DB3

# Where Do Students "Go Wrong" When Solving Newton's Second Law Problems

**Introductory Calculus-Based Physics**

Charles Henderson

Patricia Heller

University of Minnesota

http://www.physics.umn.edu/groups/physed

# Overview

- Context of this study
- Questions
- Atwood machine problem and preliminary results
- Implications

# Context of This Study

- Cooperative Group Problem Solving in calculus-based introductory physics courses since 1994
- FCI gains ≥ other universities with research-based curricula.
- FCI (post) scores ~ 70%
  - 60% suggested as the conceptual threshold for problem solving competence*
  - 80% suggested as the threshold for mastery of basic Newtonian concepts*

**But, students don't solve introductory physics problems at the desired level**

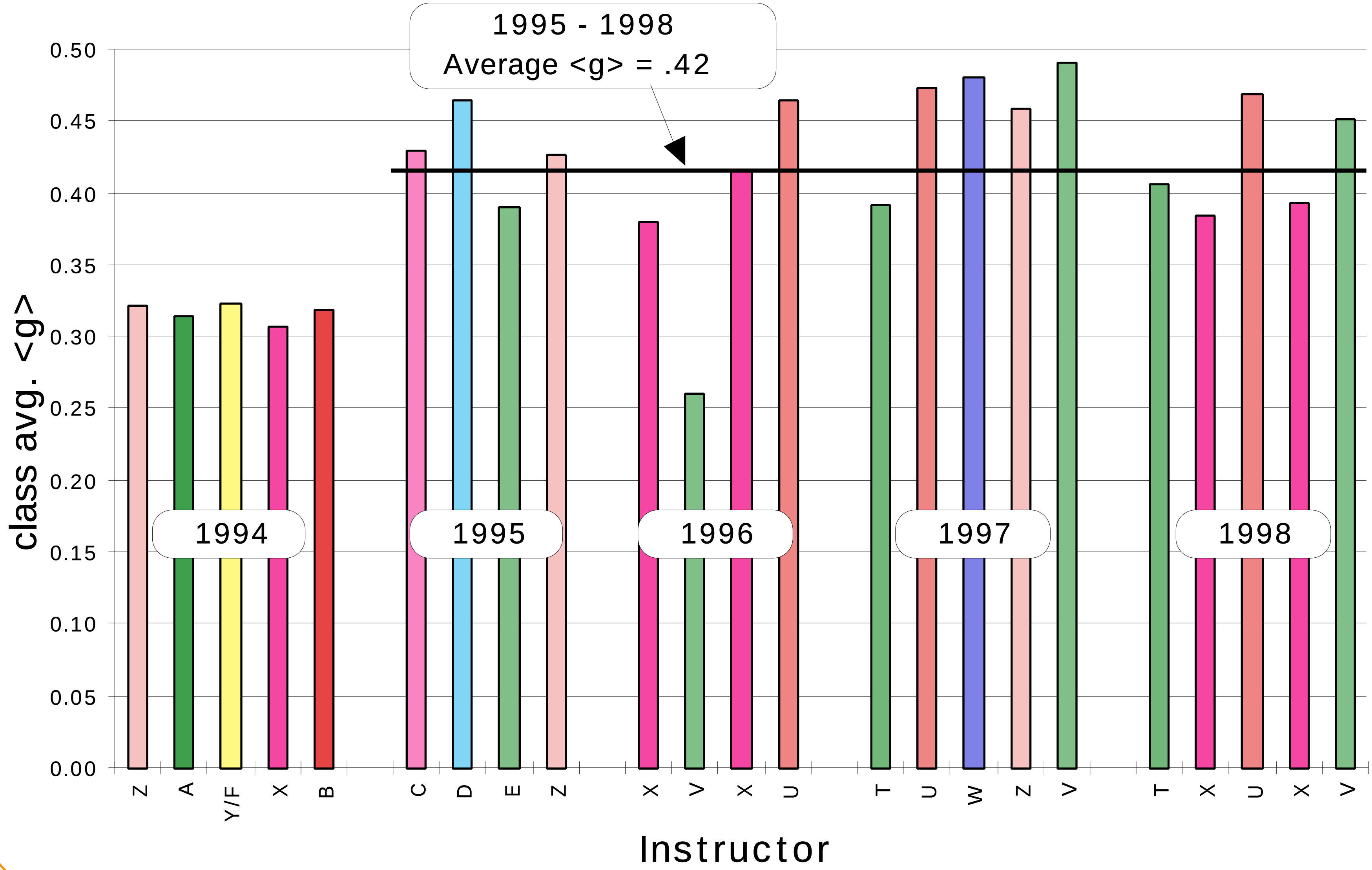
***Hestenes & Wells (1992) *TPT*, p. 161**

# Cooperative Group Problem Solving at the University of Minnesota

**(Introductory Calculus-Based Mechanics for Scientists and Engineers)**

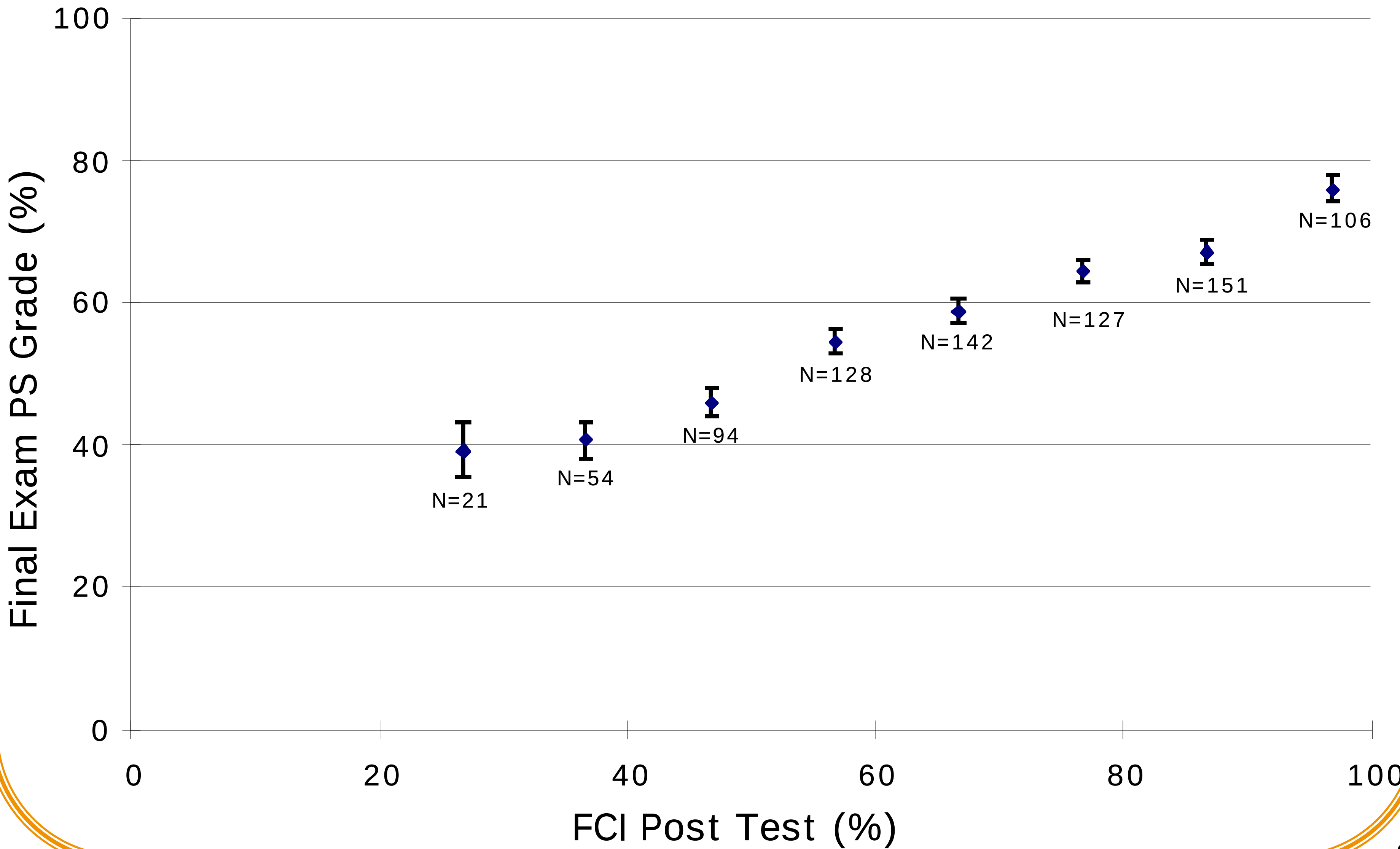
- Large Scale (~850 Students, ~30 TA's, ~5 Lecturers)
- Standard Format (3 lectures, 1 lab, 1 recitation per week)
- Context rich problems in lab and recitation
- TA Education
- Common Final Exam
- Lecture style and content varies by lecturer
- Standard Text (Halliday, Resnick, & Walker, 5th ed.)

# Force Concept Inventory
# Average <g> by Year



# FCI Post vs. Final Exam Grade

**Fall 1998, N=823 Students, 5 Lecture Sections**



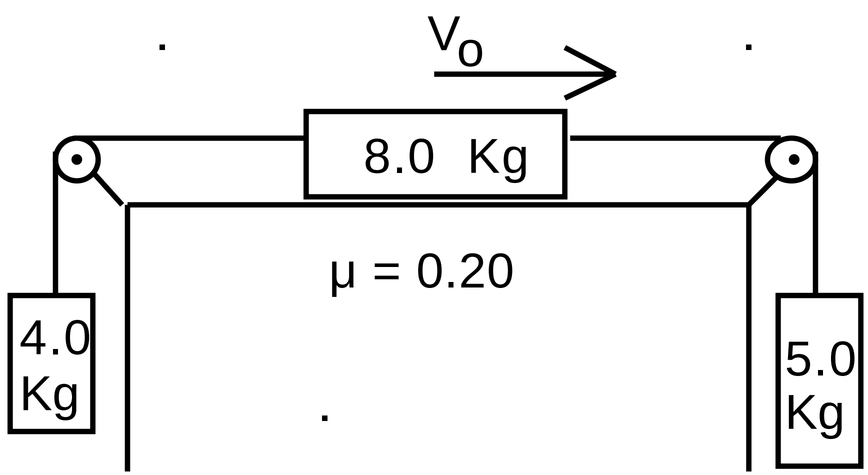
# Questions

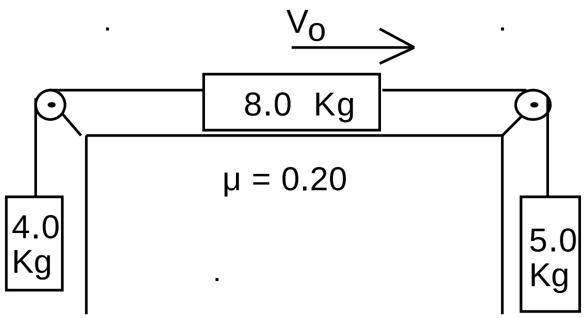
- Is examining student solutions a useful diagnostic tool for course design?
    1. Do students correctly apply Newton's Second Law when solving quantitative problems?
    2. For those students with incorrect solutions, what kinds of errors do they make?
- Can instructional design make a difference?

# Atwood Machine Problem

## Fall 1998 Final Exam

Three blocks are connected as in the diagram with strings over massless frictionless pulleys. The coefficient of kinetic friction between the 8.0 kg block and the horizontal surface is 0.20. The 8.0 kg block is initially sliding to the right. Find the magnitude and direction of the acceleration of the 8.0 kg block and the tension in each string.






# Why This Problem?

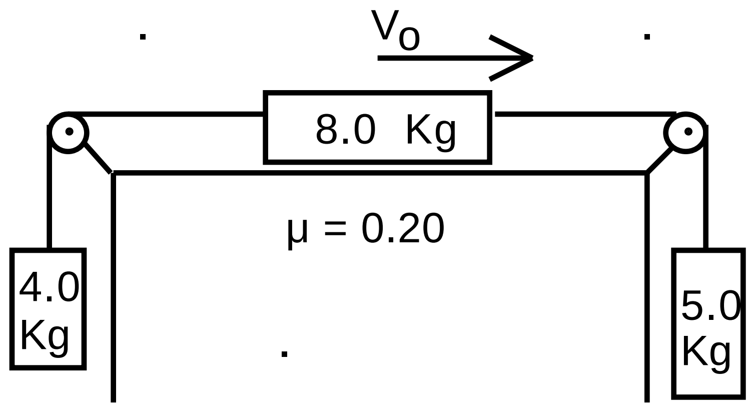
- It is very difficult for students (the average grade on this problem was 51%).
- A correct solution requires an understanding of Newton’s Second Law.
- The solution process is relatively straightforward.

# Methods

Examination of final exam solutions from fall 1998:

- ↔ 180 student solutions
  - randomly selected (stratified by course grade)
  - from all lecture sections
- ↔ Solutions categorized

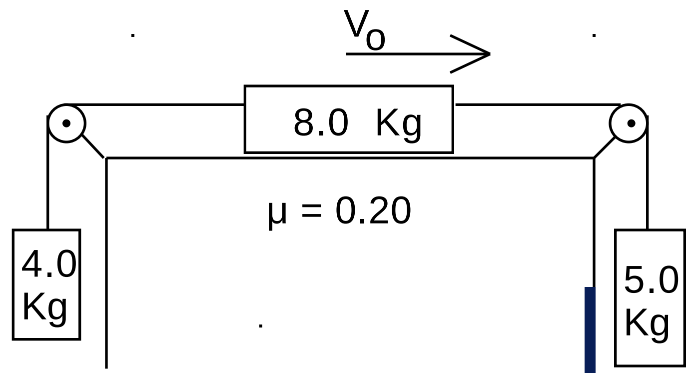
# Atwood Solutions
# Final 1998




| Part a: Solving for Acceleration | All N=179 % | High FCI* N=63 % |
|---|---|---|
| 1. Correct or minor errors | 32 | 44 |
| 2. Careless or oversimplified | 3 | 3 |
| 3. Mathematics difficulties | 6 | 5 |
| 4. Incorrect physics approaches | 59 | 48 |
| | Average FCI = 69% | Average FCI = 89% |

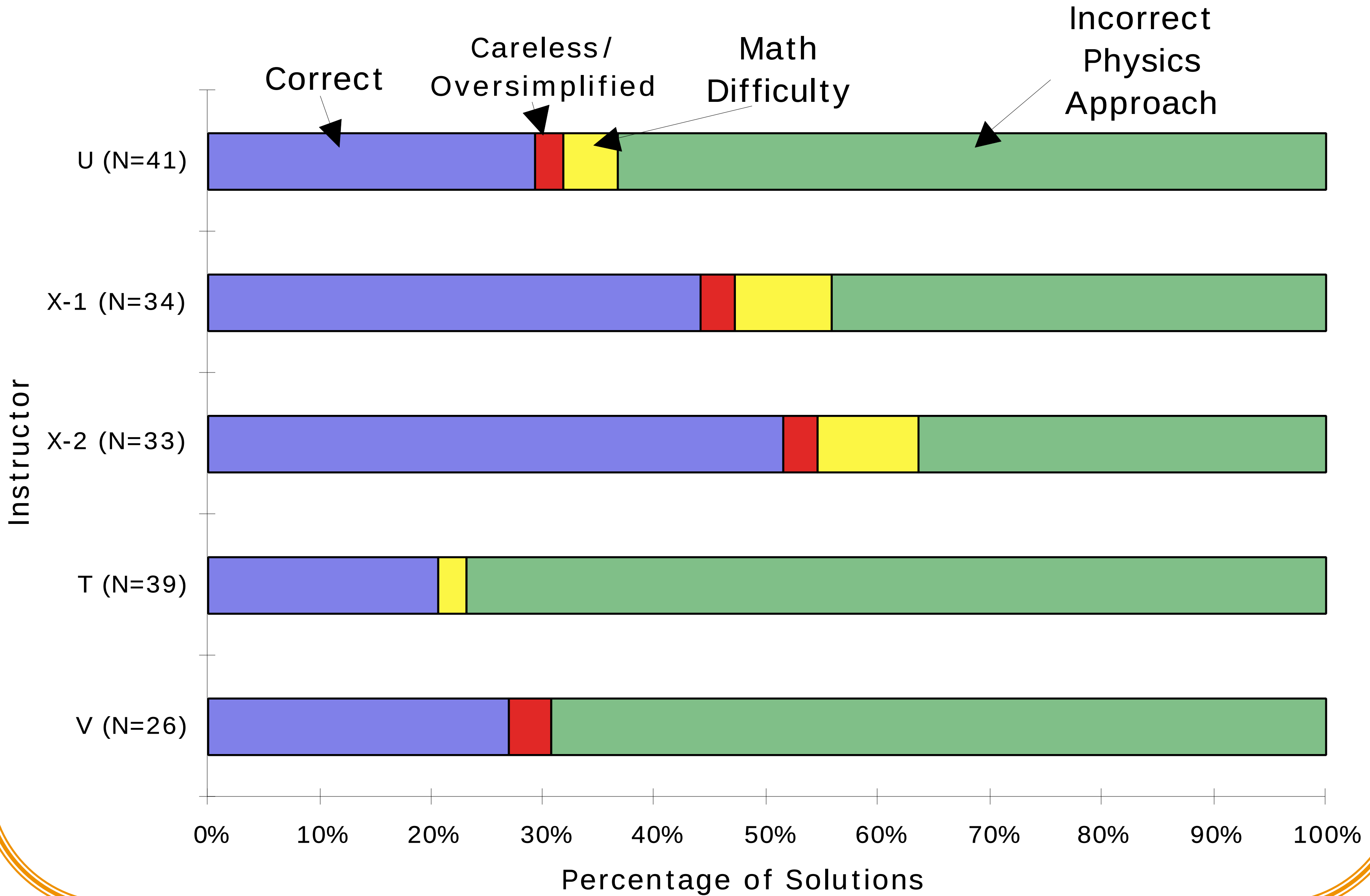
*FCI Post > 80%

# Incorrect Physics Approaches: Atwood Machine

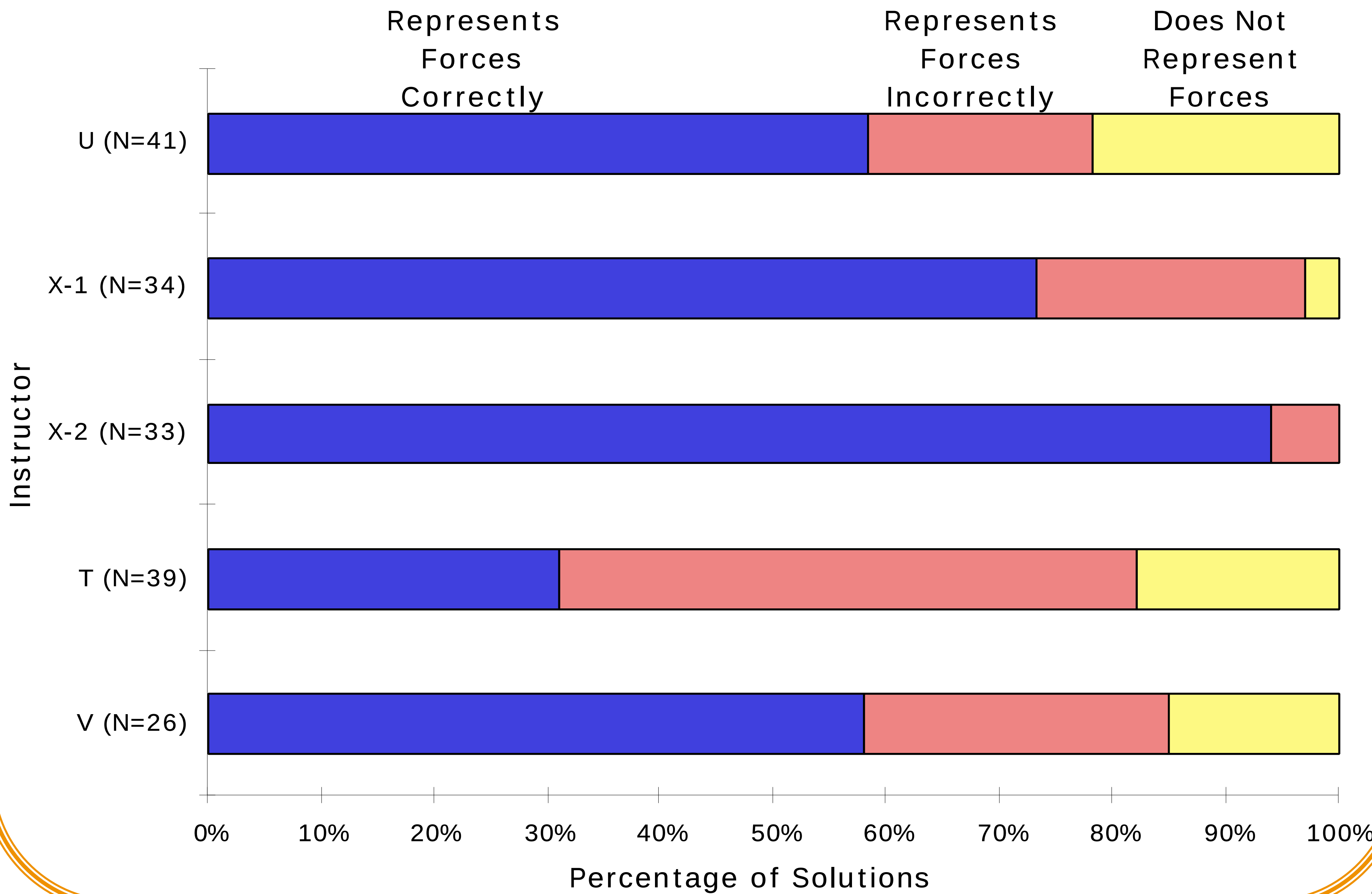



| | % |
|---|---|
| **a.** $\sum F = 0$ | **18** |
| $T_1 = M_4 g;\ T_2 = M_5 g$ | |
| **b. F = ma** (incorrect m or a) | **13** |
| $T_2 - T_1 - f_f = M_{total}\, a$ | |
| **c.** $F_{unknown} = \sum F_{known}$ | **15** |
| $m_8 a = m_5 g - T_2 - (m_4 g - T_1) - f_f$ | |
| **(often includes a "velocity force" or a normal force)** | |
| **d. More than one of the above** | **3** |
| **e. Incomplete, can't tell** | **11** |

# Types of Student Solutions from each Lecture Section



# Student Representation of Forces from each Lecture Section



# Preliminary Conclusions

**Within the Context of Cooperative Group Problem Solving at the University of Minnesota:**

- Student solutions appear to be a useful diagnostic tool.
- Students do well on the FCI but have difficulties using Newton's Second Law to solve this problem.
  - ◊ Incorrect physics approaches
  - ◊ Not Mathematical Difficulties
- Lectures may make a difference.

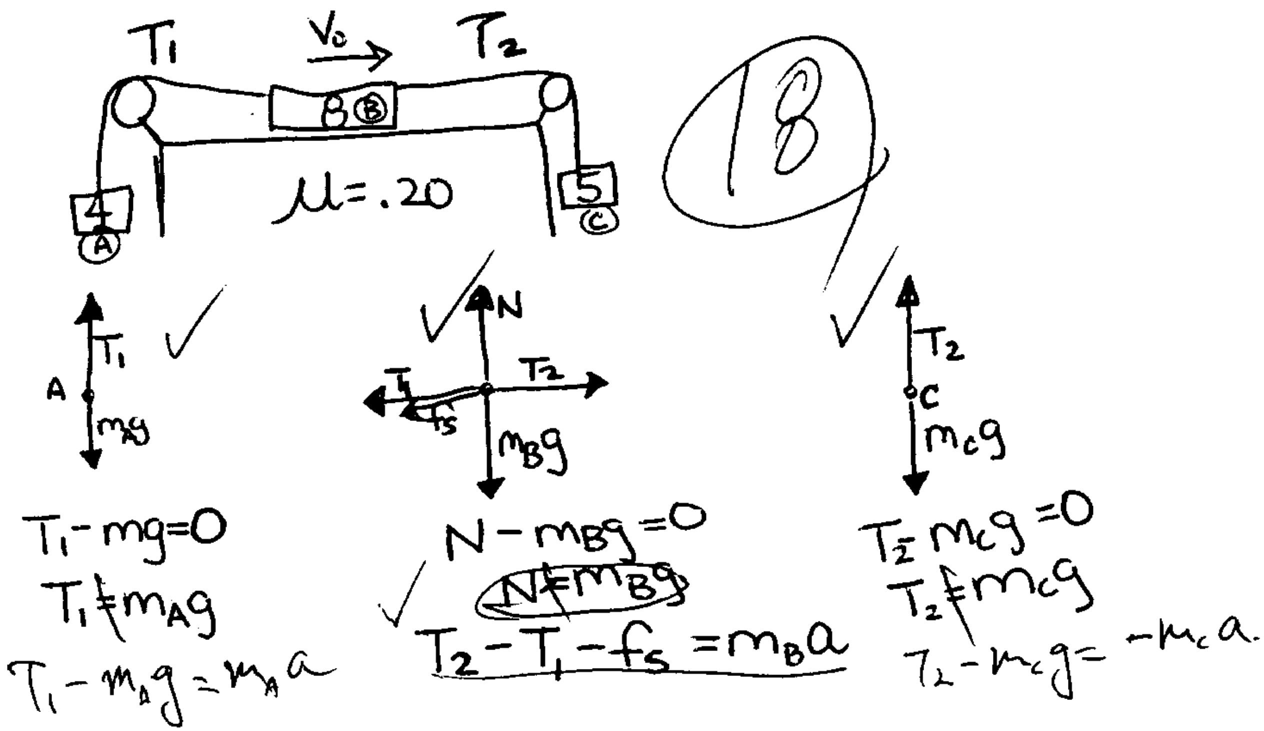
# Further Study

**Within the Context of Cooperative Group Problem Solving at the University of Minnesota:**

- Verify student solutions as a useful diagnostic tool?
- Can instructional design improve performance?
- Look at other problems.

# Incorrect Physics Approach A

$$\sum F = 0$$

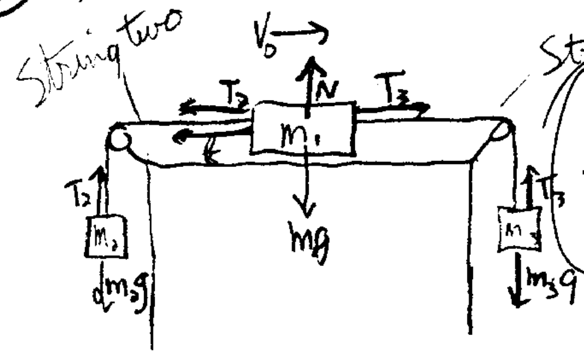


## Atwood II

# Incorrect Physics Approach B

F = ma (incorrect m or a)

② Variables / Diagram




15/30

$\mu_k = .20$
$m_1 = 8$ kg
$m_2 = 4$ kg
$m_3 = 5$ kg

f = force of friction
W = mg = weight force

a = accleration = ?
$T_3$ = Tension Force of String three = ?
$T_2$ = Tension Force of String two = ?
M = ~~total~~ mass of the system

**Setup**

$F_{1x} = T_3 - T_2 - f_k = Ma$

$F_{1y} = N - m_1 g = 0$

$N = m_1 g$

$f_k = \mu_k N = \mu_k mg$

Atwood II

# Incorrect Physics Approach C

$$F_{unknown} = \sum F_{known}$$

Pb. 2. Three blocks are connected as in the diagram with strings over massless frictionless pulleys. The coefficient of kinetic friction between the 8.0-kg block and the horizontal surface is 0.20. The 8.0-kg block is initially sliding to the right. Find the magnitude and direction of the acceleration of the 8.0-kg block and the tension in each string.