Question 3: Experimental Design and Analysis (LAB) — 10 points

A	For describing a procedure that includes **both** of the following: • Attaching the block to the meterstick • Measuring the force exerted on the left end of the meterstick while the block is attached	**Point A1**
	For a procedure that indicates a reasonable method of reducing experimental uncertainty Examples of acceptable responses may include the following: • Repeating the force measurement for one location of the block • Collecting force measurements for multiple locations of the block	**Point A2**

Example Response

Attach the block of unknown mass m_0 through one of the small holes in the meterstick. Measure the distance from the stand to the block. Record the force reading from the spring scale when the meterstick is horizontal. Repeat data collection by attaching the block to the meterstick through a different small hole in the meterstick. Repeat the measurements by attaching the block at each of the small hole locations numerous times.

B	For indicating appropriate quantities that can be plotted so that m_0 can be determined	**Point B1**

Scoring Notes:

- Any response that correctly identifies the functional dependence between force and distance earns this point, regardless of any coefficients that contain numbers or physical/fundamental constants, or which axis is chosen to graph each of those quantities.
- This point may be earned independently of the response in part A.

For describing how the slope is related to the unknown mass m_0 — **Point B2**

Examples of acceptable responses may include the following:

Graph	Analysis
Force as a function of the distance from the stand to the block	The slope is equal to m_0 times g divided by the distance from the stand to the spring scale. OR m_0 is equal to the slope times the distance from the stand to the spring scale divided by g.
Force as a function of the ratio of the distance from the stand to the block to the distance from the stand to the spring scale	The slope is equal to m_0 times g. OR m_0 is equal to the slope divided by g.
Force as a function of g times the distance from the stand to the block	The slope is equal to m_0 divided by the distance from the stand to the spring scale. OR m_0 is equal to the slope times the distance from the stand to the spring scale.
Force as a function of g times the ratio of the distance from the stand to the block to the distance from the stand to the spring scale	The slope is equal to m_0. OR m_0 is equal to the slope.
Force times the distance from the stand to the spring scale as a function of the distance from the stand to the block	The slope is equal to m_0 times g. OR m_0 is equal to the slope divided by g.
Force times the distance from the stand to the spring scale as a function of g times the distance from the stand to the block	The slope is equal to m_0. OR m_0 is equal to the slope.

Example Response

A graph of the force as a function of the distance from the stand to the block could be used to determine the unknown mass. The slope of the graph times the distance from the stand to the spring scale divided by g will result in the value of the unknown mass m_0.

C **(i)** For listing a quantity that could be plotted on the vertical axis to produce a linear graph whose slope can be used to determine the mass of the meterstick[1] **Point C1**

Examples of acceptable responses may include the following:

- F_T
- $\dfrac{F_T}{g}$
- $\dfrac{6}{5}\dfrac{F_T}{g}$
- $\dfrac{6}{5}F_T$

Scoring Note: Any response that correctly identifies the functional dependence between tension and angle earns this point, regardless of any coefficients that contain numbers or physical/fundamental constants.

Example Response

Vertical axis: F_T

(ii) For labeling the vertical axis (including units) with a linear scale **Point C2**

For correctly plotting data points consistent with **one** of the following: **Point C3**

- The quantities indicated in part C (i)
- The quantities indicated on the axes
- The quantities indicated in Table 2

(iii) For drawing an appropriate best-fit line that approximates the trend of the plotted data **Point C4**

Scoring Note: If the graph produced is nonlinear, then a line or curve that approximates the trend of that data can earn this point.

Example Response

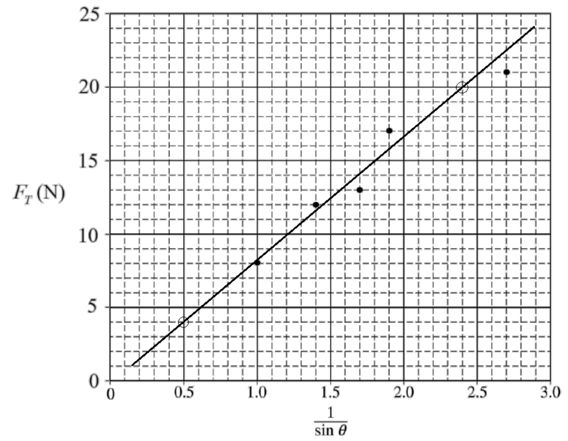


Figure 3

D	For correctly relating the slope of the best-fit line to the value of M	**Point D1**

Examples of acceptable responses may include the following:

Graph	Analysis
F_T vs. $\dfrac{1}{\sin\theta}$	slope $= \dfrac{5}{6}Mg$ OR $M = \dfrac{6}{5}\dfrac{\text{slope}}{g}$
$\dfrac{F_T}{g}$ vs. $\dfrac{1}{\sin\theta}$	slope $= \dfrac{5}{6}M$ OR $M = \dfrac{6}{5}\text{slope}$
$\dfrac{6}{5}\dfrac{F_T}{g}$ vs. $\dfrac{1}{\sin\theta}$	slope $= M$ OR $M = $ slope
$\dfrac{6}{5}F_T$ vs. $\dfrac{1}{\sin\theta}$	slope $= Mg$ OR $M = \dfrac{\text{slope}}{g}$

For a value of M within a range of 0.90 kg to 1.15 kg **Point D2**

Example Response

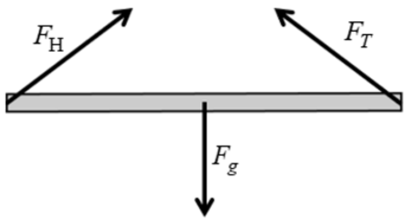
$$F_T = \frac{5Mg}{6\sin\theta}$$
$$F_T = \frac{5}{6}Mg\frac{1}{\sin\theta}$$
$$\text{slope} = \frac{5}{6}Mg$$
$$M = \frac{6(\text{slope})}{5g}$$

$$\text{slope} = \frac{20\text{ N} - 4\text{ N}}{2.4 - 0.5}$$
$$\text{slope} = 8.4\text{ N}$$
$$M = \frac{(6)(8.4\text{ N})}{(5)\left(9.8\ \frac{\text{N}}{\text{kg}}\right)}$$
$$M = 1.0\text{ kg}$$

Question 3: Qualitative/Quantitative Translation — 12 points

(a)	For drawing the gravitational force at the center of the beam that is directed downward	**1 point**
	For drawing the tension force at the right end of the beam that is directed upward and leftward	**1 point**
	For a diagram with three force vectors that represent a system in equilibrium	**1 point**

Example Response



Scoring Note: Examples of appropriate labels for the gravitational force include F_G, F_g, F_{grav}, W, mg, Mg, "grav force," F Earth on beam," "F on beam by Earth," $F_{\text{Earth on Beam}}$, $F_{\text{E,Beam}}$, or $F_{\text{Beam,E}}$. The labels G or g are not appropriate labels for the gravitational force.

Scoring Note: Examples of appropriate labels for the normal force include F_n, F_N, N, "normal force," or "wall force."

Scoring Note: Examples of appropriate labels for the tension force include F_{string}, F_s, F_T, F_{Tension}, "string force," or "tension force."

Total for part (a) 3 points

(b)	For selecting "$F_{T2} > F_{T1}$" with an attempt at a relevant justification	**1 point**
	For a justification that includes **one** of the following:	**1 point**

- For relating the vertical component of the tension in the string to the weight of the bar
- For relating the force needed to exert the same torque to the angle of the string

Example Response

In order for the beam to remain horizontal and at equilibrium, the torque exerted by the string must remain the same for all angles. When the angle decreases, the perpendicular component of the tension remains the same. Therefore, the tension in the string is greater for a smaller angle.

Total for part (b) 2 points

(c)	For a multi-step derivation that begins with Newton's second law for rotation, $\Sigma\tau = I\alpha$ or $\Sigma\tau = 0$	**1 point**
	For indicating **one** of the following: • The net torque is zero • The net force is zero	**1 point**
	For indicating **one** of the following: • The magnitude of the torque from the string is $(F_T \sin\theta)L$ • The magnitude of the torque from the weight of the beam is $Mg\frac{L}{2}$ • The correct answer, $F_T = \frac{Mg}{2\sin\theta}$	**1 point**

Example Response

$\Sigma\tau = I\alpha$

$\tau_{\text{gravity}} + \tau_{\text{string}} = 0$

$\left(F_g\right)\frac{L}{2}\left(\sin 90^\circ\right) - F_T(L)\sin\theta = 0$

$Mg\frac{L}{2} = (F_T \sin\theta)L$

$F_T = \frac{Mg}{2\sin\theta}$

Total for part (c) **3 points**

(d)	For an attempt to use functional dependance to relate the derivation in part (c) to the reasoning used in part (b) **Scoring Note:** The functional dependance does not need to be used correctly to earn this point.	**1 point**
	For an explanation that correctly relates the derivation in part (c) to the reasoning used in part (b)	**1 point**

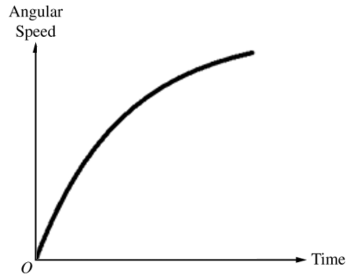
Example Response

The equation agrees with my explanation because my equation shows that the tension is inversely proportional to $\sin\theta$ *and for* $\theta < 90^\circ$, $\sin\theta$ *decreases as* θ *decreases, so the tension would be greater for smaller angles.*

Total for part (d) **2 points**

(e)	For drawing a graph that is monotonically increasing	**1 point**
	For drawing a concave down curve	**1 point**

Example Response



Total for part (e) **2 points**

Total for question 3 **12 points**

Question 4: Short Answer Paragraph Argument — 7 points

(a)	For a correct expression for the angular acceleration of the pulley in terms of the appropriate quantities: $\alpha_D = \frac{2F_T}{MR}$	**1 point**

Example Response

$\alpha_D = \frac{RF_T}{\frac{1}{2}MR^2}$ ***OR*** $\alpha_D = \frac{2F_T}{MR}$

Total for part (a) **1 point**

(b)	For indicating that the torque, τ, is the same for both pulleys	**1 point**
	For indicating that the impulse, $\tau\Delta t$, (or change in momentum ΔL) is the same for both pulleys because τ and Δt are the same	**1 point**
	For indicating that the rotational inertia, I, of the disk and hoop are different	**1 point**
	For providing reasoning that because the rotational inertia, I, are different for the disk and hoop, the kinematic quantities ($\Delta\theta$, ω, α) are also different for the disk and hoop	**1 point**
	For **one** of the following: • Relating I and ω to reason that ΔK is greater for the disk • Indicating that because $\Delta\theta$ is greater for the disk the work done on the disk is greater	**1 point**
	For a logical, relevant, and internally consistent argument that follows the guidelines described in the published requirements for the paragraph-length response	**1 point**

Example Response

The rotational inertia, I, of the hoop is larger than the rotational inertia of the disk because the hoop's mass is all on the outside instead of distributed throughout like the disk. Equal forces are applied to both pulleys at the same distance, which means that the torques exerted on the pulleys will also be equal. Since the same torque is applied to both pulleys for the same time period, the change in angular momentum will be the same for the disk and hoop. The magnitude of the angular velocity for the hoop will be smaller than that of the disk since angular velocity is inversely proportional to the rotational inertia $\left(\omega = \frac{L}{I}\right)$.

Since kinetic energy is proportional to rotational inertia and the square of angular velocity $\left(K_R = \frac{1}{2}I\omega^2\right)$*, the difference in angular velocity more greatly affects the rotational kinetic energy. That means the disk will have a greater rotational kinetic energy than the hoop.*

Total for part (b)	**6 points**
Total for question 4	**7 points**