

Statics for engineers: from diagnosis of students difficulties to a statics concept inventory and an open course

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Do we communicate?



homework



It's not about what we (instructors) say...

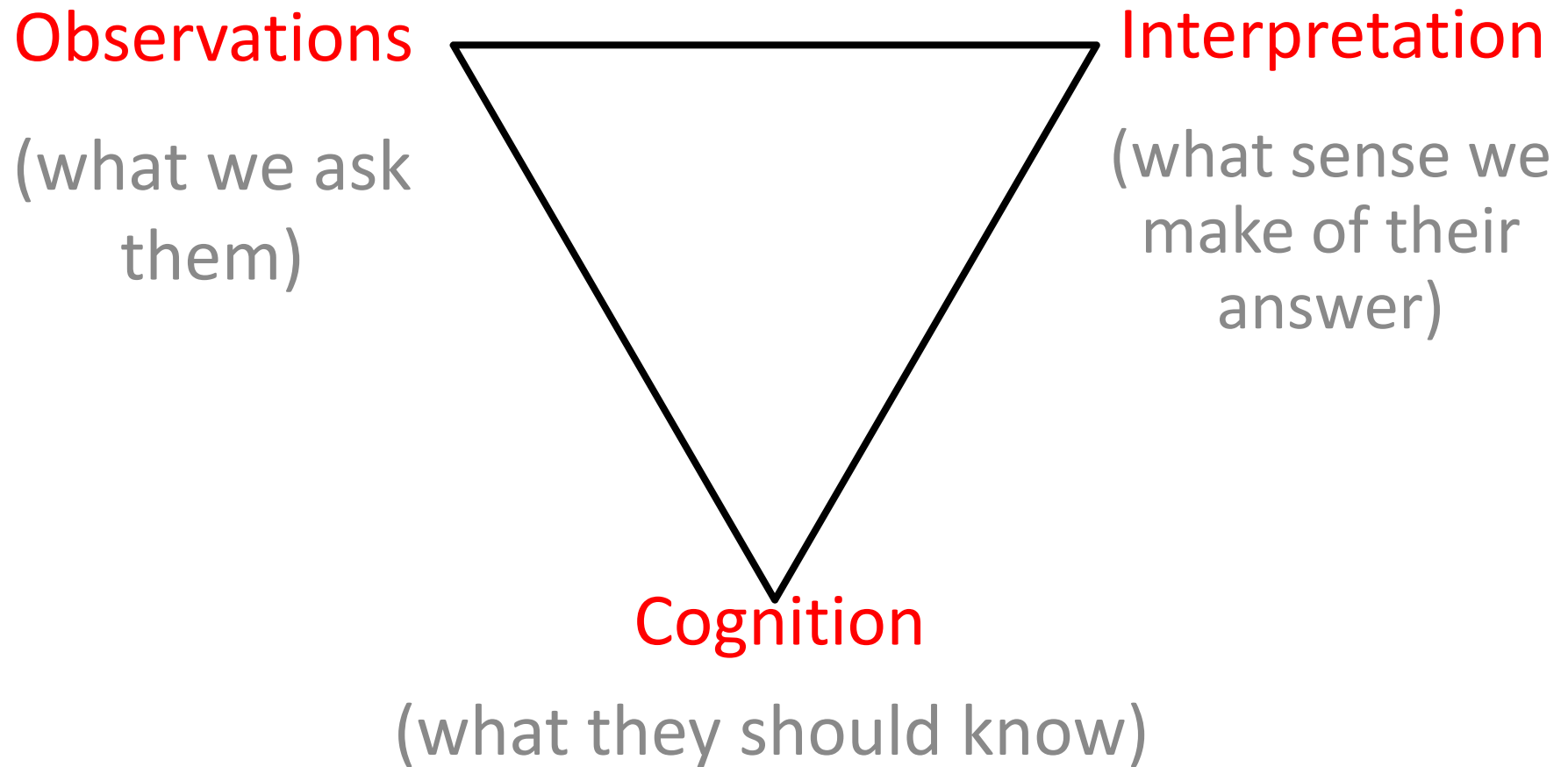
... it's about what they (students) learn

So we have to listen...but only after we ask the right question

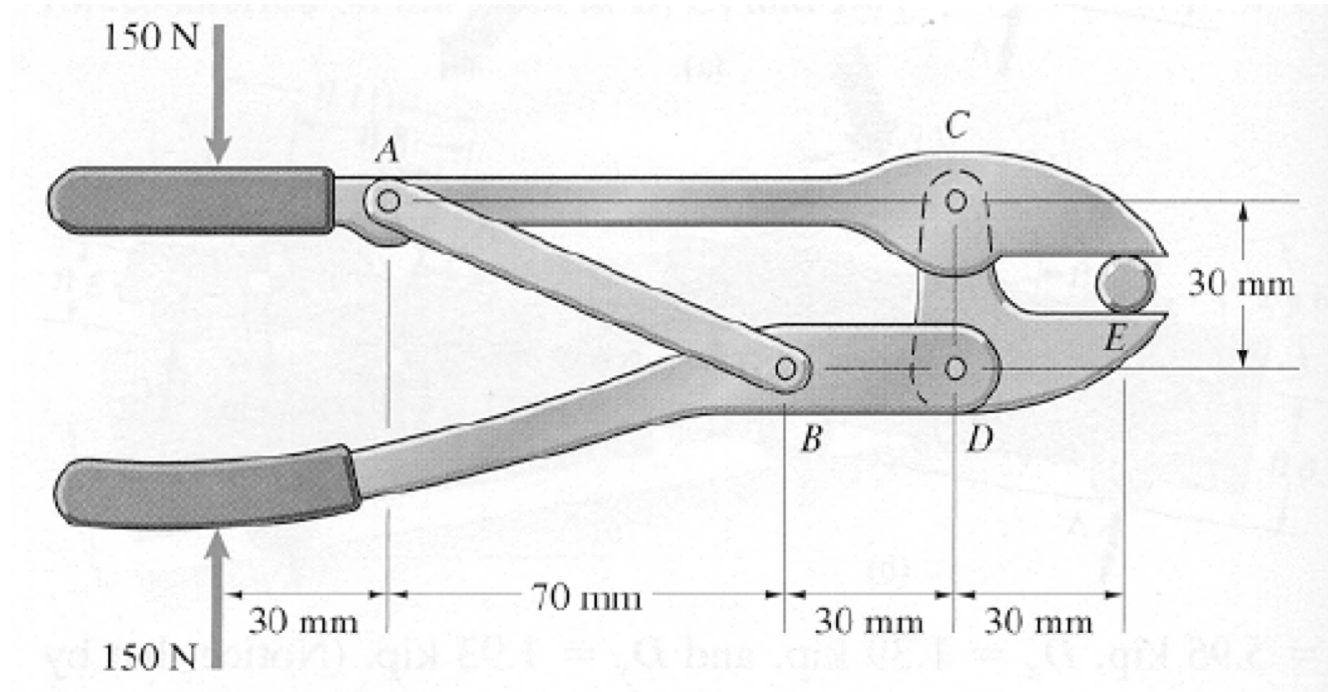
How should we debrief
students?

Assessment Triangle

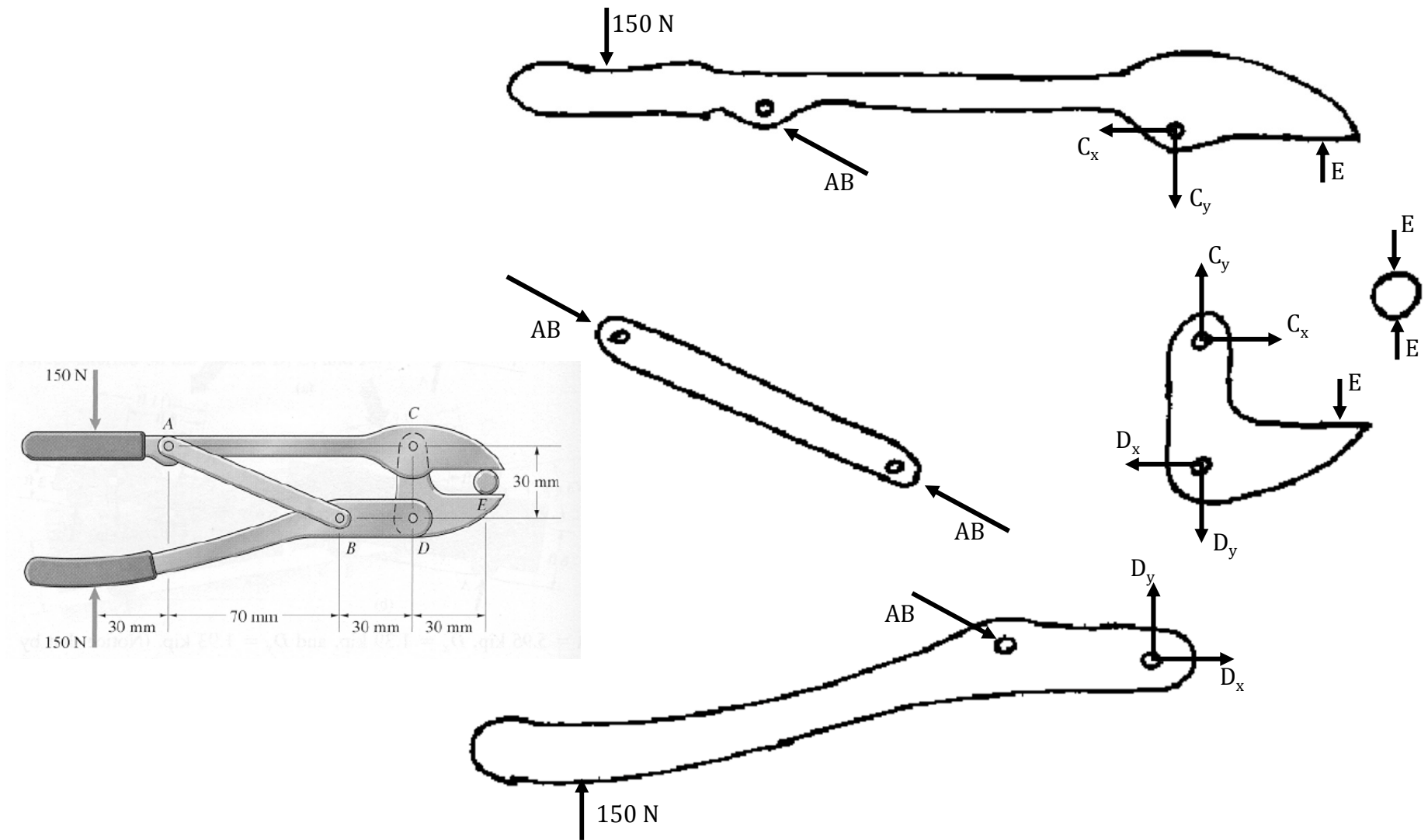
(Knowing What Students Know, 2001)



Statics – Typical Problem



Determine the forces between bodies



What is “Cognition” for Statics?

Many little bits of knowledge: principles, concepts, skills... what to choose?

Are there certain ideas that, if mastered, give students leverage on other ideas?

Are there errors students consistently make or ideas they seem not to grasp?

Taxonomy of Misconceptions in Newtonian Physics

0. Kinematics

- K1. position-velocity indiscriminated
- K2. velocity-acceleration indiscriminated
- K3. nonvectorial velocity composition

1. Impetus

- I1. impetus supplied by "hit"
- I2. loss/recovery of original impetus
- I3. impetus dissipation
- I4. gradual/delayed impetus build-up
- I5. circular impetus

from Hesthenes, Wells,
Swackhamer (1992)

2. Active Force

- AF1. only active agents exert forces
- AF2. motion implies active force
- AF3. no motion implies no force
- AF4. velocity proportional to applied force

4. Concatenation of Influences

- CI1. largest force determines motion
- CI2. force compromise determines motion
- CI3. last force to act determines motion

• • •

5. Other Influences on Motion

- CF. Centrifugal force
- Ob. Obstacles exert no force

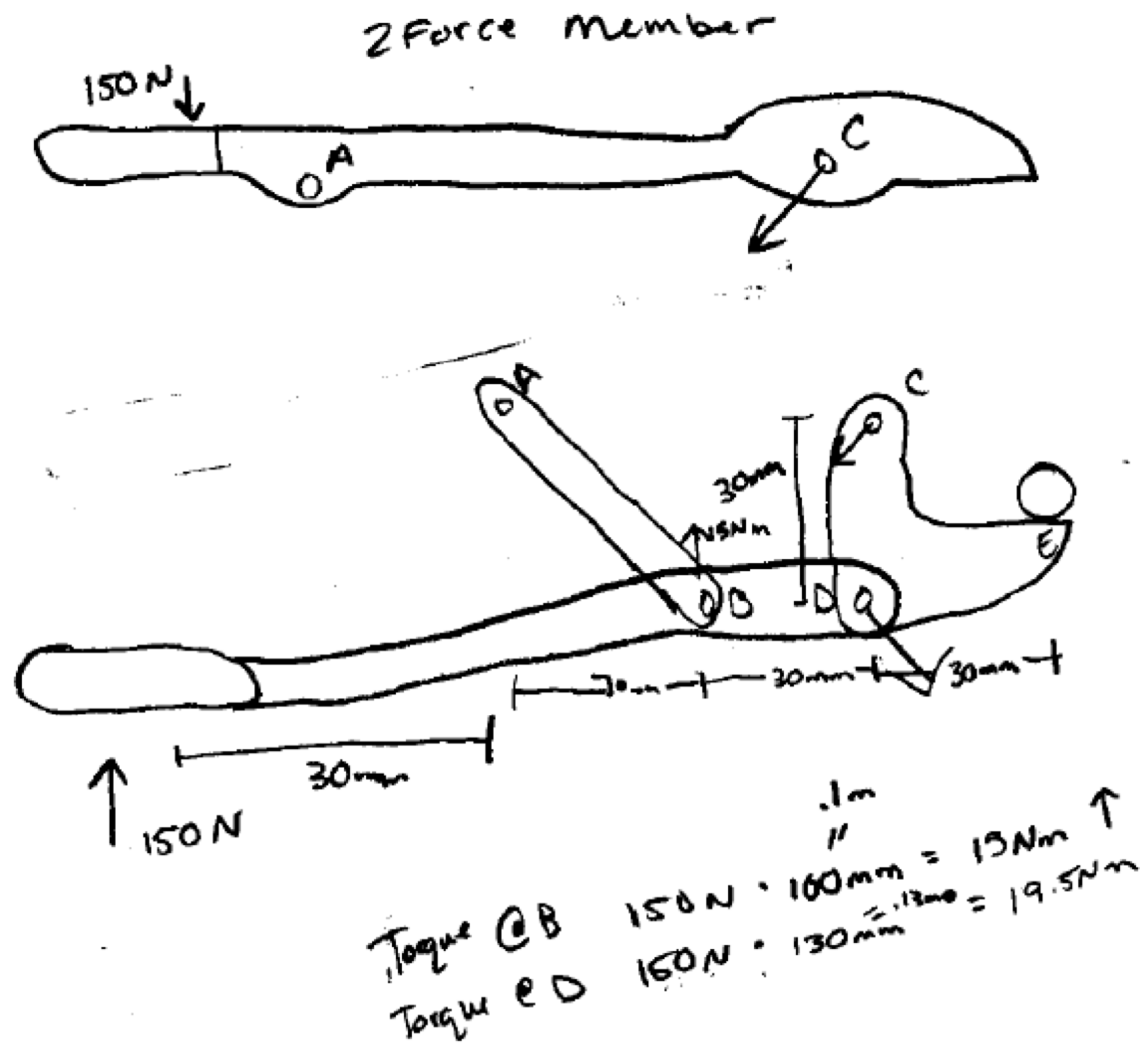
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Field Studies of Statics Problem Solving

Mechanical engineering students at early stage of 2nd year statics course

Had completed physics (Newtonian mechanics), and 3 week segment on Statics in a freshman mechanical engineering course

Typical Student Solution with Errors



Many student solutions → Common Errors

Steif (2004)

Table 1: Common Errors in Statics and Basis in Concepts and Skills

	Error	Student doesn't realize
E1	Failure to be clear as to which body is being considered for equilibrium	that the equilibrium conditions are always imposed on a specific body (C4).
E2	Failing to take advantage of the options of treating a collection of parts as a single body, dismembering a system into individual parts, or dividing a part into two	that the equilibrium conditions can be applied to any collection of material, or that if a system is in equilibrium then any subset of it must be in equilibrium (C4,S3).
E3	Leaving a force off the free body diagram (FBD) which should be acting.	that a FBD requires all external forces (C4), that the body which contacts the isolated body is exerting a force (C1) or that there is a body contacting (S1).
E4	Drawing a force as acting on the body of the FBD, even though that force is exerted by a part which is included in the body of the FBD	that a FBD requires only external forces (C4), or that the force drawn is actually between two other bodies, both of which are included in the isolated body (C1, S1).
E5	Drawing a force as acting on the body of the FBD, even though that force does not act directly on the body	that a FBD requires only external forces which act directly (C4), or that the force drawn is actually between two other bodies, both of which are outside the isolated body (C1, S1).

... total of 11 common errors

Impractical for all instructors to study
their students problems in depth

Data of interest is too sparse, time consuming to
find

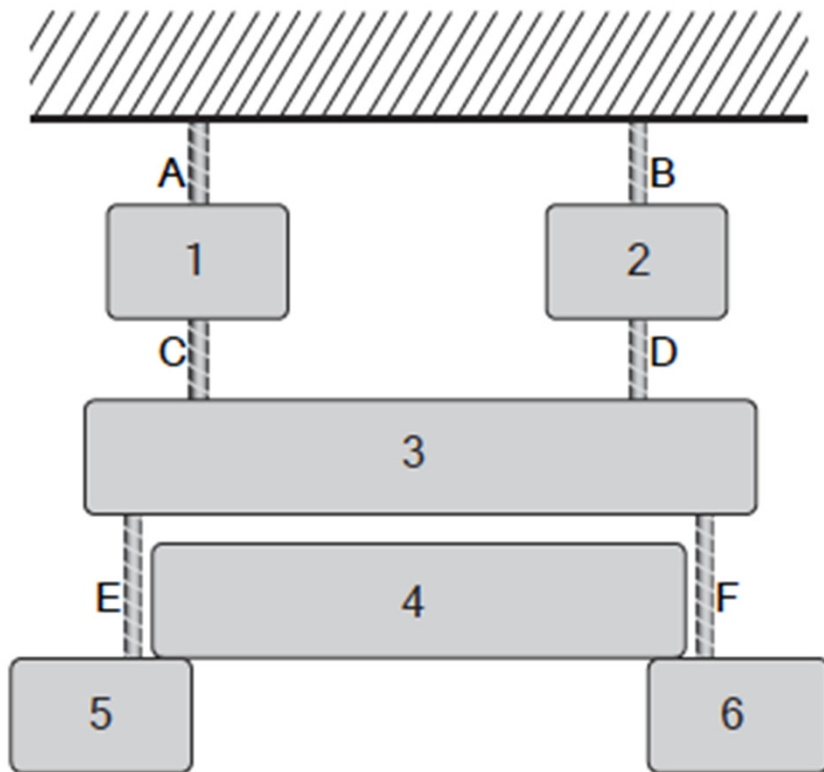
Errors could be attributed to multiple causes

Many errors are common across students

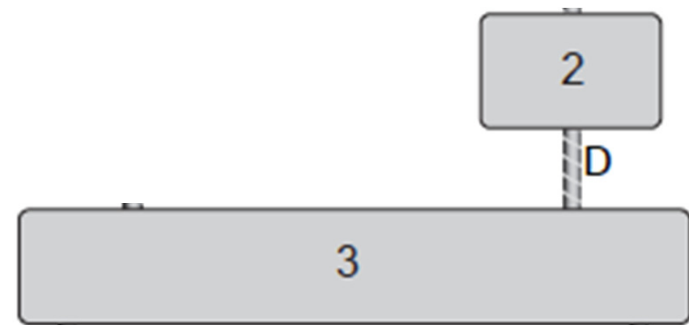
Wanted: Dense data, easily interpreted
and attributed, actionable

Questions addressing single concept

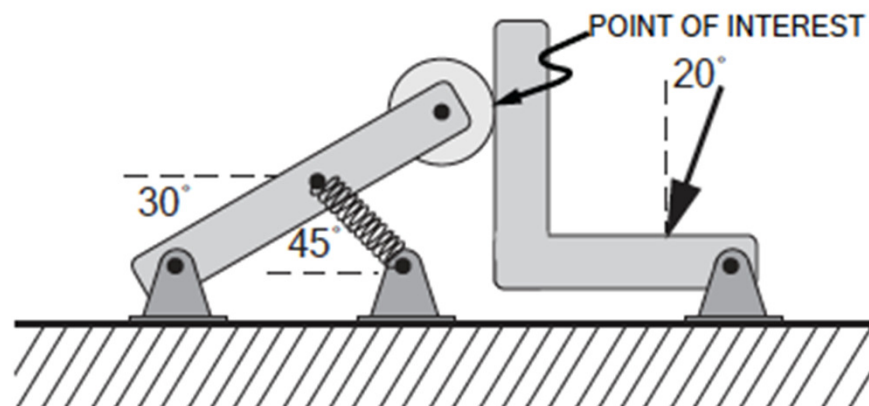
1. A free body diagram including blocks 2, 3 and the cord connecting them is to be drawn for this system.



What is the correct free body diagram?



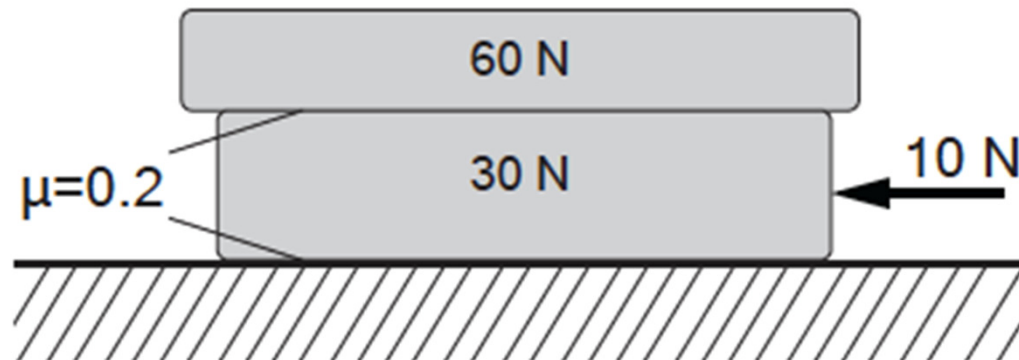
12. The L-shaped arm is kept in the position shown. The pin that the roller rotates on is frictionless. The coefficient of friction between the roller and the arm is 0.6.



What is the direction of the force exerted by the roller on the arm at the point of interest?



23. Two blocks are stacked on top of each other on the floor. The friction coefficient 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.



What is the horizontal component of the force exerted by the floor on the lower block?

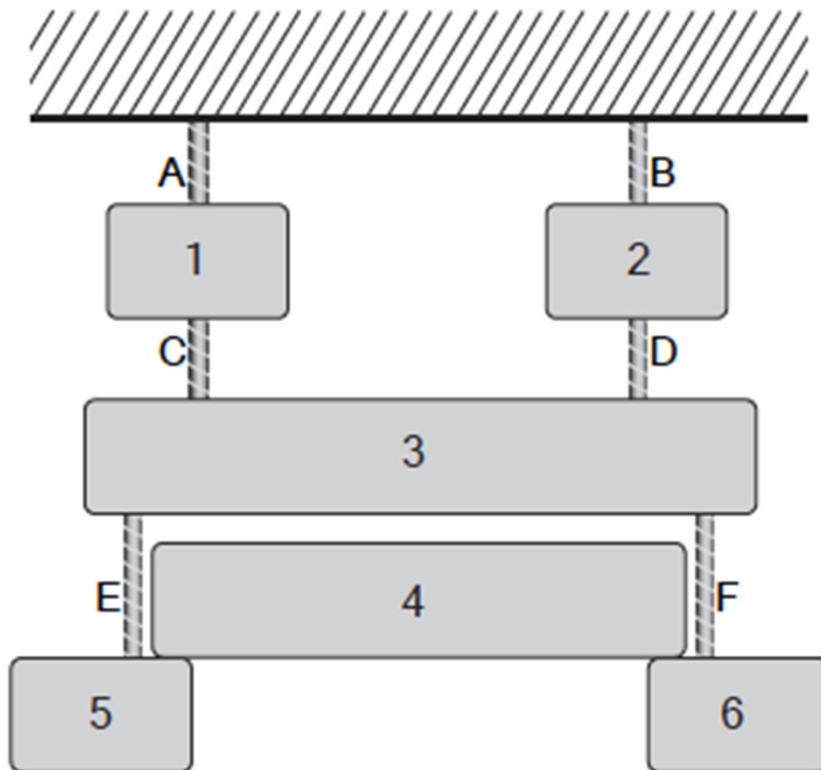
How might students answer questions?

Let students answer question

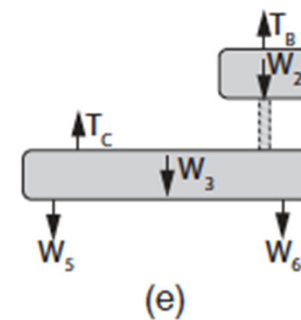
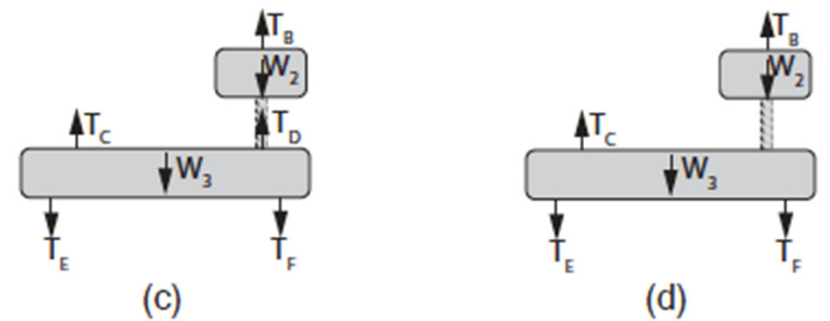
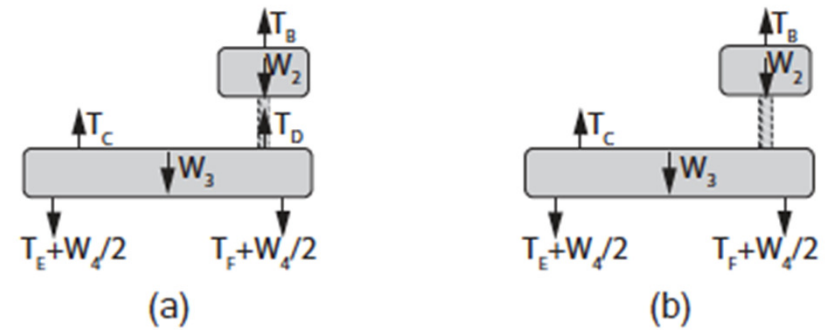
Interview students on their answer

Note typical errors from field studies

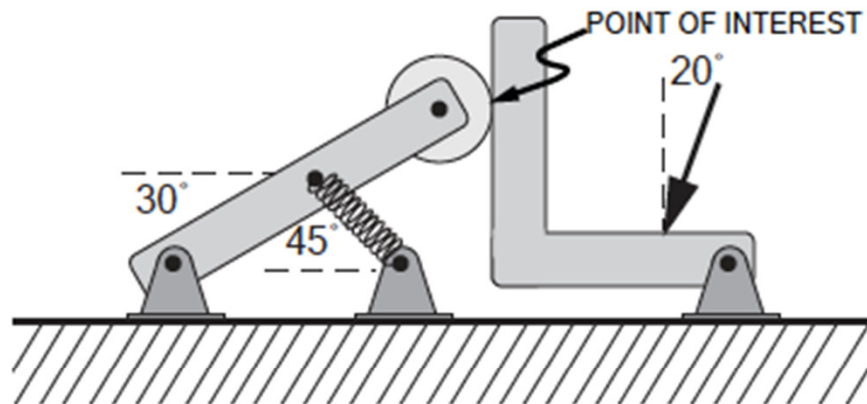
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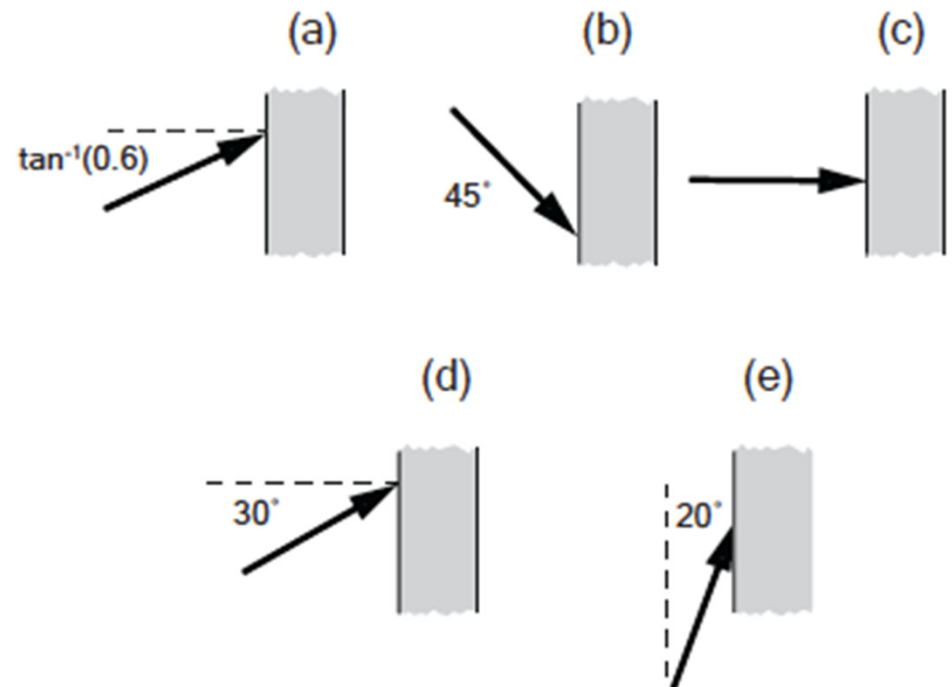
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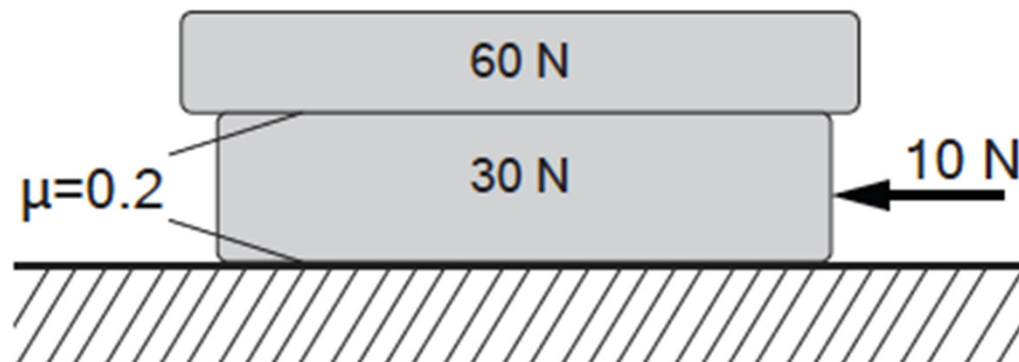
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What is the horizontal component of the force exerted by the floor on the lower block?

- (a) 4 N (b) 6 N (c) 8 N (d) 10 N (e) 18 N

How to Judge Quality of Questions?

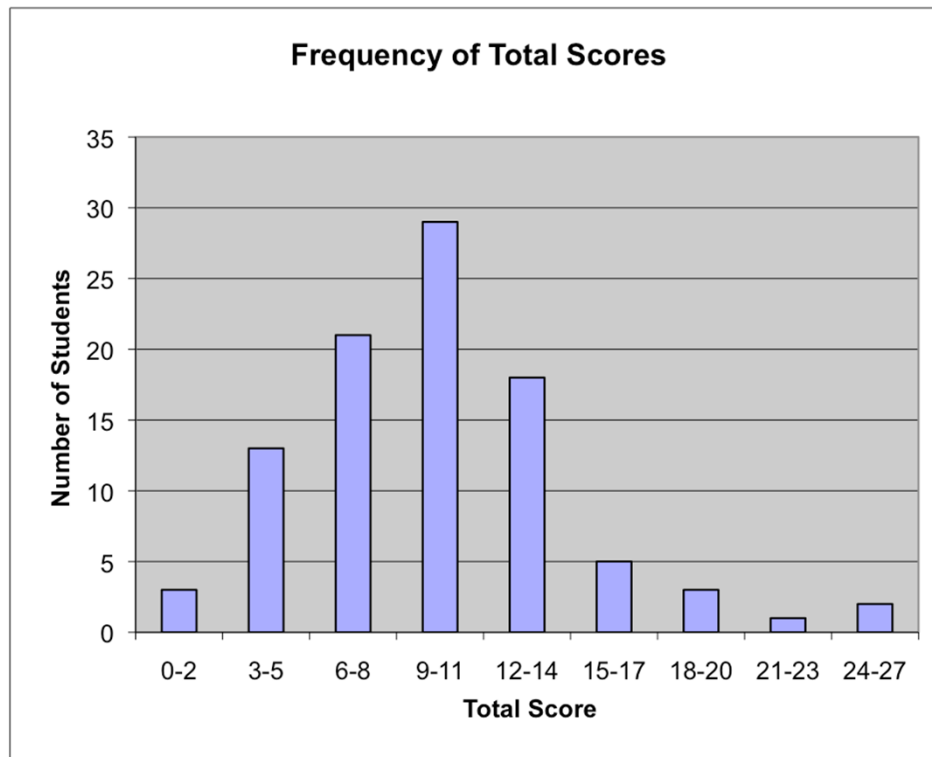
Reasonable range of difficulty

Questions discriminate (ideally between knowing and not knowing)

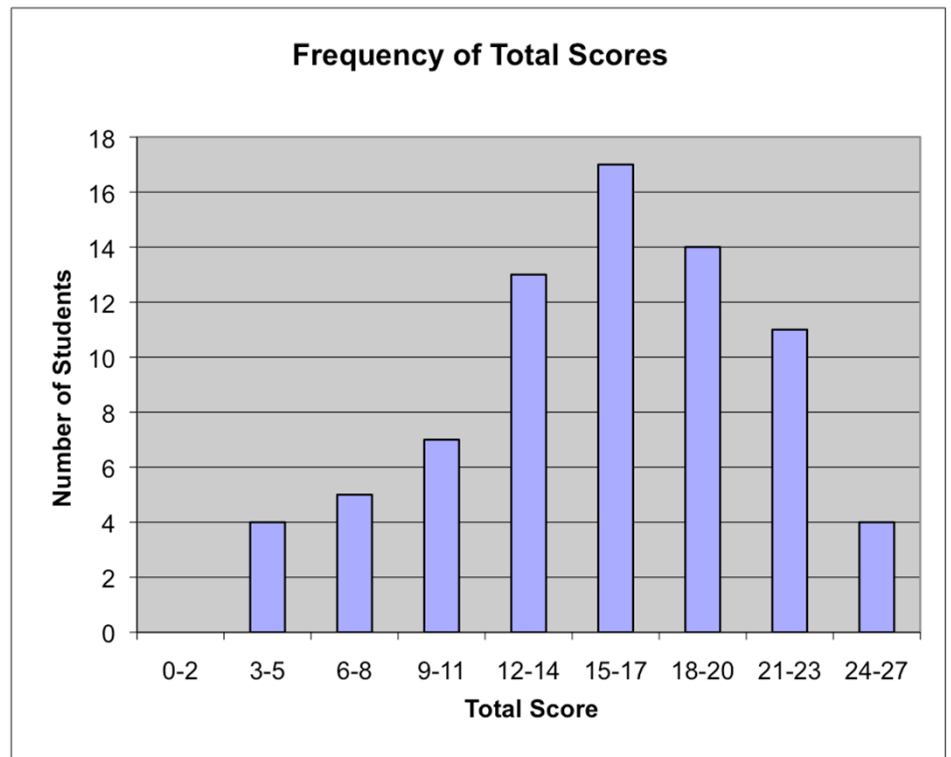
Most wrong answers seem plausible to some students

Difficulty: total score distribution

Means vary from 30% to 70%



School 1

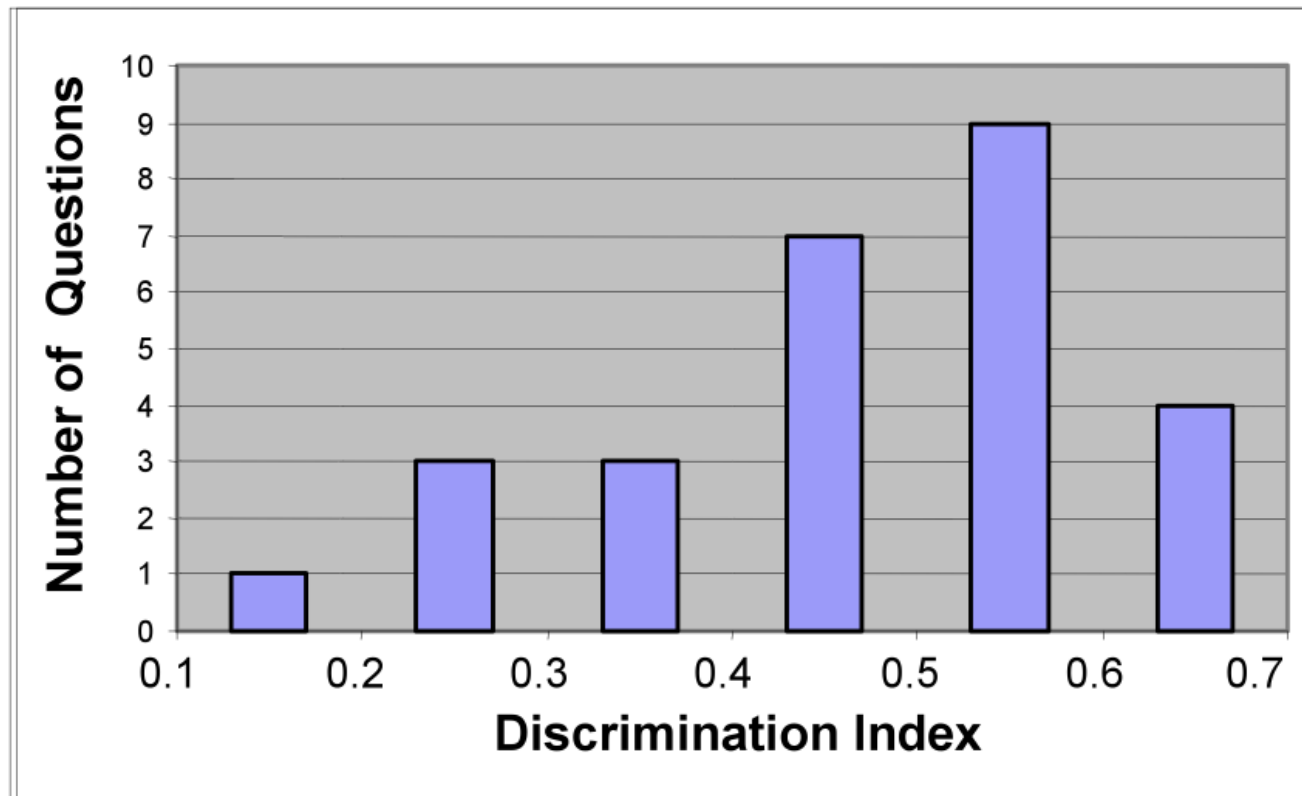


School 2

Discrimination Index of Question

- = Percentage correct of top students
- Percentage correct of bottom students

0.25–0.4 Good, 0.4-1.0 Excellent



How to Interpret Test?

What do scores mean in terms of student understanding?

Is that understanding more broadly valuable?

What understanding implied by results?

Total not meaningful - except as comparison with past and other schools

3 questions on each concept; 9 concepts

Reliability: multiple questions for each concept can remove signal from noise (guessing)

Correlations (r): Reliability of concept

Conc.	α	Intra-Conc. r	Inter-Conc. r
A	0.72	0.46	0.18
B	0.52	0.27	0.13
C	0.57	0.30	0.15
D	0.71	0.44	0.11
E	0.71	0.45	0.15
F	0.48	0.24	0.16
G	0.37	0.16	0.11
H	0.68	0.41	0.14
I	0.43	0.19	0.15

Alpha: 0.7 – 0.8 good reliability for whole test

Test results of broader relevance?

Correlations between concept test and class examinations (multiple institutions)

(Fall 2004-Spring 2005)

Class	1	2	3	4	5
r	0.62	0.59	0.24	0.48	0.41

(Fall 2005)

Class	1	2	3	4	5	6
r	0.39	0.53	0.54	0.58	0.60	0.61

What would be a high correlation?

(Fall 2004-Spring 2005)

Class	1	2	3	4	5
<i>r</i>	0.62	0.59	0.24	0.48	0.41

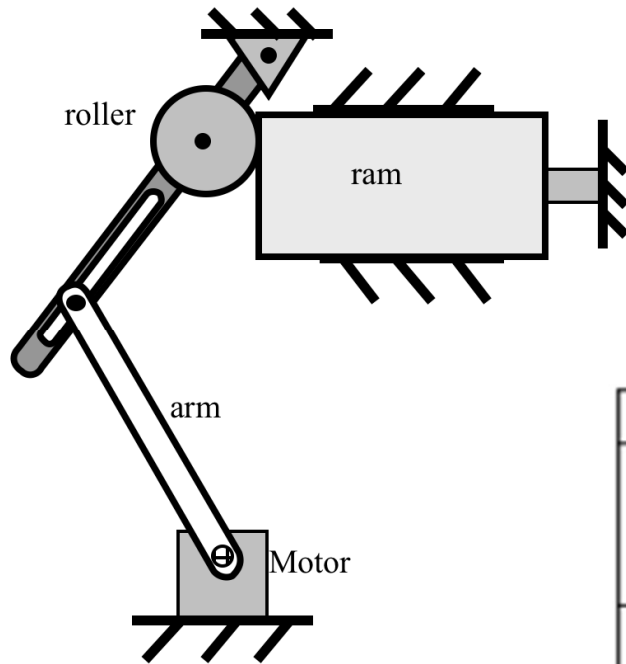
(Fall 2005)

Class	1	2	3	4	5	6
<i>r</i>	0.39	0.53	0.54	0.58	0.60	0.61

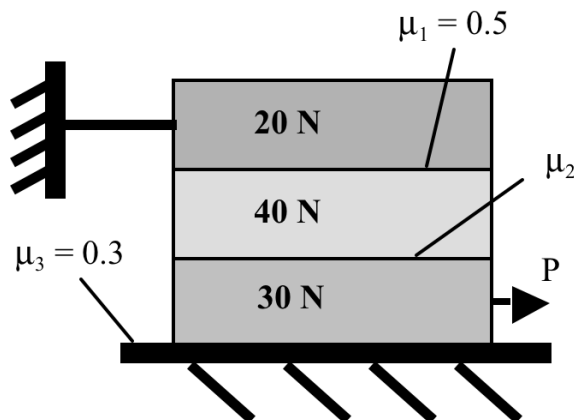
Correlations between different exams in same class
(Fall 2004-Spring 2005)

Class	Correlations <i>r</i> between course examinations
1	0.65, 0.66, 0.63, 0.59, 0.63, 0.71
2	0.57, 0.34, 0.42, 0.55, 0.71, 0.73
3	0.42, 0.33, 0.66, 0.13, 0.25, 0.47
4	0.32, 0.44, 0.49, 0.48, 0.48, 0.59

Compare errors on exam
with success in particular
group of concept questions



		Roller	Slot	Friction
Roller: 47/97 Erred	Error	0.645	0.872	0.652
	No Error	0.867	0.927	0.760
	p	0.002	0.199	0.127
Slot: 33/97 Erred	Error	0.646	0.778	0.667
	No Error	0.818	0.964	0.729
	p	0.023	0.001	0.42
Friction: 53/97 Erred	Error	0.723	0.868	0.610
	No Error	0.803	0.939	0.826
	p	0.265	0.075	0.001



How can students benefit from test?

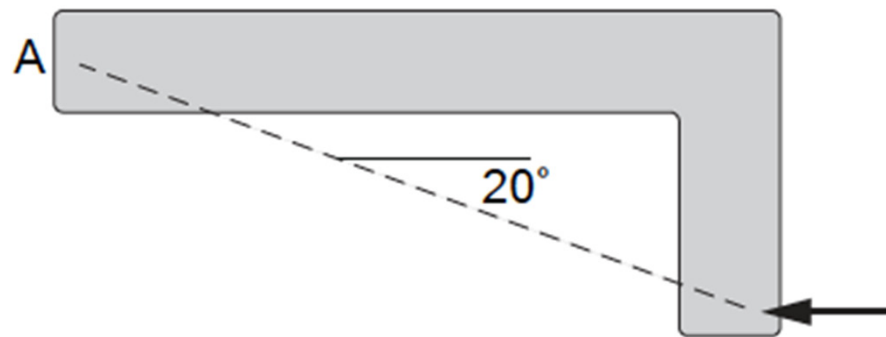
- Instructor studies test results, modifies course for following year, and re-tests
- Results obtained before end of semester; review session to discuss most problematic questions before final exam

Should students have experience answering these types of questions earlier?

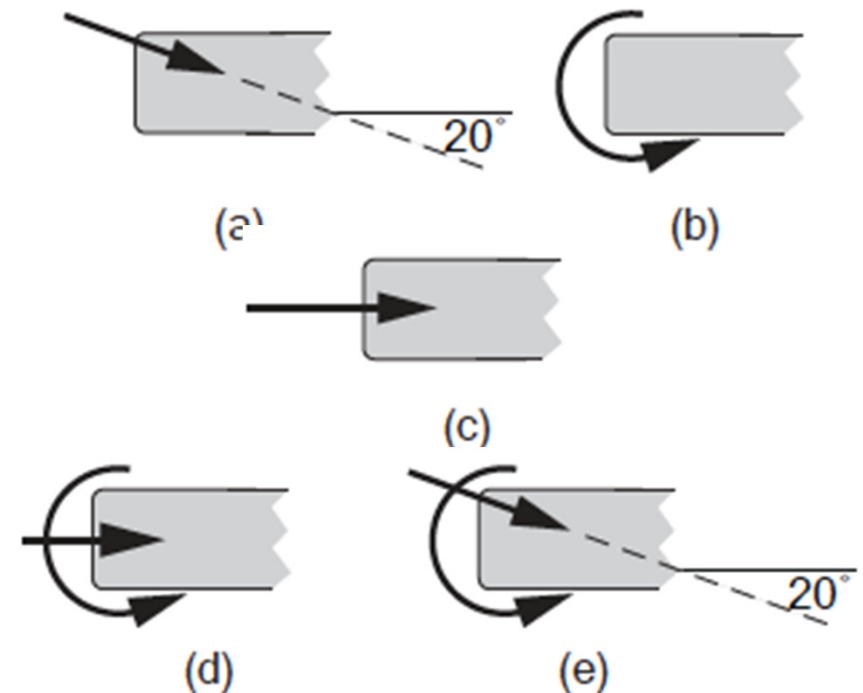
“Warm-ups”: During term, students given task to perform outside of class (Newcomer)

Give answer choice and explain your reasoning

The member is subjected to the force at the lower right corner, and is maintained in equilibrium by a hand (not shown) gripping the end A.



Which of the following could represent the load(s) exerted by the gripping hand?



Processing of student input

- Instructor collects the answers and rationales (submitted on-line) and reviews them
- Class discussion paves way for teaching the subject – thinking prior to class opens up students to topic
- Course which gave students practice with such questions ended up with high scores on test at term end

Still have high correlations between test
and final exam in course

Assess students and provide better
feedback during semester
(on conceptual matters and generally)

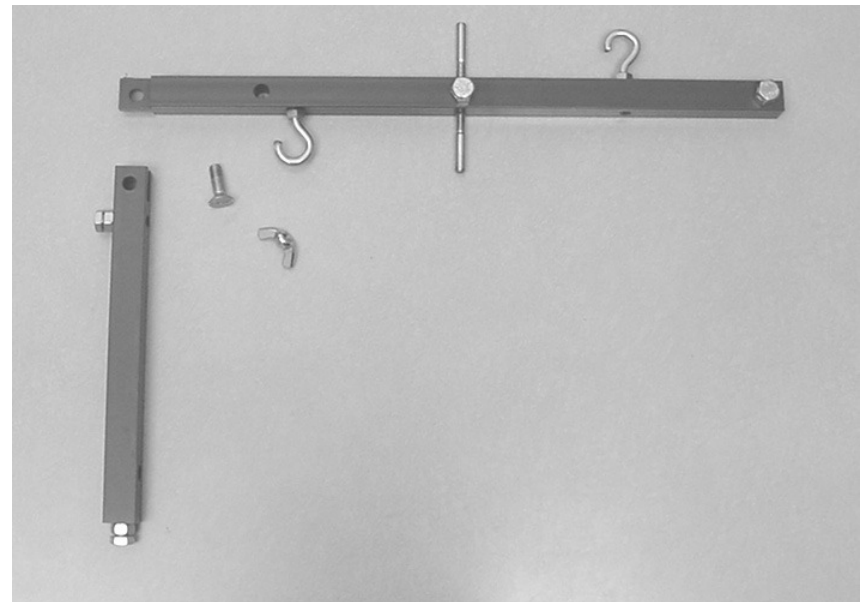
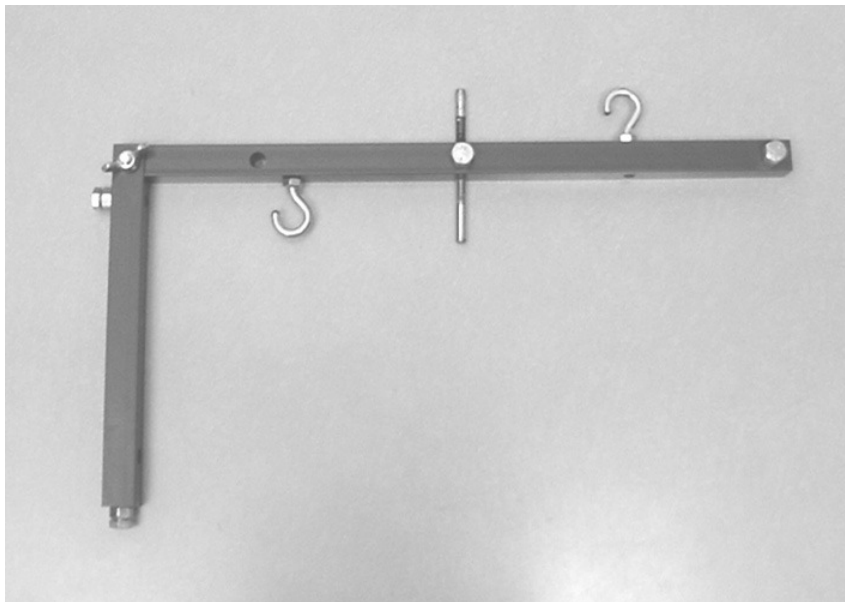
- Inside class:
interactive engagement in classroom
- Outside class:
interactive activities on-line

Peer Teaching (Eric Mazur)

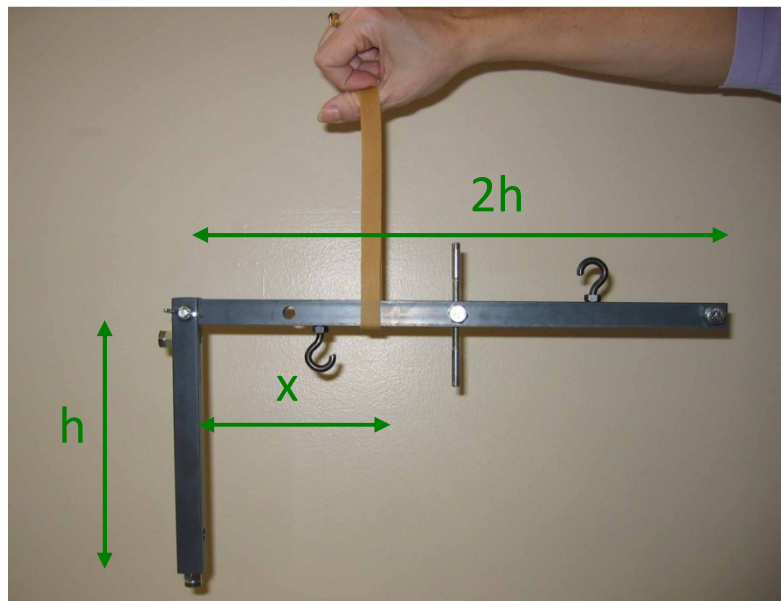
- Shocked by his students' (Harvard) performance on physics conceptual test (Force Concept Inventory)
- Engaged students more in class – but on conceptual questions

How to choose questions for statics?

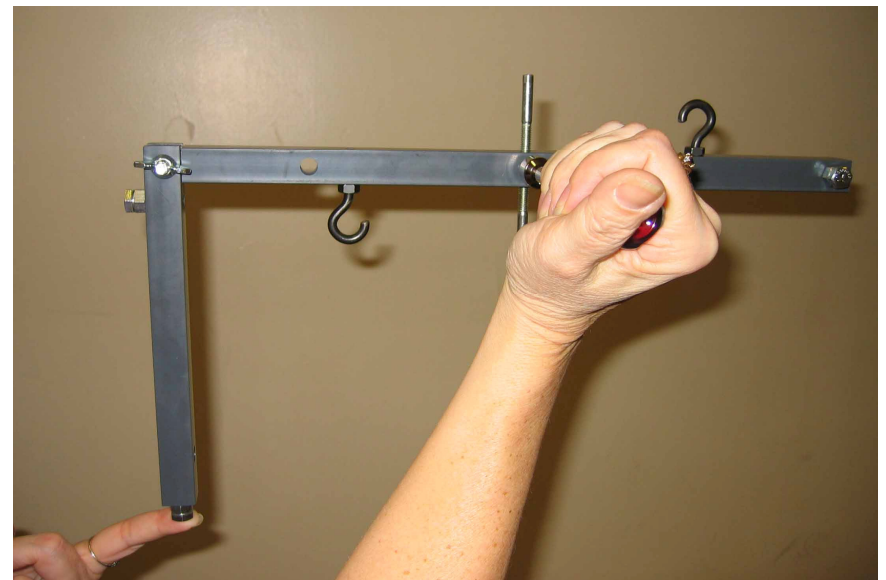
Physics misconception – only active agents exert forces. So keep it real: learn key concepts in statics by balancing simple physical objects



Learning through balancing objects

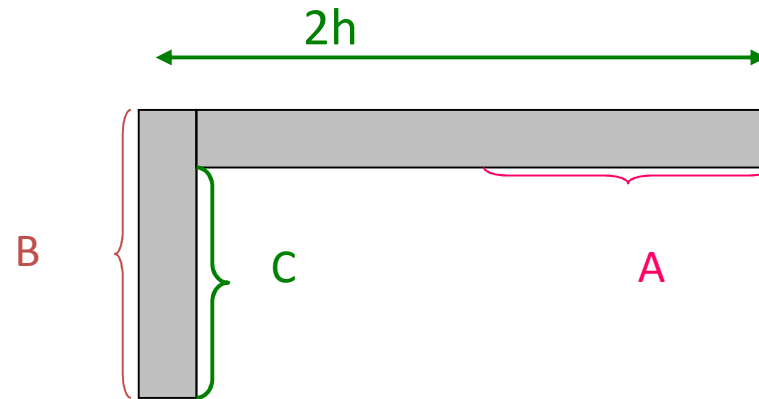


Center of
gravity



Equilibrium with
forces and couples

Consider supporting the member in the vertical plane using two smooth rods.



Can the body be supported by:
one rod placed in region A and one rod placed in region B?

Yes

Gr

No

Pi

Can the body be supported by:
one rod placed in region A and one rod placed in region C?

Yes

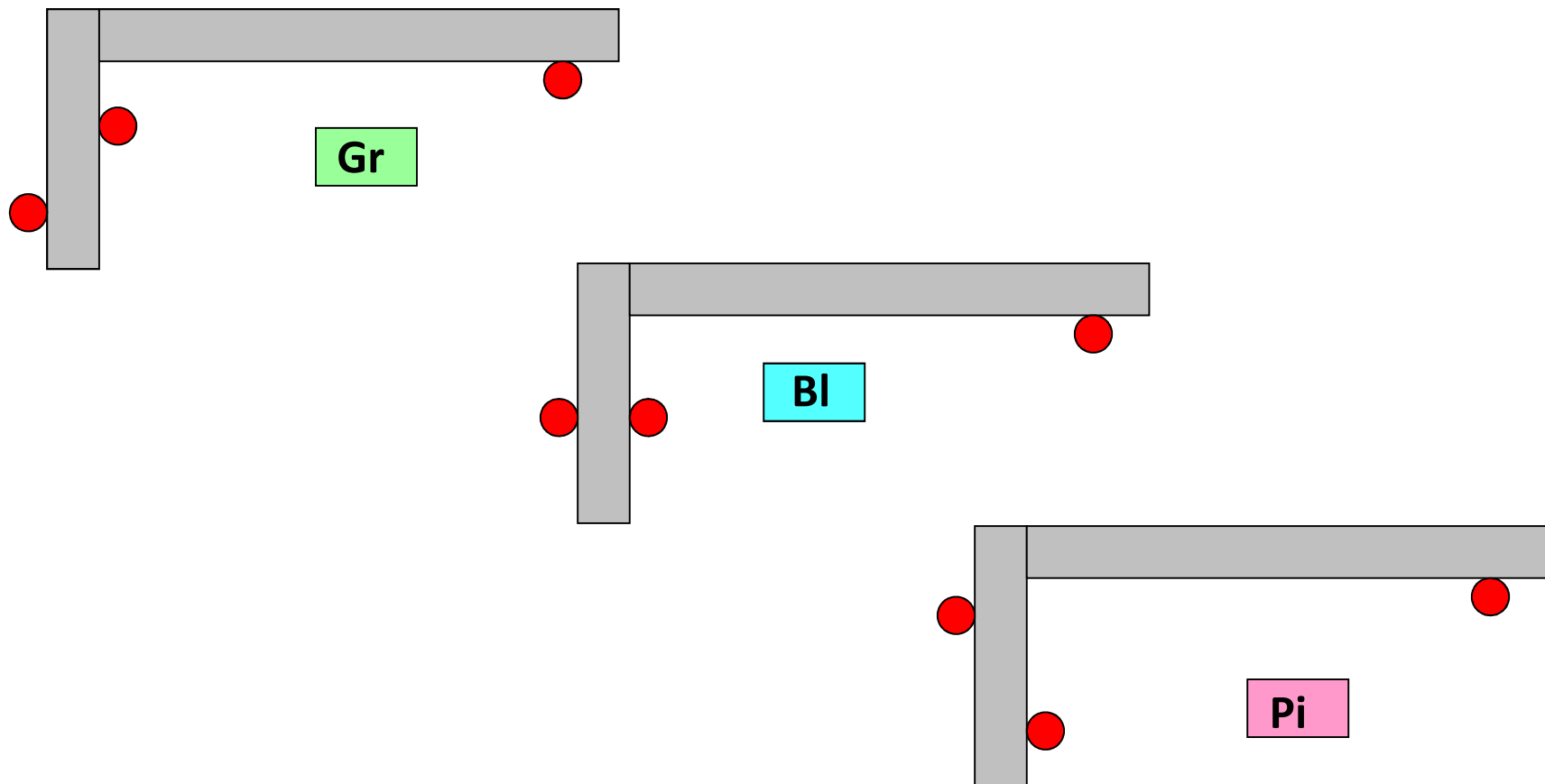
Gr

No

Pi

Consider supporting the member in the vertical plane using three smooth rods.

Which combination of rods will keep the body in equilibrium?



Majority of time spent outside of class – how to better assess learning outside?

- Interactive exercises that take advantage of computer and web connection
- Exercises offer hints and feedback appropriate to student input
- Blend exercises with text, diagrams, simulations
- Partially replace written homework

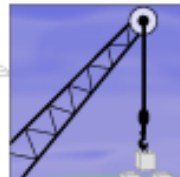
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Engineering Statics

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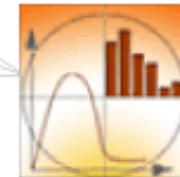


Statics is a sophomore level engineering course, offered in all mechanical and civil engineering programs. We study methods of quantifying the forces between bodies, for example parts of mechanical, structural, and biological systems.

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Statistics

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Introduces the basic concepts, logic, and issues involved in statistical reasoning. Topics include exploratory data analysis, research methods, probability, and statistical inference. Two versions of the course; eight StatTutor (cognitive tutor) labs.

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Causal &

Causal cl;
constantly
newspape
causal cla
evidence i

[LOOK](#)

instructor tools
case studies



instructor tools
case studies



Examples of Activities

“Inverted Classroom” use of On-line Materials

- Traditionally: US engineering students don't prepare for class – see material for first time
- New Approach: demand students work through on-line materials before class
- Each student decides which activities to work through, but must take end-of-module quiz
- System tracks students' work and reports back to instructor who uses that information to inform lecture

Summary

- Instructors typically don't recognize how much (or little!) students have learned
- We can seek to measure grasp of basic concepts through multiple choice tests – learning of basic concepts can enable better performance in class exams
- Other activities, inside and outside the classroom, offer opportunities to assess learning

Observations (concepts)

- Some concepts difficult for most students (equilibrium and static equivalence that involves forces & couples; friction)
- Early focus on concepts can boost scores on concept test and still have broader relevance to class exams
- Some concepts (engineering connections) have good scores, but questions are superficial

Observations (On-line learning)

- Computer best for practicing concepts or skills in isolation. Harder for computer to give students free reign to assemble solutions of complex problems.
- On-line learning is effective for some, but not all, students. On-line exercises can be very stimulating - constant need to reflect is sometimes intense. Additional questions are raised in student's mind, which instructor is not present to resolve.
- Interaction with instructor is still critical!

Acknowledgments

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