Using the AP Physics 1/2 paragraph-length response item format for teaching low-latency network audio

Worked example I: Mouth-to-ear delay has variable and fixed contributions

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The College Board® administers the AP® Physics 1 and AP® Physics 2 exams, which assess student mastery of algebra-based physics. Each test contains a paragraph-length response item. To see how a multiple representations approach can be used to solve such a question, see D. Liao, "A SiQuENC for solving physics problems," *Phys. Teach.*, **56**, 264-265 (April 2018) doi:10.1119/1.5028250 (free copy at https://davidliao.com/pubs/Liao.1.5028250.pdf). Borrowing this test question style provides an option for assessing students' quantitative reasoning in a course on low-latency network audio.

SAMPLE PARAGRAPH-LENGTH RESPONSE QUESTION

A voice teacher in city A teaches lessons with a student in city B and lessons with a student in city C. The table below presents average one-way home-to-home transit delays.

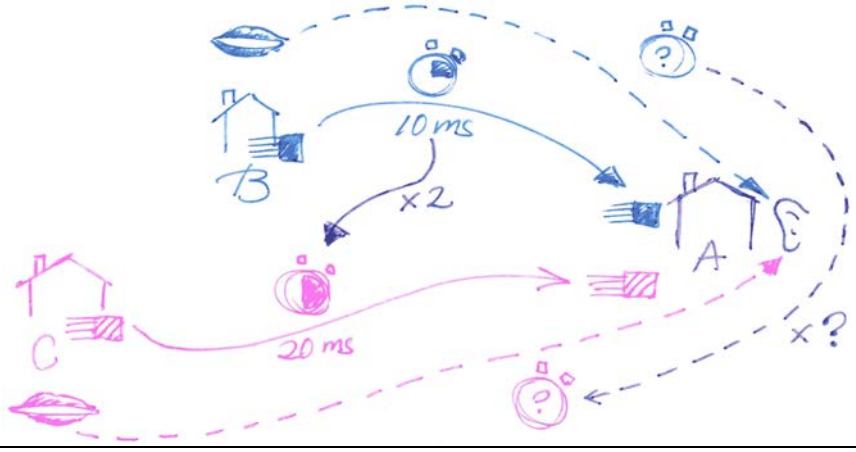
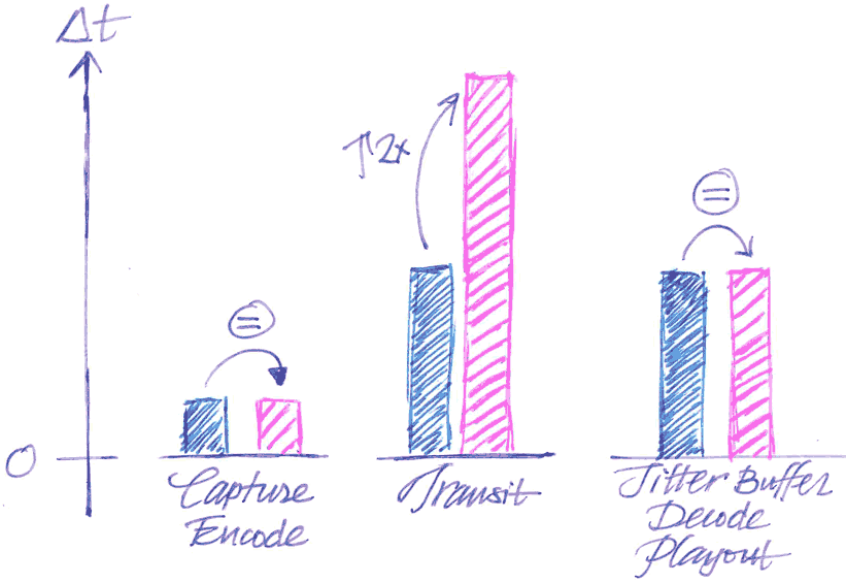
TABLE 1: Average home-to-home one-way transit delays

	A. Packet of audio data departs from home in	B. Packet of audio data arrives at home in	C. Average one-way transit delay	D. One-way mouth-to-ear latency
1.	City B	City A	10 ms	
2.	City C	City A	20 ms	

The teacher wants to fill in column D, "One-way mouth-to-ear latency." The teacher and their students all use the same audio equipment, computer, and low-latency audio application settings. So, the teacher reasons, the only reason the mouth-to-ear latency could change is variation in average one-way transit delay. The teacher reasons that since going from row 1 to row 2 corresponds to doubling the average one-way transit delay (doubling 10 ms yields 20 ms), going from row 1 to row 2 should also correspond to doubling the one-way mouth-to-ear latency.

Is the teacher correct? Explain your reasoning.

SAMPLE SOLUTION USING MULTIPLE REPRESENTATIONS

SiQuENC step	Example
Neatly and graphically represent **Situation(s)**.	
Graphically represent **Quantities**.	
Identify allowed starting point **Equation(s)** and/or inequalities.	$\Delta t_{\substack{\text{CAPTURE}\\\text{ENCODE}}} + \Delta t_{\text{TRANSIT}} + \Delta t_{\substack{\text{JITTER BUFFER}\\\text{DECODE}\\\text{PLAYOUT}}} = \Delta t_{\substack{\text{MOUTH}\\\text{TO}\\\text{EAR}}}$
Analyze your representations.	$\overbrace{\Delta t_{\substack{\text{CAPTURE}\\\text{ENCODE}}}}^{=} + \overbrace{\Delta t_{\text{TRANSIT}}}^{\uparrow 2\times} + \overbrace{\Delta t_{\substack{\text{JITTER BUFFER}\\\text{DECODE}\\\text{PLAYOUT}}}}^{=} = \overbrace{\Delta t_{\substack{\text{MOUTH}\\\text{TO}\\\text{EAR}}}}^{\uparrow \text{ by } < 2\times}$
Communicate your reasoning in writing.	(See REASoNing below).

REASoNing step	Example
Relationship/rule (Warrant)	The **total** one-way mouth-to-ear **latency** between two musicians equals the **sum** of the duration that an audio packet spends in the midst of **transport** between residences and the duration that that audio data spends in **earlier** and **later processes** (e.g. capture, encoding, jitter buffering, decoding, and playout), of which jitter buffering is often a major contributor.
Equal/matched (Data/Grounds)	Because the teacher and students all use the same settings, the time-delay associated with processes occurring outside of house-to-house transport are fixed (example: perhaps the teacher and students all use a **common** default **jitter buffer size** of 10.7 ms (512 samples at 48,000 samples/sec) for all incoming connections.
Altered/mismatched (Data/Grounds)	Going from row 1 in the table to row 2, the average one-way **transit** delay **doubles**.
So what? (Conclusion)	HAD BOTH the average one-way transit delay AND also the duration spent in other processes (e.g. capture, encoding, jitter buffering, decoding, and playout) doubled, the total one-way mouth-to-ear latency would have doubled. However, since, going from row 1 to row 2 in the table, **merely** the average one-way **transit** delay, but **not also** the **jitter buffer delay** (and other delays like encoding/decoding delay, etc.), **doubled**, the **total** one-way mouth-to-ear **latency less than doubled**. So, the teacher is incorrect.
Next?	(Solution is complete, no additional reasoning is needed).

SAMPLE SCORING GUIDELINES

Points	Criterion
+1	Indicates that mouth-to-ear delay is a sum of one-way transit delay and delays from other steps in the signal chain
+1	Uses the fact that the teacher uses the same hardware and low-latency application settings when calling both students to conclude that time delays for processes in signal chain outside of network transit are the same when the teacher calls the two students.
+1	Uses the fact that only a portion (average one-way transit delay) of the total mouth-to-ear delay doubles but the remaining portion of the total mouth-to-ear delay remains the same to conclude that the mouth-to-ear delay less than doubles.
+1	Response makes sense on first reading, contains no incorrect information, and contains no extraneous/irrelevant information.