2021

AP CollegeBoard

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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Free Response Question 2

- ☑ **Scoring Guideline**
- ☑ **Student Samples**
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Question 2: Experimental Design — 12 points

(a)

For measuring the radius or diameter of rods with different radii using an appropriate tool	**1 point**
For measuring force using an appropriate tool	**1 point**
For a plausible/practical way to directly or indirectly determine F_{max} for a given rod	**1 point**
For attempting to reduce experimental uncertainty in an experiment that involves breaking the rods	**1 point**

Example response for part (a)

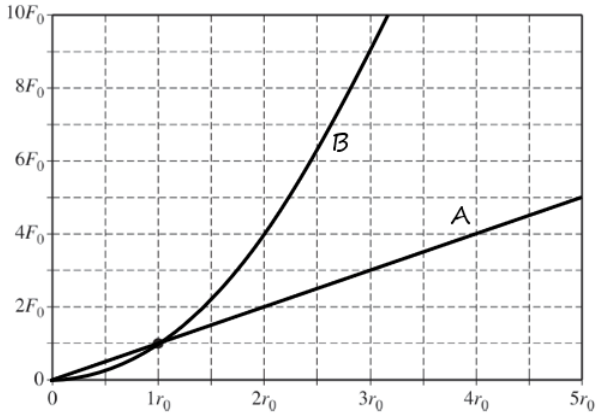
Measure the diameter D of each rod with a ruler.
Students should pull on the rod with the force probe until the rod breaks.
Record the force F_{max} just before breaking.
Repeat each trial several times to reduce error.
Then trade for a new set of rods with different radii.
Repeat this experiment for several different radii rods.

Total for part (a) **4 points**

(b)

For a straight-line graph marked "A" with a slope of $\frac{F_0}{r_0}$	**1 point**
For a graph marked "B" that is concave up	**1 point**
For a graph marked "B" that shows a quadratic relationship at the correct points	**1 point**
For two graphs that both contain the point (r_0, F_0)	**1 point**

Example response for part (b)



Total for part (b) **4 points**

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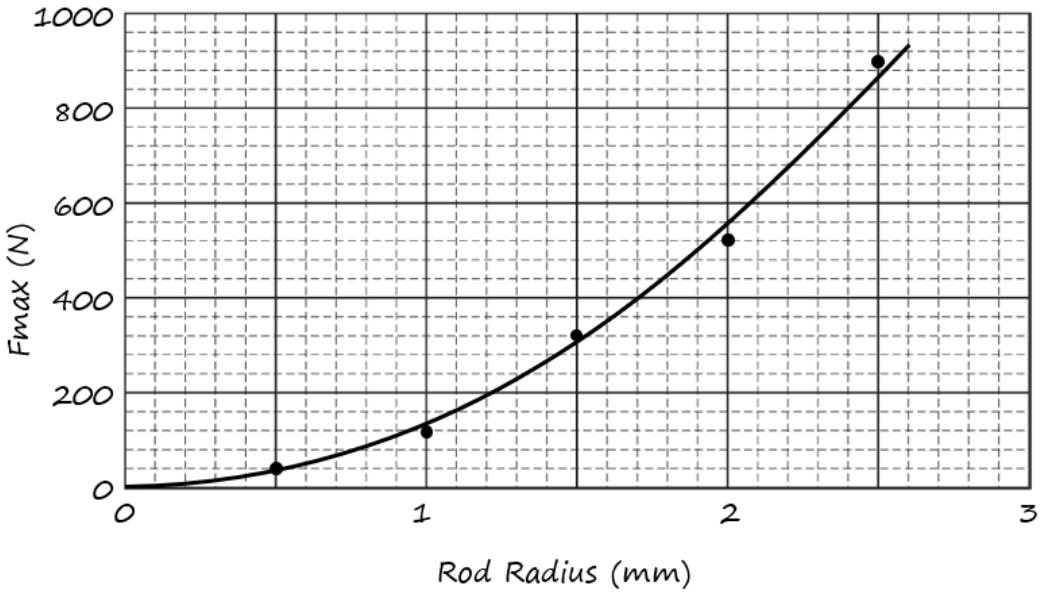
(c)	For linear scales with appropriate labels and units **AND** for a graph where the plotted points cover at least half of the grid's width and height	**1 point**
	For plotting the points correctly	**1 point**
	For drawing a reasonable best-fit curve	**1 point**

Example response for part (c)



Total for part (c) 3 points

(d)	For identifying Model B and for indicating that F_{max} increases as the square of the radius increases	**1 point**

Example response for part (d)

In this graph, F_{max} seems to be proportional to R^2, so that if we graph F_{max} on the vertical axis and R^2 on the horizontal axis, it should show a linear graph.

Total for question 2 12 points

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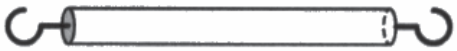

2. (12 points, suggested time 25 minutes)

A group of students is investigating how the thickness of a plastic rod affects the maximum force F_{max} with which the rod can be pulled without breaking. Two students are discussing models to represent how F_{max} depends on rod thickness.

Student A claims that F_{max} is directly proportional to the radius of the rod.

Student B claims that F_{max} is directly proportional to the cross-sectional area of the rod—the area of the base of the cylinder, shaded gray in the figure above. πr^2

(a) The students have a collection of many rods of the same material. The rods are all the same length but come in a range of six different thicknesses. Design an experimental procedure to determine which student's model, if either, correctly represents how F_{max} depends on rod thickness.

In the table below, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity, and also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
Force needed to break rod	N	Force Sensor
Radius of rod	mm	Ruler

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Continue your response to **QUESTION 2** on this page.

Describe the overall procedure to be used, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

1) Students would measure radius of rod and calculate the cross section from this.

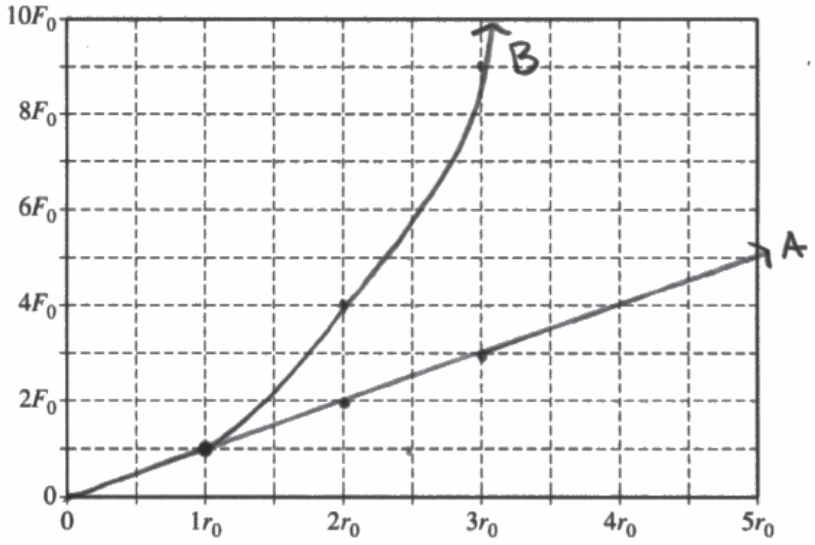
2) Students would connect force sensor to one end of rod and pull until rod breaks. Record N.s. Repeat with rod of same thickness.

3) Repeat steps 1 & 2 with Rods of different material to reduce experimental uncertainty.

4) Students will then graph average N and r to find the line of best fit and analyze.



(b) For a rod of radius r_0, it is determined that F_{max} is F_0, as indicated by the dot on the grid below. On the grid, draw and label graphs corresponding to the two students' models of the dependence of F_{max} on rod radius. Clearly label each graph "A" or "B," corresponding to the appropriate model.



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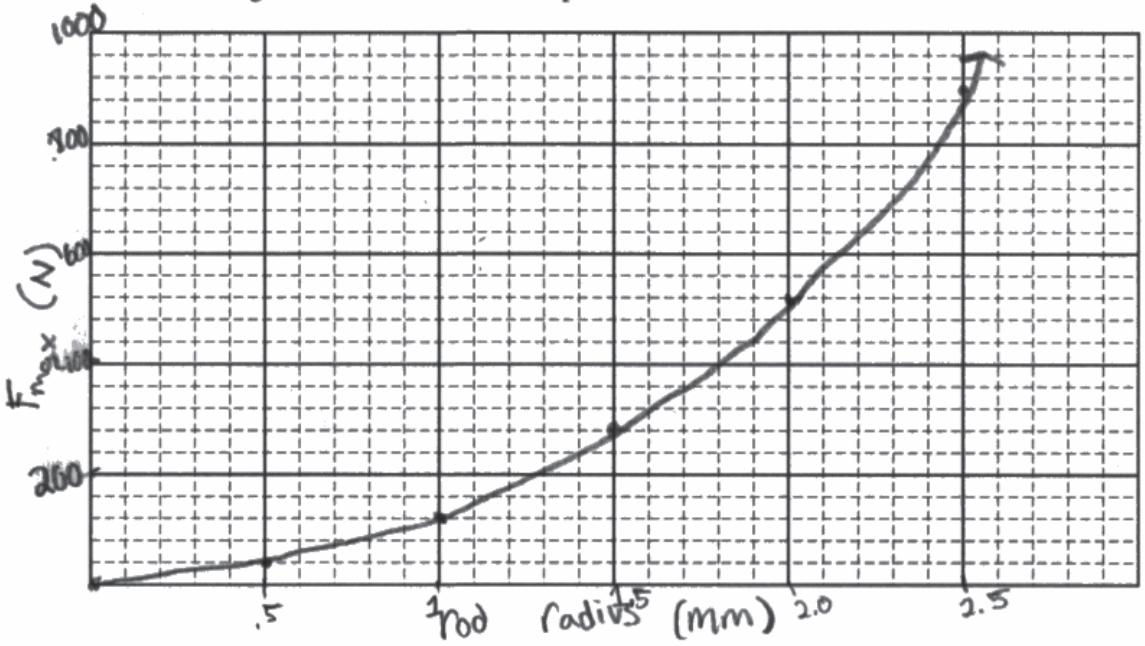
Continue your response to **QUESTION 2** on this page.

The table below shows results of measurements taken by another group of students for rods of different thicknesses.

Rod radius (mm)	0.5	1.0	1.5	2.0	2.5
F_{max} (N)	40	120	320	520	900

(c) On the grid below, plot the data points from the table. Clearly scale and label all axes, including units. Draw either a straight line or a curve that best represents the data.



(d) Which student's model is more closely represented by the evidence shown in the graph you drew in part (c) ?

___ Student A's model: F_{max} is directly proportional to the radius of the rod.

✓ Student B's model: F_{max} is directly proportional to the cross-sectional area of the rod.

Explain your reasoning.

Student B claims F_{max} is directly proportional to the cross section which holds the value r^2. F_{max} & r^2's relationship would not be linear as shown in the graph.

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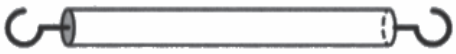

2. (12 points, suggested time 25 minutes)

A group of students is investigating how the thickness of a plastic rod affects the maximum force F_{max} with which the rod can be pulled without breaking. Two students are discussing models to represent how F_{max} depends on rod thickness.
Student A claims that F_{max} is directly proportional to the radius of the rod.
Student B claims that F_{max} is directly proportional to the cross-sectional area of the rod—the area of the base of the cylinder, shaded gray in the figure above.

(a) The students have a collection of many rods of the same material. The rods are all the same length but come in a range of six different thicknesses. Design an experimental procedure to determine which student's model, if either, correctly represents how F_{max} depends on rod thickness.

In the table below, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity, and also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
applied force	Fa	spring w/ hook and scale
radius	r	ruler
time	t	stopwatch

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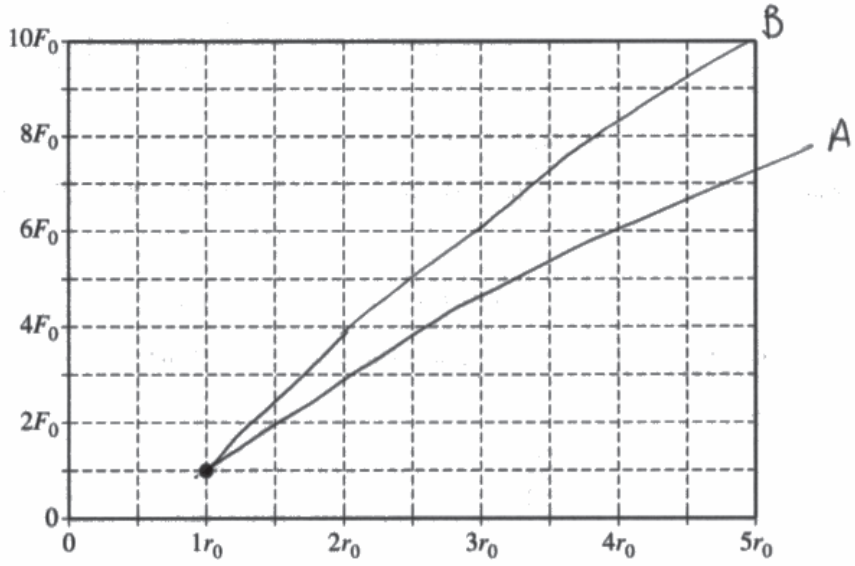
Describe the overall procedure to be used, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

The students should take a tube (1 of the 6) and measure the thickness and radius. This will allow the students to later compare the strength to the thickness. The student will attach the rod to a hook on the wall so they all have equal forces holding them in place. The students will then attach the spring w/ the scale to the tube and pull on it while ~~measuring the~~ monitoring the force. The stopwatch will have started when the student started pulling to measure the amount of time each tube lasts. The students will pull and apply force to the tube until it breaks and ~~record~~ write down the force it took until the tube broke. Repeat w/ all six tubes and compare data.

(b) For a rod of radius r_0, it is determined that F_{max} is F_0, as indicated by the dot on the grid below. On the grid, draw and label graphs corresponding to the two students' models of the dependence of F_{max} on rod radius. Clearly label each graph "A" or "B," corresponding to the appropriate model.



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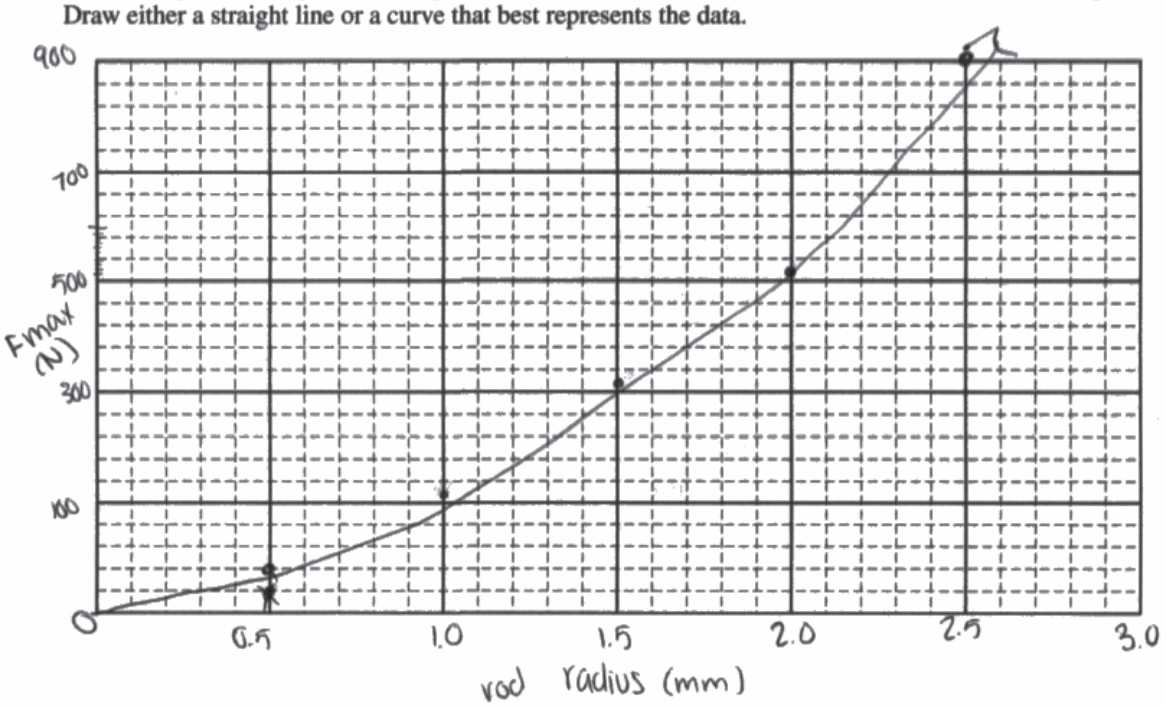
(c) On the grid below, plot the data points from the table. Clearly scale and label all axes, including units. Draw either a straight line or a curve that best represents the data.



(d) Which student's model is more closely represented by the evidence shown in the graph you drew in part (c) ?

X Student A's model: F_{max} is directly proportional to the radius of the rod.

____ Student B's model: F_{max} is directly proportional to the cross-sectional area of the rod.

Explain your reasoning.

The graph is labled as radius. The cross-sectional area is not represented in the graph.

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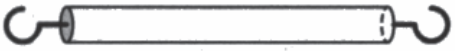

2. (12 points, suggested time 25 minutes)

A group of students is investigating how the thickness of a plastic rod affects the maximum force F_{max} with which the rod can be pulled without breaking. Two students are discussing models to represent how F_{max} depends on rod thickness.
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(a) The students have a collection of many rods of the same material. The rods are all the same length but come in a range of six different thicknesses. Design an experimental procedure to determine which student's model, if either, correctly represents how F_{max} depends on rod thickness.

In the table below, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity, and also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement
Least thick	#1 put label on rod	hook on wall, ruler/yardstick, slow motion camera, tape
second least thick	#2 put label on rod	
middle of thick ~~rod~~ rod not thick	#3 put label on rod	
second thickest	#4 put label on rod	
thickest	#5 put label on rod	

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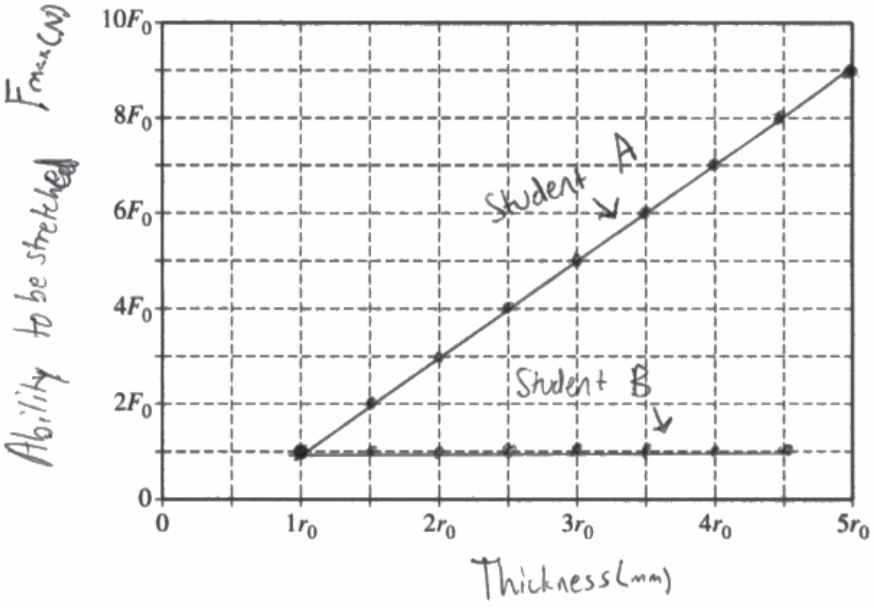
Describe the overall procedure to be used, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

Take 5 rods of all different thicknesses, but same length. label them and write on each rod to correlate with a graph you make. Then take one hook from one side and carefully take steps backwards with the other sides. Take small, measured steps (tape on the ground), while doing this have a ruler or yardstick measure how far the rod is being pulled. Keep doing this carefully until the rod breaks. For better result have a camera watching you, filming in slow motion. This will give you the exact time the rod breaks. This way you can see when the rod broke and put that with the measurement of how far it was stretched. Take notes of when the rods broke and see if there is a relationship between how far they can be stretched and their thickness.

(b) For a rod of radius r_0, it is determined that F_{max} is F_0, as indicated by the dot on the grid below. On the grid, draw and label graphs corresponding to the two students' models of the dependence of F_{max} on rod radius. Clearly label each graph "A" or "B," corresponding to the appropriate model.



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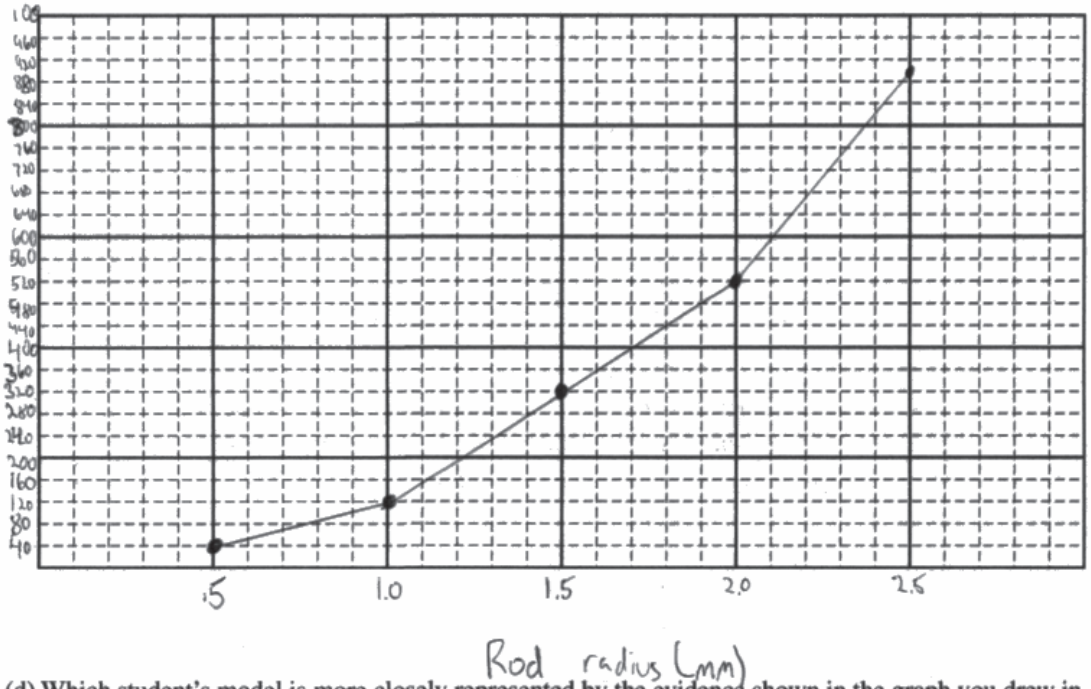

(d) Which student's model is more closely represented by the evidence shown in the graph you drew in part (c) ?

✓ Student A's model: F_{max} is directly proportional to the radius of the rod.

Student B's model: F_{max} is directly proportional to the cross-sectional area of the rod.

Explain your reasoning.

It is evedident that as the radius of the rod increased F_{max} increased This means that the reason F_{max} is increasing is because the radius is increasing.

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Question 2

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

Overview

Responses to this question were expected to demonstrate an understanding of Science Practice 4, Experimental Methods. Students designed an experiment to determine whether the relationship between two variables was more accurately described as linear or quadratic. Students had to realize they would need to perform trials with different values of the independent variable, rod thickness, to determine how thickness affects breaking force. The response also needed to devise practical ways to apply and measure the force necessary to break a rod and be specific about how that force would be applied to the rod using common laboratory equipment. The response needed to include steps to reduce experimental error, such as repeating the same measurement multiple times.

Responses to this question were expected to demonstrate Science Practice 1, Modeling. Students were asked to re-express two opposing narrative models as graphical models. Students were required to sketch a graph of what experimental results would look like if breaking force depended on radius and what the results would look like if breaking force depended on area.

Responses to this question needed to demonstrate well-developed graphing skills, such as making appropriately scaled axes, labeling axes, including units, and sketching an appropriate line of best fit.

Sample: P1 Q2 A
Score: 11

The response did not earn the first point in part (a). Although the response does mention measuring radius with a ruler, the response does not refer to measuring the radius of rods with different thicknesses. The response earned each of the other points.

Sample: P1 Q2 B
Score: 6

Part (a) earned 3 points. In the table, the response mentions measuring radius with a ruler. The last sentence of the procedure states to “repeat (the procedure) with all six tubes.” Because the response includes instructions to measure the radii of rods of different thicknesses with an appropriate tool, it earned the first point. In the table, the response mentions measuring force with “spring w/ hook and scale,” which is a spring scale, an appropriate tool for measuring force, so it earned the second point. The response further describes pulling the rod with this device. The response mentions attaching one end of the rod to a hook on the wall and the other end to the device used to measure force. Although the response refers to the time the tube lasts, the response specifically states to write down the force it took to break the tube, so it earned the third point. Although the response states to repeat the procedure with all six tubes, the response does not mention repeating the measurement with tubes of equal radius, so the fourth point was not earned. Part (b) earned 1 point. The graph marked A in the response is not linear, nor does it have the correct slope. The graph marked B in the response is concave down and does not show the correct quadratic relationship. Both graphs contain the point (r_0, F_0), so it earned this point. Part (c) earned 2 points. In this response, the scale on the vertical axis is not linear, as the force interval between the bottom two major grid lines is 100 N while the interval between other adjacent major grid lines is 200 N. The points are plotted correctly relative to the scale on the axes, so the response earned 1 point. The best-fit line drawn in this response is appropriate for the points that are plotted, so the response earned 1 point. Part (d) earned no points because the response does not indicate that student B's model is more closely represented by the evidence shown in the graph.

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Question 2 (continued)

Sample: P1 Q2 C
Score: 2

Part (a) earned no points. The response does not mention measuring the radius with an appropriate tool and does not mention repeating the measurement of breaking force with identical rods. The response does not include an appropriate tool for measuring force and does not include a practical way to measure the breaking force. Part (b) earned 1 point. The response only earned the fourth point in part (b) because both graphed lines contain the point (r_0, F_0). Part (c) earned 1 point for the points being plotted correctly. The vertical axis in the response is not labeled, and the plotted points are connected by a series of line segments instead of a smooth curve, so the response did not earn these points. Part (d) earned no points because the response does not identify student B's model as the one most closely represented by the evidence shown in the graph.

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