AP Physics 1 & 2 FRQs test for more than rote calculation

To produce AP Physics questions, use the scenario maker (separate handout) to generate situations and stems for problem parts. Then, organize situations and problem parts using the various problem type templates in this document.

FRQ Problem types:

BOLD: AP Physics B old problem types

Deducing implications of differences
DID-CABp: Compare features of A to features of B
DID-CABy: Find feature(s) for explaining a difference
DID-EMS: Does equation make sense?
DID-RIO: Rank [interrelated] objects according to . . . and justify
DID-WHA?: What will happen after . . . ?

WEE-Y/D: Without using equations, explain why/determine
WEE-HOW: Explain how to calculate

Theory of mind
TOM-CR: Critique reasoning (ability to scrutinize an argument that might or might not be consistent with "reality")
TOM-VIOL: Create a representation that violates a physics principle (ability to construct a false condition)

MXB: Linearization of datasets

Procedure, sources of error, analysis
PEA-VAL: Designing an experiment to obtain a value
PEA-BOOLEAN: Designing an experiment to test a falsifiable proposition

PLR: Paragraph-length response

Suggested combinations

7 points, 13 minutes
Expand on any **~2 templates** from **BOLD through PEA-BOOLEAN**.

12 points, 25 minutes
Combine any **~2-3 templates** from **BOLD through PEA-BOOLEAN** (repetition OK).

7 points, 13 minutes
Use the template for **PLR** to develop one question.

All **descriptions must be** dense and **filled with sentences** to ensure sufficient cognitive load.

Problem-solving method correlation chart

SiQuENC	Knight	Etkina
Neatly and graphically represent situation(s)	Prepare	Sketch and translate
Graphically represent quantities and their relationships		Simplify and diagram
Identify relevant allowed starting point (in)equation(s)	Solve	Represent mathematically
Analyze		Solve and evaluate
	Assess	
Communicate		

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To organize solutions, use the comments in dark red throughout this problem-type inventory. Here is a rough SiQuENC structure helpful for many "comparison" problem types.

Neatly and graphically represent situation(s)

1. Divide page into two columns

2. Illustrate situation A

3. Illustrate situation B

Graphically represent quantities and their relationships

5. Visualize quantities from situation A

6. Visualize quantities from situation B

7. Identify feature that is different between the two situations

$x_A =$

$x_B =$

8. Working vertically down this column, develop a sequence of deductive reasoning that connects x_A to y_A.

9. Either redo the calculation in step 6 or, if that would cause recopying of a lot of unchanged expressions/figures, write shorthand notes of differences that would appear in the deductive reasoning describing situation B.

Identify relevant allowed starting point (in)equation(s)

Analyze

4. Write down name of quantity for which a resulting increase, decrease, or absence of change is to be understood

$y_A =$

$y_B =$

10. Does the problem ask merely for a comparison of y_B and y_A (without explanation)? Can such a comparison be made by inspecting the expression for y_A in step 4 and the values x_A and x_B in step 7? If you answered YES to both these questions, then STOP. You are done.

If the problem asks for an explanation for the result of a comparison of y_B and y_A, then continue to step 11.

Communicate

11. Use numbers to plan a sequence in which to introduce concepts in sentences.

12. Write out sentences that translate the numbered items. Consider reporting key features that are the same in both columns and key features that are different between the two columns.

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Write **scoring guidelines** to prevent students from earning "accidental credit."

Lower-quality scoring example	Higher-quality scoring example
+1 point for mentioning energy conservation	+1 point for correct use of energy conservation that leads to correct answer
+1 point for mentioning that the tangential velocities are the same	+1 point for reasoning that the tangential velocities are the same because[1] the radii are the same

[1] The role of the word "because" in written explanations in AP Physics 1/2 is similar to the role that the word "because" took on in AP Calculus after it was decided that students needed to demonstrate an "appeal" to calculus principles and, as a result, calculus teachers started teaching students to memorize special sentences to describe the analysis of extrema, where functions are increasing/decreasing, curvature, and points of inflection.

BOLD: <u>Calculate/draw</u> (classic AP Physics B problem type)

Given: Description/illustration

(a) Draw a picture (e.g. FBD).

FBD acronym for mechanics: BETA
B – Draw a bubble around the object(s) in the system
E – Is the Earth nearby?
T – Is anything external to the system touching any object(s) in the system?
A – Indicate axes

(b) Determine (quantity).

Write down one or more fundamental relationships
Substitute
Solve

(c) Draw a graph

Write down one or more fundamental relationships
Substitute
Solve
Graph the resulting expression

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DID-CABp: Compare features of A to features of B

Given: Description/illustration of two similar situations or objects, for example, labeled A and B.

(a) How does [feature X] of A compare to the [feature X] of B? Indicate whether [feature X] of A is greater than, less than, or the same as [feature X] of B.

____ Greater than ____ Lesser than ____ Same as

Briefly justify your answer.

Combine as many copies of reasoning similar to the reasoning outlined below as needed.

Scratchwork

Equation for fundamental principle involving feature X

$x_A =$ | $x_B =$

Point out quantities that are the same (and reasons why)

Point out quantities that are different (and reasons why)

Label which value, if any, is bigger

Convert scratchwork keypoints into sentences

Fundamental principle says ____

The [quantity] is the same for A and B because ____.

The [other quantity] is greater/lesser for A than for B because ____.

Thus, [feature X] is greater/lesser/same for A compared to [feature X] for B.

DID-CABy: Find feature(s) for explaining a difference

Given: Description/illustration of two similar situations or objects, for example, labeled A and B.

(a) Why is [feature X] of A different (problem might indicate greater than or lesser than) from [feature X] of B? Explain how you arrived at your answer.

Combine as many copies of reasoning similar to the reasoning outlined below as needed.

Scratchwork

Equation for fundamental principle involving feature X

$x_A =$ | $x_B =$

Point out quantities that are the same (and reasons why)

Point out quantities that we can immediately or almost immediately conclude are different (and reasons why)

Conclude that [feature X] is different for A and B (if appropriate, indicate for which of A and B [feature X] is greater)

Convert scratchwork keypoints into sentences

Fundamental principle says ____

The [quantity] is the same for A and B because ____.

If the question states the direction in which [feature X] for A is different from [feature X] for B (greater than or less than), modify the following two sentences to indicate directions of differences (greater than or less than).

The [other quantity] is different for A and B because ____.

Thus, [feature X] is different for A and B.

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DID-EMS?: Does equation <u>make sense?</u>

Given: Description/illustration of situation and equation proposed to relate aspects of situation.

(a) Does the equation make physical sense?

Explain how you arrived at your answer.

Copy the variables that appear in the equation into the row and column headers of the following table. Each cell corresponds to a question (one example is provided). Answer as many such questions as it takes to determine whether the equation makes sense (hopefully, it will be easy to quickly identify a nonsense relationship between two variables).

	Variable 1	Variable 2	Variable 3	. . .
Variable 1		When variable 2 is increased, how is variable 1 predicted to be affected? Does this predicted effect make sense (perhaps compare with conclusions drawn in other parts of the problem)?		
Variable 2				
Variable 3				
. . .				

To answer a question corresponding to a cell of the table, combine as many copies of reasoning similar to the reasoning outlined below as needed.

Scratchwork

Equation for fundamental principle involving feature X

$x_A =$ | $x_B =$

Point out quantities that are the same (and reasons why)

Point out quantities that are different (and reasons why)

Label which value, if any, is bigger

Is there physical reasoning elsewhere in your solution to this problem that this prediction contradicts?

Convert scratchwork keypoints into sentences

Fundamental principle says ____

The [quantity] is the same for A and B because ____.

The [other quantity] is greater/lesser for A than for B because ____.

Thus, [feature X] is greater/lesser/same for A compared to [feature X] for B.

Choose one option:
Option 1: This prediction contradicts our reasoning in part __, where we argued that ____ because _____. Thus, the equation does not make physical sense.

Option 2: This prediction is consistent with our reasoning in part ___, where we argued that ___ because ___. [If the problem writers are cruel, the equation will make physical sense and validation will occur for every pair of variables in the table of variables—if this is obviously the case, a mathematical derivation of the equation in question, rather than an exhaustive filling in of the table of variables, might be a more efficient way to demonstrate that the equation makes physical sense].

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DID-RIO: Rank inter-related objects according to . . .

Given: Description of a system with various similar components, possibly related by being materially connected. Often an illustration will be provided (e.g. circuit diagram).

(a) Rank the _____s from greatest to least according to _____. Use = to indicate when two quantities are equal.

Ranking:

Briefly justify your ranking.

Combine as many copies of the following heuristics and sentences as needed.

Scratchwork

Example heuristics:
Can any of the objects be recognized as forming simple sub-combinations?

Is the quantity of interest apportioned among the components in a sub-combination?

Is the quantity equal for each component in a sub-combination?

Convert scratchwork keypoints into sentences

Objects A and B are combined in _____ (manner of combination).

Objects A and B have the same ____ because objects in (manner of combination) have the same _____.

The total of ___ for object A and ____ for object B equals the ___ of the combination of A and B because objects in (manner of combination) share ____. This means that the individual ____ of object A and the individual ____ of object B are less than the ____ of the combination of A and B (don't say this if the ___ of object A or B equals zero).

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DID-WHA?: <u>What will happen after</u> . . . ?

Given: Description of a system

(a) If [some action occurs], how will [feature Y] of [system] be affected? Indicate whether [feature Y] of [system] will increase, decrease, or stay the same.

____ Increase ____ Decrease ____ Stay the same

Justify your answer.

Combine as many copies of reasoning similar to the reasoning outlined below as needed.

Scratchwork	**Convert scratchwork keypoints into sentences**
Equation for fundamental principle involving feature Y *(Hint: To narrow down the list of possibly relevant equations, ask whether the question seems to describe a "before and after" process?)*	Fundamental principle says ____.
Translate "some action occurs" into a quantity that can be related to a quantity that appears in the fundamental principle	When [some action occurs], [immediate consequence].
Conclude how feature Y is affected	Because _____ is defined as _____, the [immediate consequence] means [deduced consequence about some quantity appearing in fundamental principle].
	Because this quantity is [choose one: +, -, 0], one can conclude that feature Y [choose one: increases, decreases, stays the same].

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WEE-Y/D: Without using equations, explain why/determine

Given: Description/illustration of complicated situation with multiple parts and/or multiple time stages.

(a) Without using equations, explain why [changing X] will result in [resulting change to output variable Y]. - OR - Without using equations, determine the consequence of [changing X] for [output variable Y].

2. Identify the part of the derivation in part (b) that illustrates how variable X influences output variable Y.

Consider looking at a couple lines of work near the place in the derivation where the variable X is first introduced.

a. Look for variables that variable X immediately influences.
b. Look for fundamental principles.

3. Write sentences that outline how variable X influences intermediate variable(s) that eventually can influence output variable Y. Use fundamental principles to provide justification for each asserted influence. Once you have outlined how variable X influences other variable(s) that eventually influence Y, state your conclusion about how X influences Y.

(b) Now, using equations, mathematically derive an algebraic expression for variable Y in terms of the given variables in the problem and fundamental constants.

1. Solve part (b) as a normal SiQuENC "calculation" homework problem. Work vertically down the page so that it is easy to see the flow of the derivation.

(c) Identify the equation in your derivation in part (b) that supports your argument in part (a). Do not simply copy the final expression you obtained in part (b). Briefly explain why the equation you identified supports your argument in part (a).

4. Copy the equation underlying the sentences in step 3. Briefly, walk the reader through how algebraic quantities and relationships reflect the line of reasoning you presented in part (a).

5. A typical grading rubric for such a problem part will read something like (College Board AP Physics 1 and 2 Course Description pg. 187):
(2 points)
1 point "For linking math to one aspect of qualitative reasoning that explains . . ."
1 point "For linking math to all other qualitative reasoning that explains . . ."

6. Examples of possibly helpful sentence structures (adapted from the College Board AP Physics 1 and 2 Course Description pg. 187):

a. "The only difference in the calculations is the difference in _____. This means that the [quantity in one calculation] will be [comparator] than the [quantity in the other calculation]."
b. "The equation _____ [in part (b)] corresponds to _____ [interpretation from part(a)]. This shows that _____ [interpretation]."
c. "This means that _____ as argued in part (a)."

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WEE-HOW: Without relying exclusively on equations, <u>explain how to calculate</u>

Given: Description/illustration of complicated situation with multiple parts and/or multiple time stages.

(a) Explain how [desired quantity] can be calculated. Provide instructions that allow another student to calculate [desired quantity].

Scratchwork	**Convert scratchwork keypoints into sentences**
Perform a SiQuENC mathematical derivation Circle each equation in your derivation that corresponds to a first principle (laws, theorems, definitions—a reasonable heuristic is that equations that were copied from the exam formula sheet are quite possibly considered “first” principles).	Without actually copying every equation from the mathematical derivation in your scratchwork, describe the principle and the quantity to be computed in every key step of your derivation. Examples of sentence structures that can be repeated and combined include the following. Use the law of _____ to relate the ____ of the ____ and the _____ of the ____. The ____ of the ____ can be computed using the definition for _____, which states that _____.

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TOM-CR: **Critique** reasoning (theory of mind)

Given: Description/illustration of complicated situation with multiple parts and/or multiple time stages. A student claims "blah, blah, blah because blah, blah, blah."

[Wording for (a)-(c) is superficially modified from wording of 2015 AP Physics 1 FRQ 3 (b)-(d) to avoid copyright violation as much as possible]:

(a)

i. Identify all features of this student's argument that are correct (there might not be any). Justify your answer.

2. Circle claims in the student's reasoning that are consistent with and/or voiced with your solution in part (b). Justify each of the correct aspects of the student's reasoning by stating, "the student was correct to claim that _____ because (correct reason upon which student relied)."

ii. Identify all features of this student's argument that are incorrect (there might not be any). Justify your answer.

3. Circle claims in the student's reasoning that are inconsistent with your solution in part (b). Do not merely describe each incorrect claim. Explain why each incorrect claim is incorrect. For example, write, "the student incorrectly claimed that _____ because the student incorrectly (describe confusion between two variables, inappropriate application of a relationship outside its domain of validity, etc.)."

(b) Show how you can use mathematical relationships to derive an expression for (quantity about which the student made the claim).

1. Solve part (b) as a normal SiQuENC "calculation" homework problem. Work vertically down the page so that it is easy to see the flow of the derivation.

(c) Explain how mathematical relationships from your answer to part (b) represent all those correct features of the student's argument cited in your answer to part (a). Explain how all those incorrect features of the student's argument cited in your answer to part (a) are corrected by your relationships in part (b). Do not simply refer to the final answer you derived in part (b); instead, identify connections with intermediate relationships you wrote inside your answer to part (b).

4. For each of the student's claims that you identified as correct in part (a)i, identify the corresponding portions in your solution to (b). For example, write, "The student's reasoning that ____ is expressed in my derivation by equation _____ in which (quantitative reason, for example, "term A is greater than term B, so term C is negative")."

5. For each of the student's incorrect claims that you identified as incorrect in part (a)ii, identify the corresponding correct portions in your solution to (b). For example, write, "The student's mistaken reasoning that ____ because ____ is corrected in my derivation in equation _____ because (quantitative reason, for example, "term A is actually inversely proportional to variable X")."

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TOM-VIOL: <u>Create a false representation</u> (theory of mind)

Given: Description/illustration of situation and a description of a graph that can be obtained.

[Problem part wording superficially modified from 2016 AP Physics 1 FRQ 2 part (c) to avoid copyright violation as much as possible]:

(a)

i. In the form of a graph or table, present an example of a hypothetical dataset that displays [some sort of physically plausible behavior] in [some regime] but shows disagreement with a physical law when [another regime is explored].

4. Make a graph or table based on the two versions of the equation you wrote in steps 2 and 3.
   - **a.** For the portion of the graph or table for which physically plausible behavior is supposed to occur, use the correct version of the equation written in step 2.
   - **b.** For the portion of the graph or table for which a basic physics principle is supposed to be violated, use the incorrect version of the equation written in step 3.

ii. Identify one physical law with which the graph or table you provided in part (a)i appears to disagree.

1. Write the name of a physics principle to violate.

Describe a feature of your answer to part (a)i that is inconsistent with the physics law you just named. Explain your answer.

Scratchwork	**Convert scratchwork keypoints into sentences**
2. Write down an equation in which the chosen physics principle can be applied. **3.** Change a quantity in the equation so as to violate the chosen physics principle.	The graph or table has (describe feature), which means that (quantitative implication). This means that (secondary quantitative implication, if needed) because _____. This result contradicts (name of basic principle), which states that ____.

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MXB: Linearization of datasets

Given: Quantity to be experimentally determined, description of an experiment, data table of resulting measured values for various trials

(a) Identify a pair of expressions involving [variable X] and [variable Y] that can be used to create a scatterplot that will be linear that can be used to determine an experimental value for the [desired quantity].

3. Using your response to part (c) as a guide, write,
"We can plot _____ [expression in terms of variable Y] vs. _____ [expression in terms of variable X] to obtain a scatter plot that will be linear and whose slope can be used to determine an experimental value for [desired quantity]."

(b) Explain how you would analyze your data to obtain an experimental value for the [desired quantity].

4. Using your response to part (c) as a guide, write
"I could carry out the following analysis:"
- **a.** Make a scatter plot using the variables identified in part (a).
- **b.** Draw a line of best fit
- **c.** Calculate the slope m of the line of best fit
- **d.** Use the equation $m = \text{cluster of variables determined in part (c)}$ to solve for the [desired quantity]
  –and/or-
  use the equation $b = \text{cluster of variables determined in part (c)}$ to solve for the [desired quantity]

(c) Explain how you know that your analysis will provide an experimental value for the [desired quantity].

1. Use SiQuENC to derive a relationship between [variable X] and [variable Y].
2. For linearization problems, it should be possible to write something like "My equation _____ can be recognized as having $y = mx + b$ form by identifying _____ as y, _____ as m, _____ as x, and _____ as b."

(d)

5. [Read the rest of the problem carefully to determine whether they want you to simply demonstrate the technique you have already described or, instead, to analyze some similar, but distinct data using a method that might not by identical to the method you have already described].

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PEA-VAL: Designing an experiment to obtain a value

Given: List of materials and quantity to be experimentally determined

(a) Describe a procedure that can be carried out to determine an experimental value for [desired quantity]. Provide enough detail so that another student could carry out your procedure.

1. Draw a diagram of the experimental setup.
8. Describe the following with enough detail so that an ordinary physics student could correctly perform the experiment based only on your instructions (without having a copy of this test problem statement).
- **a.** Describe any procedure needed to arrange materials or start processes (e.g. “launch the carts toward each other so that they will have a head-on collision”).
- **b.** For each measurable quantity that is needed to be substituted into calculations or a scatter plot in part (c), say “measure the _____ [variable] of the _____ [rest of prepositional phrase] using the _____ [instrument].”
- **c.** Please list your procedures chronologically (i.e. if you need to change the mass of a cart before a measurement, please describe changing the cart’s mass before describing the subsequent measurement).

(b) For your procedure, will the uncertainty in the calculated value of _____ be affected more by the error in the measurement(s) of _____, more affected by the error in the measurement(s) of _____, or equally affected by the errors in both (sets of) measurements? Justify your answer.

9. Make an assumption about the relative size of errors in the measurements described in the prompt and correctly reason from this assumption to draw a conclusion that compares the effects of the errors from the measurements on the calculated value of __.

For example, “The error in measuring __ is greater during the ___ part of the experiment because the faster motion of the ___ during this part of the experiment makes it harder to visually identify exactly when/where to stop the stopwatch/to draw the mark/etc. This means that the error in ____ will have a greater effect on the calculated value of ___.”

TEMPLATE CONTINUES ON NEXT PAGE

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(c) Describe an analysis that can be used to analyze the data obtained by carrying out the procedure you described in part (a) to obtain an experimental value for [desired quantity].

5. For both of the following types of analysis, it might be necessary to explain how to calculate a simple quantity before substituting into the main expression or plotting. For example, if you need to graph velocity from multiple trials, provide an instruction to "calculate the velocity from the measured displacements and times using $v = \Delta x/\Delta t$."
6. If you were unable to see how the equation you derived in part (d) could be expressed in $y = mx + b$ form, then simply state your final equation from part (d) and what values from the dataset obtained in part (a) need to be substituted where.
7. If you were able to express the equation you derived in part (d) in $y = mx + b$ form, then write the following instructions
   a. Plot _____ along the horizontal axis
   b. Plot _____ along the vertical axis
   c. Draw a line of best fit
   d. Calculate the slope m of the line of best fit
   e. Use the equation $m = \text{cluster of variables determined in part (d)}$ to solve for the [desired quantity] –and/or- use the equation $b = \text{cluster of variables determined in part (d)}$ to solve for the [desired quantity]

(d) Explain why the analysis method you described in part (c) will be able to produce an experimental value for [desired quantity].

2. Pretend that the problem is a standard "just calculate" problem. Use ~~Si~~QuENC to derive an expression for the [desired quantity] in terms of other quantities.
3. Lightly circle the other quantities whose values you need to have before you can use your final expression.
4. If your equation can be linearized, write something like "Equation _____ can be recognized as having $y = mx + b$ form by identifying _____ as y, _____ as m, _____ as x, and _____ as b."

(e) Describe an assumption you made about the design of your experiment, and explain how it might affect the value obtained for ____.

10. Think of a way that an experimental setup/procedure can deviate from an assumption that justifies the application of a relationship. Own the assumption. Admit that the assumption can be false. Use reasoning to determine how negation of the assumption affects the calculated value of ___ (indicate direction of error).

For example, a student might have applied the impulse-momentum theorem to obtain momentum conservation by assuming that impulse is zero. The student could write, "I assumed that the air track was frictionless. However, a physical glider will be subject to air resistance. This will create an impulse against the direction of the glider's motion, which will reduce the glider's final momentum. Newly including this impulse in my calculation would result in a lower value of calculated final velocity, which means that a value of ____ calculated according to the analysis described in part (c) would be an overestimate."

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PEA-BOOLEAN: Designing an experiment to test a falsifiable proposition

Given: List of materials and a YES/NO question to be experimentally answered

(a) Describe a procedure that can be carried out to answer [given question]. Provide enough detail so that another student could carry out your procedure.

1. Draw a diagram of the experimental setup.
3. Describe the following with enough detail so that an ordinary physics student could correctly perform the experiment based only on your instructions (without having a copy of this test problem statement).
   a. Describe any procedure needed to arrange materials or start processes (e.g. “launch the carts toward each other so that they will have a head-on collision”).
   b. For each measurable quantity that is needed to be substituted into a comparison/ranking or plotted as described in part (b), say “measure the _____ [variable] of the _____ [rest of prepositional phrase] using the _____ [instrument].”
   c. Please list your procedures chronologically (i.e. if you need to change the mass of a cart before a measurement, please describe changing the cart’s mass before describing the subsequent measurement).

(b) Explain how the data from the experiment you described in (a) can be used to answer the [given question].

2. Make a comparison chart for the possible truth values for the answer to the given question. Two examples (not the only possibilities) are provided.

Example 1: Qualitative comparison/ranking

Scratchwork		**Convert scratchwork keypoints into sentences**
Make a contingency chart for the possible answers to the given question.		If [affirm proposition in question], then [state in English the variable comparison/ranking from the first column of the contingency table]. If, instead, [negate proposition in question], then [state in English the variable comparison/ranking from the second column of the contingency table]. Thus, we can distinguish between the possibility that [affirm proposition in question] and the possibility that [negate proposition in question] by measuring and comparing [list as many variables as need to be considered according to the contingency table].
Suppose the answer to the question is YES	Suppose the answer to the question is NO	
Variable X will be ___ Variable Y (greater than, less than, equal?) because ____. (You can also state a ranking if it would make sense to relate more than 2 variables).	Variable X will be ___ Variable Y (greater than, less than, equal?) because ____. (You can also state a ranking if it would make sense to relate more than 2 variables).	

Example 2: Quantitative trend

Scratchwork

Make a contingency chart for the possible answers to the given question.

Suppose the answer to the question is YES	Suppose the answer to the question is NO
___ means ___, so variable Y will be a ___ function of Variable D (linear? nonlinear?).	___ means ___, so variable Y will be a ___ function of Variable X (linear? nonlinear?).
or	or
Variable Y will be a ___ function of Variable X (linear? nonlinear?) because ____.	Variable Y will be a ___ function of Variable X (linear? nonlinear?) because ____.

Convert scratchwork keypoints into sentences

If [affirm proposition in question], then variable X will be a _____ function of variable Y. However, if [negate proposition in question], then variable X will be a ____ function of variable Y. Thus, we can determine whether [proposition in question] by analyzing a plot illustrating how variable Y varies with variable X. If the graph (describe appearance), then [proposition in question] is true, but if the graph (describe distinct appearance), then [proposition in question] is false.

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PLR: Paragraph-length response

"In a clear, coherent, paragraph-length response that may also contain figures and/or equations, explain why _____." (Each exam contains one FRQ that includes this kind of phrasing).

(SiQuENC should work; the following is very detailed).

1. **Read** the problem carefully.
2. **Underline** the sentence(s) that specifically state the **question** you are to answer **and** describe the **level of detail** that **your explanation is requested to provide**.

Does the problem ask you to compare **two situations?** If so, divide your sheet into **two columns** and follow steps 3-5 before continuing with step 8.

3. **Populate one column** by drawing/writing the following as you **parse each sentence** while re-reading the problem statement.
   a. **Diagram** of situation
   b. Relevant **analytic diagrams** (e.g. vector component decomposition, free-body diagrams, bar charts, etc.)
   c. **First principle laws/equations**
   d. **Relate** physical **variables and parameters** (e.g. this is big because that is small).
4. **Populate** the **second column** in the same way, unless doing so would produce a second column almost completely redundant with the first. In such a case, write out those **expressions and** draw those **figures in which changes occur**, and **circle** the **items** that are **different in column two**.
5. In each column, **circle** the **quantity that** most directly **addresses the question**. For example, if the question asks you to compare two heights, circle the variable and/or illustrated height in each column. This way, you can see how the quantity compares between the two columns.
   a. **Circle** each **quantity**, **equation**, and/or small **portion of a figure** that **can be used to logically explain** why the quantity to be compared compares the way it does in the two columns. (You can circle quantities in one column, rather than circling pairs of quantities).

If the problem describes essentially **one situation**, you need not divide your sheet. Instead, follow steps 6-7, and then continue with step 9.

6. Draw/write the following content as you **parse each sentence** while re-reading the problem statement.
   a. **Diagram** of situation
   b. Relevant **analytic diagrams** (e.g. vector component decomposition, free-body diagrams, etc.)
   c. **First principle laws/equations**
   d. **Relate** physical **variables and parameters** (e.g. this is big because that is small).
7. **Circle the quantity that most directly addresses the question**.
   a. **Circle** each **quantity**, **equation**, and/or small **portion of a figure** that **can be used to logically explain** why the quantity to be investigated has the property or value you have deduced.

8. **Determine a logical order** in which to guide the reader through the items you have just circled. Place **circled numbers** near each item. For example, the first item to be described should have a 1 next to it.
9. **Write** your paragraph-length response in **English** explaining and expressing your circled items. Each sentence of English has the capacity to explain/mention approximately one free-body diagram, one vector component from a figure illustrating vector component decomposition, one quantity's relationship to another quantity, or one equation. If comparing two situations, strengthen your **discuss**ion of **which factors** cause the observed **difference** by **also mention**ing **which factors are the same** in both situations (and which, thus, cannot be factors contributing to the observed difference).