Question 3: Qualitative/Quantitative Translation — 12 points

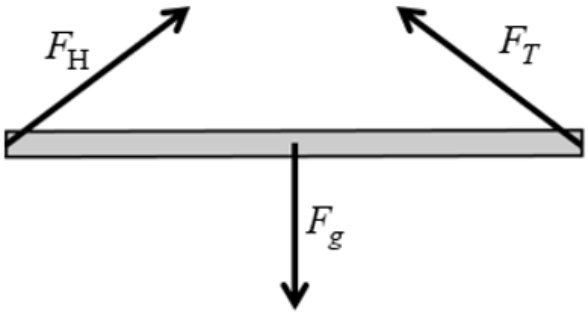
(a)

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 "$F_{\text{T2}} > F_{\text{T1}}$" 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: **1 point**

- The net torque is zero
- The net force is zero

For indicating **one** of the following: **1 point**

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

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) **1 point**

Scoring Note: The functional dependance does not need to be used correctly to earn this point.

For an explanation that correctly relates the derivation in part (c) to the reasoning used in part (b) **1 point**

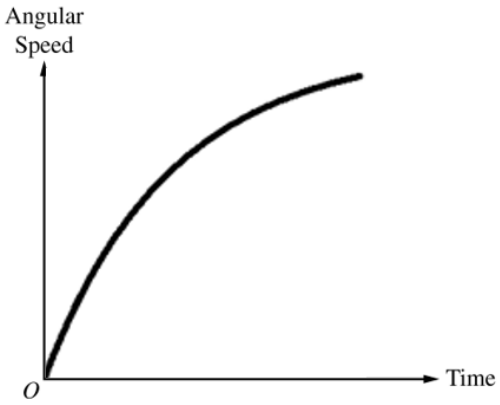
Example Response

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 5: Short Answer — 7 points

(a) **i.** For correct expressions for the torques from the weight of each object — **1 point**

The torques are $m_0 g(2r_0)$ for object 1 and $(1.5m_0 g)r_0$ for object 2

For indicating that the two torques are exerted in opposite directions — **1 point**

$\tau_{\text{net}} = m_0 g(2r_0) - (1.5m_0 g)r_0$

For the derivation of a correct answer of $0.5m_0 g r_0$ — **1 point**

Example response for part (a)(i)

$\tau_{\text{net}} = \tau_1 - \tau_2$
$\tau_{\text{net}} = m_0 g(2r_0) - (1.5m_0 g)r_0$
$\tau_{\text{net}} = 0.5m_0 g r_0$

ii. For an explanation that object 1 exerts a larger torque than object 2 — **1 point**

Example response for part (a)(ii)

Object 1 is twice as far from the axle as object 2, while object 2 has only 1.5 times the weight of object 1. So, object 1 exerts a larger torque.

Total for part (a) 4 points

(b) Correct answer: "Opposite directions"

Scoring note: If the wrong answer is selected, the response is not graded.

For a correct answer and a correct explanation — **1 point**

Example response for part (b)

The objects exerted torques in opposite directions, with object 1 exerting a larger torque, so object 1 determines the net torque direction. With the torque from object 1 removed, the net torque and angular acceleration switch direction (becoming clockwise) to the torque from object 2. The angular velocity does not change direction immediately and is still counterclockwise.

(c) For a linear graph between 0 and t_C, with an initial angular velocity of zero and nonzero slope **1 point**

Scoring note: The slope can be positive or negative.

For a change in the sign of the slope at $t = t_C$ **1 point**

AND

no discontinuity.

Example response for part (c)

Total for part (c) 2 points

Total for question 5 7 points