Question: Given a cart traveling along a metal track in a modified Atwood's machine with an external force being applied upon the cart, does the relationship between force, mass, and acceleration obey Newton's Second Law?

Hypothesis: The relationship between the force from the hanging weight and the acceleration measured in the cart will be linear, with the slope being the total mass of the system and the y-intercept representing the external force.

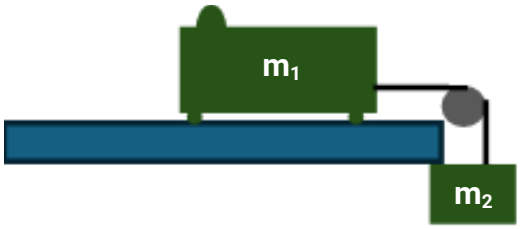
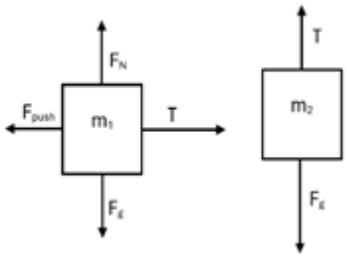


Fig. 1: Modified Atwood's Machine

Strategy:
1. The hanging mass in a modified Atwood's machine was altered by varying the number of washers on a paper clip tied to the string. This acceleration was measured using a Vernier motion detector.
2. The total mass was kept constant by using a total of 10 washers across the cart and paper clip, but the number of washers on the cart or the paper clip was varied. The independent variable was the hanging mass, and the dependent variable was the acceleration.
3. An additional external force, a Vernier fan, was attached to the cart, which accelerated the cart in the opposite direction of the tension in the string.
4. The applied force (the hanging weight) was graphed vs. the net acceleration as seen in Fig. 2 to verify that the slope of the line of best fit was equal to the total mass of the system



$$m_2g - T = m_2a$$

$$-F_{push} + m_2g = m_1a + m_2a$$

$$-F_{push} + m_2g = a(m_1 + m_2)$$

$$m_2g = a(m_1 + m_2) + F_{push}$$

Fig. 2: Free Body Diagram with derived equations

Data: We varied the hanging mass by using 2, 4, 6, 8, and 10 washers, conducting three trials for each case. The table displays the hanging mass in kilograms and the corresponding average acceleration measured for each mass. The weight of m_2 (the hanging mass) was calculated by multiplying the mass values by g = 9.8 m/s^2. The average acceleration was determined by averaging the slopes obtained from the Vernier motion detector readings. The collected values can be seen in Fig. 3.

Washers on hanging mass	m2(kg)	Average Acceleration
2	0.006	-0.09152667
4	0.011	0
6	0.017	0.074281667
8	0.022	0.1889
10	0.028	0.291783333

Fig. 3: Data table containing data of all trials that varied hanging mass

Analysis:
Our experiment demonstrates that hanging mass varies linearly with the product of acceleration and total mass. The linear regression yielded $R^2 = 0.995$, showing a strong linear relationship. However, the experimental total mass (0.5715 kg) exceeded the actual value (0.4618 kg) by 19.20%. This disagreement indicates that the acceleration was lower than expected, likely due to friction between the cart wheels and track, and the friction between the string and pulley. Additionally, mounting the fan increased the cart's cross-sectional area and shape irregularity, increasing air resistance and reducing acceleration.
Despite this error, the experiment accurately predicted the linear relationship between hanging mass weight and total system force. The fan contributed 0.1117 N of force without disrupting linearity, consistent with free body diagram predictions. These results support our hypothesis: the modified Atwood machine with an additional force obeys Newton's Second Law.

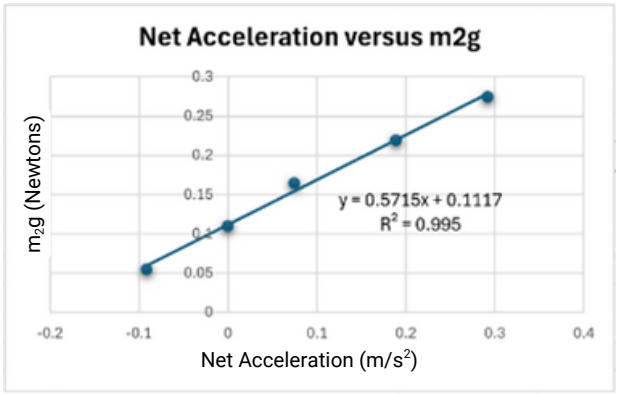


Fig. 4: Plot of hanging weight varying with net acceleration