

Analysis of Student Understanding of Statics Principles

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Abstract

An analysis of introductory physics students' understanding of statics principles was conducted. The prior development and use of *Tutorials in Introductory Physics* [4] has addressed student difficulties concerning introductory physics concepts, including fundamental statics principles; yet, conceptual difficulties persist, particularly when the complexity of an assessment question increases. To assess the extent to which the introductory physics curriculum prepared students for an engineering statics course, students completed multiple-choice questions taken from the "Statics Concept Inventory" [5]. Responses illuminated remaining areas of difficulty for students, as well as trends in student understanding. Interestingly, students commonly made the same errors as those reported in the analysis of the "Statics Concept Inventory," especially with regard to applying a limit on the friction force in order to maintain static equilibrium. Further exploration of student difficulties with statics concepts is needed so curricula can be adapted for extensive instruction.

Description of Research

Population:

- Freshman students (N=86) enrolled in Physics 114A, an algebra-based introductory physics course at UW.
- Freshman students (N=72) enrolled in Physics 121A, a calculus-based introductory physics course at UW.

Assessment:

- Completed 3 multiple choice questions taken from the "Statics Concept Inventory" on a mechanics exam after instruction had been completed [5].
 - 1 free body diagram problem
 - 2 static friction problems

Analysis:

- Results were compared with the performance of mechanical engineering students (N=125) entering a sophomore statics course at Carnegie Mellon University before any instruction had taken place [6].

5 Classes of Questions in the "Statics Concept Inventory":

1. Free body diagrams
2. Static equivalence of combinations of forces and couples
3. Equilibrium conditions
4. Type and direction of loads at connections
5. Limit on the friction force due to equilibrium conditions

An Example: Limit on the Friction Force

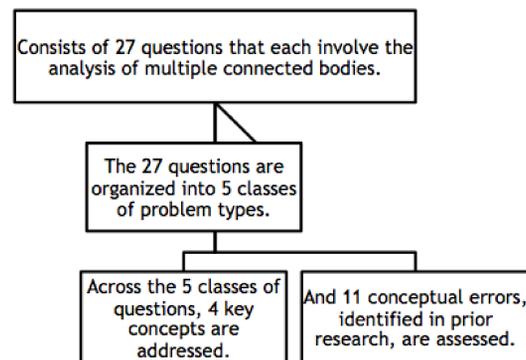
Key Concepts

- "The *possibilities* of forces between bodies that are connected to, or contact, one another can be reduced by virtue of the bodies themselves, the geometry of the connection, and/or assumptions on friction" [5].
 - In this case, knowing that stationary contacting bodies remain in static equilibrium requires that the friction force between the bodies be less than μN .

Anticipated Errors

- Failure to recognize that μN is the limiting value of the static friction force, and instead consider the friction force to be equivalent to μN even though equilibrium is maintained with a friction force of lesser magnitude [5].
- Presuming the friction force is the difference between the driving force and the slipping limit, μN [5].

Outline of the "Statics Concept Inventory"



Analysis of Question 1 Responses

Response	Understanding Reflected by Response	% Physics 114A	% Physics 121A	% CMU Statics
D	Correct answer.	35	50	25
E	Friction force = μN	25	35	
C	Friction force is the difference between μN and the driving force.	20	5	
A	Friction force is the difference between μN and the driving force, but the 30 N is used as the normal force.	10	5	
B	Friction force = μN , but 30 N is used as the normal force.	10	5	

Analysis of Question 2 Responses

Response	Understanding Reflected by Response	% Physics 114A	% Physics 121A	% CMU Statics
B	Correct answer.	25	35	20
E	Friction force = μN .	25	15	
C	Friction force is the difference between μN and the driving force.	25	20	
D	Balances driving forces but does not satisfy the friction condition for equilibrium.	15	25	
A	Friction force is the difference between μN and the driving force, but in the wrong direction.	5	5	

Physics 114A—an algebra based introductory physics course at UW in which N=86 students participated.
 Physics 121A—a calculus based introductory physics course at UW in which N=72 students participated.
 CMU Statics—a sophomore mechanical engineering course in which N=125 students participated.

Trends in Student Understanding

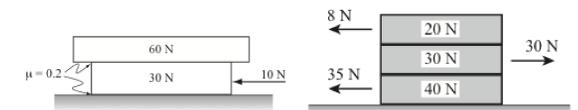
How often do students employ the same incorrect method for finding the friction force in both questions?

Trend: Friction force found by equating it to μN .	% Physics 114A	% Physics 121A
Select "E" for question 1.	25	35
Select "E" for question 2.	25	15
Select "E" for both questions.	10	10

Trend: Friction force found by taking the difference between the driving force and μN .	% Physics 114A	% Physics 121A
Select "C" for question 1.	20	5
Select "C" for question 2.	25	20
Select "C" for both questions.	10	<5

How does the difference in difficulty between question 1 and question 2 affect student responses?

Trend: Greater percentage of students correctly answer question 1 than question 2.	% Physics 114A	% Physics 121A
Correctly answered question 1.	35	50
Correctly answered question 2.	25	35
Correctly answered question 1, but incorrectly answered question 2.	30	20



Of those students that correctly answered question 1 and incorrectly answered question 2, the most commonly chosen incorrect response to question 2 was choice "D," which was arrived at by balancing the driving forces (Physics 114A 35 %, Physics 121A 65 %).

Further Curriculum Development and Research

The students at UW enrolled in Physics 114A and Physics 121A performed comparatively well to the sophomore mechanical engineering students at CMU. This suggests that the tutorials used at UW may improve student understanding of friction force concepts and thereby help to prepare them for more advanced engineering courses [1], [2], [3]. The results may also demonstrate a need for greater use of the friction tutorials developed by PEG since known conceptual errors persist. Further research could focus on the following pursuits in order to improve student understanding of difficult physics concepts:

- Development of friction tutorials that present more complicated systems.
- Development of friction tutorials that require analysis of a subsystem of contacting bodies.
- Continued use of the "Statics Concept Inventory" to determine widespread and tenacious student difficulties.

References

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- ⁵ P. S. Steif and J. A. Dantzer, "A Statics Concept Inventory: Development and Psychometric Analysis," *Journal of Engineering Education*, 2005, p. 363.
- ⁶ P. S. Steif, "Initial Data from a Statics Concept Inventory," American Society for Engineering Education, 2004.

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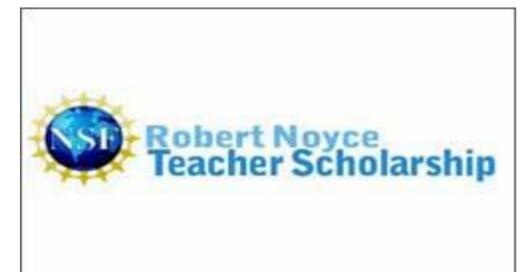
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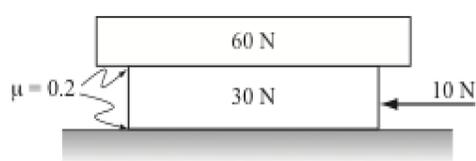
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Assessment Questions and Analysis of Student Understanding

Limit on Friction Force: Question 1



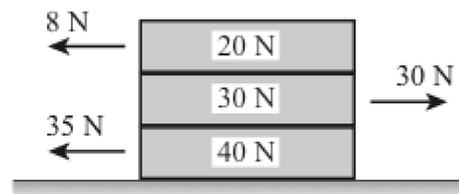
Two blocks are stacked on top of each other on the floor. The friction coefficient, μ , is 0.2 between all contacting surfaces. (Take this to be both the static and kinetic coefficient of friction). Then, the horizontal 10 N force is applied to the lower block. It is observed that neither block moves. What is the horizontal component of the force exerted by the floor on the lower block?

- 4 N
- 6 N
- 8 N
- 10 N
- 18 N

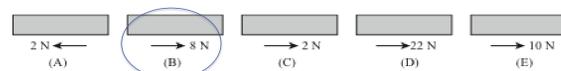
Correct Answer:

Balances 10 N and satisfies the friction condition since $\mu N = 0.2 \times 90 \text{ N} = 18 \text{ N}$.

Limit on Friction Force: Question 2



Three blocks are stacked on top of one another on a table. Then the horizontal forces shown are applied. The friction coefficient, μ , is 0.5 between all contacting surfaces. (This is both the static and kinetic coefficient of friction). It is observed that none of the blocks move. Which of the following diagrams best represents the horizontal component of the force acting on the lower face of the top (20 N) block?



Correct Answer: Balances 8 N and satisfies the friction condition since $\mu N = 0.5 \times 20 = 10 \text{ N}$.