood that this gene is not expressed. For instance, the mRNA ~~might be spliced~~ resulting from transcribing the DNA might be spliced, preventing the protein from being produced.

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BEGIN Question 6

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

a) The cap structure most likely to protect the end of the mRNA from degradation is modified cap II because it yielded the highest total amount of protein translated from mRNA and has the longest half life.

b) ~~The relation~~ There is a positive relationship. As the mRNA half-life increases, the total amount of protein produced also increases.

c) The hypothesis is supported because while the normal GTP cap had a longer mRNA half-life (16.10 ± 1.83) compared to modified cap I (15.50 ± 1.57), cap I yielded a higher total amount of protein produced (4.777 ± 0.042) compared to the normal cap (1 ± 0.007). This shows that modified cap I produced proteins more frequently in a short time as its mRNA had a shorter half life.

d) The production of a foreign protein may be more likely from the introduction of mRNA than DNA into cells because mutations may occur during DNA transcription that will change the genetic code and therefore produce different amino acids during translation, ultimately producing an entirely different protein. Also, pre-mRNA processing before it leaves the nucleus occurs, splicing out introns and rearranging exons that may not produce the mature mRNA strand that matches the ~~intended~~ intended foreign protein. Inserting mRNA directly will ~~allow~~ most likely allow the exact amino acids to be translated from, and produce the appropriate protein.

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0114482

Q5329/14

BEGIN Question 6

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

a) Modified cap II
b) The larger the half life, the higher total Amount of protein produced.
c) The normal GTP cap had about 1 protein produced while Modified cap I had about 4.777 proteins produced meaning it was translated more frequently than the normal GTP cap.
d) mRNA is more likely to have mutations resulting in innacurate transcription and translation which will produce a different protein than it would normally produce.

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Q5329/14

Question 6

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

Overview

Question 6 described research aimed at developing RNA vaccines. A data table presented the half-life of mRNAs with various cap structures, as well as the total amount of protein translated from each mRNA.

Responses to part (a) were expected to identify modified cap II as the cap structure most likely to protect mRNA from degradation (Science Practice 4.B).

Responses to part (b) were expected to describe a positive correlation between mRNA half-life and total amount of protein translated (Science Practice 4.B).

Part (c) described the researchers' hypothesis that "each mRNA molecule with modified cap I was translated more frequently than was each mRNA molecule with the normal GTP cap." Responses were expected to make the evaluation that the data supported the hypothesis because the two mRNAs did not differ in half-life, but the amount of translated protein from mRNA with modified cap I was higher than that from mRNA with the normal GTP cap (Learning Objective IST-1.O).

Responses to part (d) were expected to explain that cells are more likely to produce foreign proteins from introduced mRNA than from introduced DNA because the mRNA can be directly translated, while the cell may not be able to transcribe the DNA or correctly process the transcripts produced from the introduced DNA (Learning Objective IST-2.C).

Sample: 6A
Score: 4

The response earned 1 point in part (a) for identifying modified cap II. The response earned 1 point in part (b) for describing that a longer half-life is associated with "more protein … translated from the mRNA." The response earned 1 point in part (c) for evaluating that the hypothesis is correct *and* the half-lives of the two mRNAs are statistically identical *and* the amount of protein produced by the mRNA with modified cap I is greater. The response earned 1 point in part (d) for explaining that mRNA resulting from transcribing the DNA "might be spliced, preventing the protein from being produced."

Sample: 6B
Score: 3

The response earned 1 point in part (a) for identifying modified cap II. The response earned 1 point in part (b) for describing the relationship as "positive." The response did not earn a point in part (c) because the response incorrectly states that the half-life of the mRNA with the normal GTP cap was greater than that of the mRNA with modified cap I. The response earned 1 point in part (d) for explaining that, after transcription from introduced DNA, pre-mRNA processing "may not produce the mature mRNA strand" encoding the intended foreign protein.

Sample: 6C
Score: 2

The response earned 1 point in part (a) for identifying modified cap II. The response earned 1 point in part (b) for describing that the "larger" half-life is associated with more protein produced. The response did not earn a point in part (c) because, while the response says that the amount of protein produced from modified cap I was more, the response does not state that the hypothesis was supported *and* that the half-lives of the two mRNAs are the same.

Question 6 (continued)

The response did not earn a point in part (d) because the response does not explain that the cells might be unable to transcribe the DNA or process mRNA transcribed from the DNA.