E-mail message seeking volunteers:

Greetings!
I am seeking graduate student volunteers to participate in a "pilot" study for my thesis work in physics education research. I estimate that the total time involved will be less than 1.5 hours spread out over a week.

The broad topic of my research is physics problem solving assessment. I am designing and testing a grading tool (called a rubric) to evaluate students' written solutions to physics problems.

I need you (an experienced graduate student) to try using the rubric on student solutions, and give me feedback / recommendations for changes. The time spent will involve assigning scores to students' solutions on two separate occasions and meeting with me for 10-15 minutes in an informal interview.

Please let me know if you are or are not willing to help me out with this pilot study some time in the next 2-3 weeks. Your help is much appreciated!

Jen Docktor
Office: 161B, 625-9323
http://groups.physics.umn.edu/physed/People/Docktor/index.html

P.S. – I plan to host a pizza lunch for the volunteers upon completion of the pilot.

Dear graduate student,

Thank-you for agreeing to help me with my research on physics problem solving assessment! Below you will find instructions for the first part of the task. When you have completed all steps, please return the documents to my mailbox in the envelope provided. I will contact you by e-mail with instructions for Part II.

Jen Docktor
Office 161B, 625-9323
docktor@physics.umn.edu

Instructions Part I:

1. Read the scoring document (rubric) and category descriptions printed on the next page. If there is anything unclear in the wording, make note of it on page 4 of the scoring template Part I.
2. Read the physics problem statement and instructor solution.
3. Look at student solution #1. Use the rubric to assign a separate score of 0, 1, 2, 3, 4, NA(P), or NA(S) for each of the five categories. On the scoring template sheet Part I, record the scores for student #1 and brief notes about your reasoning for each score.
4. Continue the scoring process for student solutions #2-8.
5. Record scoring difficulties on page 4 of the scoring template sheets, and answer the remaining questions.
6. Write your name at the top of each scoring template sheet and the question sheet (four pages). This is only for my reference, and your name will not in any way be associated with results of the study.

Problem Solving Rubric

Jennifer Docktor [docktor@physics.umn.edu]

	4	3	2	1	0
Physics Approach	The solver has clearly stated an appropriate and complete physics approach.	The approach is clear but contains minor omissions or errors.	The approach is unclear, or an important physics concept or principle of the approach is missing or inappropriate.	An attempt is made to identify relevant physics concepts or principles, but most of the approach is vague, incomplete, or inappropriate.	The solution does not indicate a basic physics approach, or all of the chosen concepts and principles are inappropriate.
Useful Description*	The solution includes an appropriate and useful problem description.	The description is useful but contains minor omissions or errors.	The description is not useful, or a key feature of the description is missing or incorrect.	An attempt is made, but most of the description is not useful, incomplete, or incorrect.	The solution does not include a description, or all of the description is incorrect.
Specific Application of Physics**	The solution indicates an appropriate and complete application of physics to the specific conditions in this problem.	The specific application of physics to this problem contains minor omissions or errors.	An important specific relationship or condition is missing or applied incorrectly.	An attempt is made, but most of the specific application of physics to this problem is missing or incorrect.	The solution does not indicate a specific application of physics, or all of the application is incorrect.
Mathematical Procedures	Suitable mathematical procedures are used during the solution execution.	Suitable mathematical procedures are used with minor omissions or errors.	An important mathematical procedure is missing or is used with errors.	Attempted mathematical procedures are inappropriate, left unfinished, or contain serious errors	There is no evidence of mathematical procedures in the problem solution or all mathematical procedures are inappropriate.
Logical Organization	The entire problem solution is clear, focused, and logically connected.	The solution is clear and focused with minor inconsistencies.	Parts of the solution are unclear, unfocused, and/or inconsistent.	Most of the solution parts are unclear, unfocused, and inconsistent.	The entire solution is unorganized and contains obvious logical breaks.
NA (Problem)	The skill is not necessary for this <u>problem</u>, or constitutes a very small part of the solution.				
NA (Solver)	Explicit statement is not necessary for this <u>solver</u>, as indicated by the overall solution.				

Category Descriptions:

Physics Approach assesses a solver's skill at selecting appropriate physics concepts and principle(s) to use in solving the problem. Here the term *concept* is defined to be a general physics idea, such as the basic concept of "vector" or specific concepts of "momentum" and "average velocity". The term *principle* is defined to be a fundamental physics rule or law used to describe objects and their interactions, such as the law of conservation of energy, Newton's second law, or Ohm's law.

Useful Description assesses a solver's skill at organizing information from the problem statement into an appropriate and useful representation that summarizes essential information symbolically and visually. The description is considered "useful" if it guides further steps in the solution process.

*A *problem description* could include restating known and unknown information, assigning appropriate symbols for variables, defining variables, stating a goal or target, a visualization (sketch or picture), stating qualitative expectations, an abstracted physics diagram (force, energy, motion, momentum, ray, etc.), drawing a graph, stating a coordinate system, and choosing a system.

Specific Application of Physics assesses a solver's skill at applying the physics concepts and principles from their selected approach to the specific conditions in the problem. If necessary, the solver has set up specific equations for the problem that are consistent with the chosen approach.

**A *specific application of physics* could include a statement of definitions, relationships between the defined variables, initial conditions, and assumptions or constraints in the problem (i.e., friction negligible, massless spring, massless pulley, inextensible string, etc.)

Mathematical Procedures assesses a solver's skill at following appropriate and correct mathematical rules and procedures during the solution execution. The term *mathematical procedures* refers to techniques that are employed to solve for target variable(s) from specific equations of physics, such as isolate and reduce strategies from algebra, substitution, use of the quadratic formula, or matrix operations. The term *mathematical rules* refers to conventions from mathematics, such as appropriate use of parentheses, square roots, and trigonometric identities. If the course instructor or researcher using the rubric expects a symbolic answer prior to numerical calculations, this could be considered an appropriate mathematical procedure.

Logical Organization assesses the solver's skills at communicating reasoning, staying focused toward a goal, and evaluating the solution for consistency (implicitly or explicitly). It checks whether the entire problem solution is clear, focused, and organized logically. The term *logical* means that the solution is coherent (the solution order and solver's reasoning can be understood from what is written), internally consistent (parts do not contradict), and externally consistent (agrees with physics expectations).

Problem 3:

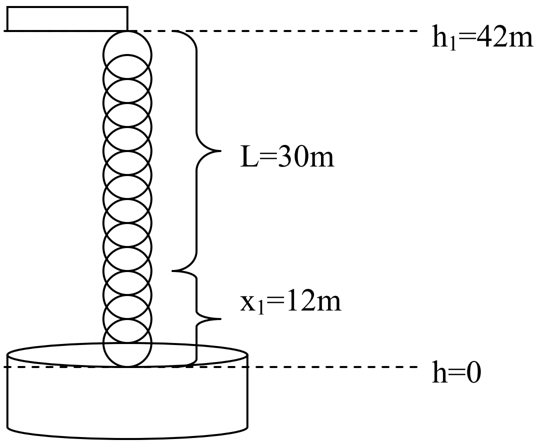
To raise money for a University scholarship fund, the new IT dean has volunteered to bungee jump from a crane if contributions can be found for 10 scholarships. To add some interest, the jump will be made from 42 m above a pool of water. A 30m bungee cord would be attached to the dean. First you must convince the dean that your plan is safe for a person of his mass, 70kg. The dean knows that as the bungee cord begins to stretch, it will exert a force which has the same properties as the force exerted by a spring. Your plan has the dean stepping off a platform and being in free fall for 30 m before the cord begins to stretch.

a) Determine the spring constant of the bungee cord so that it stretches only 12m, which will just keep the dean out of the water. (Assume that the dean is a point-like object).
b) Using the result of a), find the dean’s speed 7m above the water.

Instructor solution:

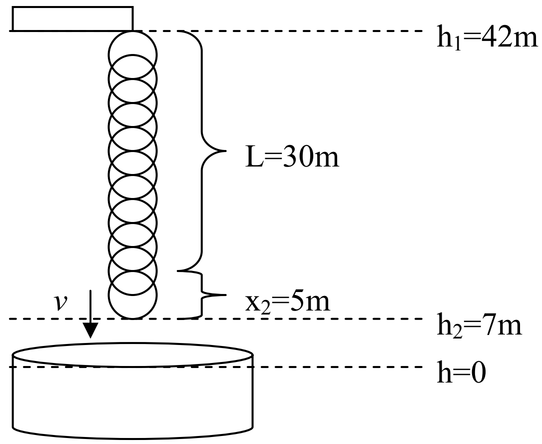
Description

Part a): Find the spring constant, k



L=30m; length of the bungee cord
h_1=42 m; initial height of the dean
x_1=12 m; spring stretch when the dean is at the water surface (h_1-L)

Part b): Find the velocity of the dean, v



h_1=42 m; initial height of the dean
h_2=7 m; final height of the dean above the water
x_2=5 m; spring stretch when the dean is 7 m above the water (h_1-h_2-L)

Part a): Use conservation of energy: The initial energy is gravitational potential energy at the top of the platform and the final energy is potential energy stored in the stretched spring at h=0.

$$E_{initial} = E_{final}: \qquad mgh_1 = \frac{1}{2}kx_1^2 \qquad \textit{solve for the spring constant } k$$

$$k = \frac{2mgh_1}{x_1^2} = \frac{2(70kg)(9.8m/s^2)(42m)}{(12m)^2} = 400\ kg/s^2 = \boxed{400\ N/m}$$

Part b): Use conservation of energy: The initial energy is gravitational potential energy at the top of the platform and the final energy is kinetic energy, gravitational potential energy at 7m, and potential energy stored in the stretched spring.

$$E_{initial} = E_{final}: \qquad mgh_1 = mgh_2 + \frac{1}{2}mv^2 + \frac{1}{2}kx_2^2 \qquad \textit{solve for velocity}$$

$$mg(h_1 - h_2) = \frac{1}{2}mv^2 + \frac{1}{2}kx_2^2 \quad \rightarrow \quad 2mg(h_1 - h_2) - kx_2^2 = mv^2$$

$$v = \sqrt{\frac{2mg(h_1 - h_2) - kx_2^2}{m}} = \sqrt{\frac{2(70kg)(9.8m/s^2)(42m - 7m) - (400N/m)(5m)^2}{70kg}} = \boxed{23.3\ m/s}$$

Check: The units are correct for both calculations. The velocity value is reasonable because the dean free-falls for 30m and has velocity $v = \sqrt{2gL} = 24.2\ m/s$ before the bungee spring starts to stretch and slows him down.

Scoring Template Part I   Name:______________________

Student # 1	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 2	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 3	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Scoring Template Part I Name:______________________

Student # 4	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 5	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 6	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Scoring Template Part I Name:______________________

Student # 7	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 8	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Scoring Template Part I Name:______________________

Questions:

1. What difficulties did you encounter while using the scoring rubric?
    - Which of the five categories was most difficult to score and why?
    - Which student solutions were the most difficult to score and why?

2. What changes, if any, would you recommend making to the rubric? Why?

3. If you were deciding how to grade these student solutions for an introductory physics course exam, how would you assign points? (out of 20 total points)

Dear graduate student,

Thank-you once again for agreeing to help me with my research on physics problem solving assessment! Below you will find instructions for the *second* part of the task. When you have completed all steps, please return the documents to my mailbox in the envelope provided. I will contact you by e-mail to arrange a brief meeting to discuss your suggestions and comments.

Jen Docktor
Office 161B, 625-9323
docktor@physics.umn.edu

Instructions Part II:

1. If necessary, re-read the scoring document (rubric) and category descriptions printed on the next page.
2. If necessary, read the physics problem statement and instructor solution again.
3. Look at the example scores for student solutions #1-3 and the reasoning for each score on page 5. Compare these scores to your own scores for these solutions from Part I.
4. Look at the student solutions #4-8, which you scored on Part I. Use the rubric to assign a separate score of 0, 1, 2, 3, 4, NA(P), or NA(S) for each of the five categories (you may review your scoring template from Part I as needed). On the blank scoring template sheets for Part II, record your new scores for students #4-8 and brief notes about your reasoning for each score.
5. Continue the scoring process for five new student solutions, #9-13.
6. Record questions and scoring difficulties on page 10 of the scoring template sheets, and answer the questions. Include your name at the top of each scoring sheet. (Note that this is only for my reference, and your name will not in any way be associated with results of the study.)

Problem Solving Rubric

Jennifer Docktor [docktor@physics.umn.edu]

	4	3	2	1	0
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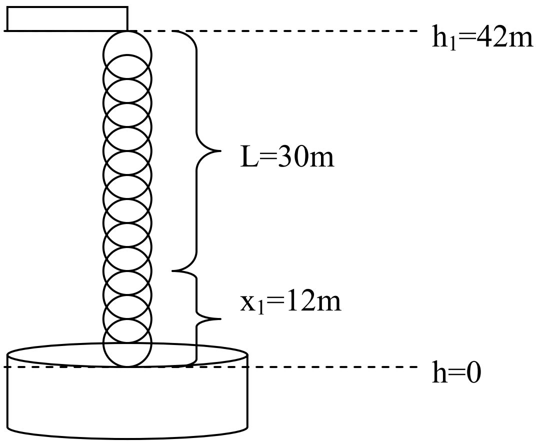
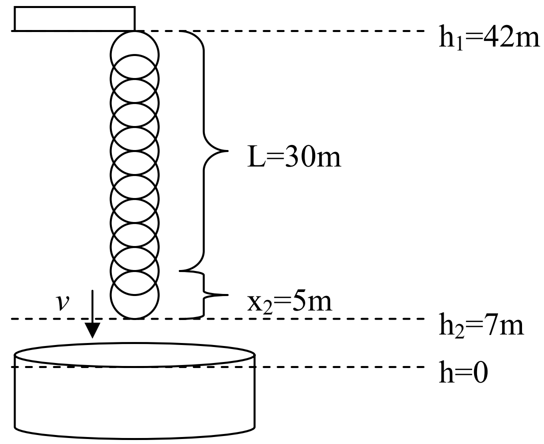
c) Determine the spring constant of the bungee cord so that it stretches only 12m, which will just keep the dean out of the water. (Assume that the dean is a point-like object).
d) Using the result of a), find the dean’s speed 7m above the water.

Instructor solution:

Description

Part a): Find the spring constant, k	Part b): Find the velocity of the dean, v
	
L=30m; length of the bungee cord h_1=42 m; initial height of the dean x_1=12 m; spring stretch when the dean is at the water surface (h_1-L)	h_1=42 m; initial height of the dean h_2=7 m; final height of the dean above the water x_2=5 m; spring stretch when the dean is 7 m above the water (h_1-h_2-L)

Part a): Use conservation of energy: The initial energy is gravitational potential energy at the top of the platform and the final energy is potential energy stored in the stretched spring at h=0.

$$E_{initial} = E_{final}: \qquad mgh_1 = \frac{1}{2}kx_1^2 \qquad \textit{solve for the spring constant } k$$

$$k = \frac{2mgh_1}{x_1^2} = \frac{2(70kg)(9.8m/s^2)(42m)}{(12m)^2} = 400\ kg/s^2 = \boxed{400\ N/m}$$

Part b): Use conservation of energy: The initial energy is gravitational potential energy at the top of the platform and the final energy is kinetic energy, gravitational potential energy at 7m, and potential energy stored in the stretched spring.

$$E_{initial} = E_{final}: \qquad mgh_1 = mgh_2 + \frac{1}{2}mv^2 + \frac{1}{2}kx_2^2 \qquad \textit{solve for velocity}$$

$$mg(h_1 - h_2) = \frac{1}{2}mv^2 + \frac{1}{2}kx_2^2 \quad \rightarrow \quad 2mg(h_1 - h_2) - kx_2^2 = mv^2$$

$$v = \sqrt{\frac{2mg(h_1 - h_2) - kx_2^2}{m}} = \sqrt{\frac{2(70kg)(9.8m/s^2)(42m - 7m) - (400N/m)(5m)^2}{70kg}} = \boxed{23.3\ m/s}$$

Check: The units are correct for both calculations. The velocity value is reasonable because the dean free-falls for 30m and has velocity $v = \sqrt{2gL} = 24.2\ m/s$ before the bungee spring starts to stretch and slows him down.

Scoring Template Part II Name:______________________

Student # 1	Score	Notes
Physics Approach	**1**	Newton's second law is inappropriate during spring stretch; missing energy conservation for part a); approach in b) is unclear
Useful Description	**NA(S)**	Visualization is unnecessary for this solver; Free-body diagram assumes = forces; defined variables for part b) but not a);
Specific App. of Physics	**2**	Incorrectly assumes acceleration is zero at bottom of jump; does not identify "initial" and "final" energy terms
Mathematical Procedures	**3**	Missing substitution of numerical values during calculations (except d-7); makes a calculation error when finding k in part a)
Logical Organization	**2**	Parts of the solution are unclear due to implicit reasoning; velocity value is greater than free fall after 30 m;

Student # 2	Score	Notes
Physics Approach	**4**	Kinematics is appropriate before spring stretch; conservation of energy approach is explicitly stated
Useful Description	**1**	missing variable definitions; used "h" and "x" w/multiple values; picture is missing variable labels and height/stretch for part b)
Specific App. of Physics	**2**	Does not identify "initial" and "final" energy terms; part b) is missing a mgh term; used incorrect stretch value in part b)
Mathematical Procedures	**2**	Important algebraic mistakes when solving for k (did not need to take square root and incorrectly drops root from k)
Logical Organization	**2**	Should have checked units for k equation in part a) – might have caught inconsistencies;

Student # 3	Score	Notes
Physics Approach	**0**	Equal forces approach is inappropriate; kinematics inappropriate because acceleration not constant; missing energy conservation
Useful Description	**2**	Missing variable definitions such as "y"; picture is missing variable labels; included stretch/height for b)
Specific App. of Physics	**1**	Incorrectly assumes acceleration is constant during spring stretch in part b) and zero in a); doesn't identify initial and final v's
Mathematical Procedures	**1**	Missing steps in calculations; early numerical substitutions make procedures difficult to follow (procedures inappropriate);
Logical Organization	**1**	Reasoning for most of the solution is unclear – especially part b); inconsistent assumptions about acceleration

Scoring Template Part II Name:______________________

Student # 4	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 5	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 6	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Scoring Template Part II   Name:______________________

Student # 7	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 8	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 9	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Scoring Template Part II Name:______________________

Student # 10	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 11	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Student # 12	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Scoring Template Part II Name:______________________

Student # 13	Score	Notes
Physics Approach		
Useful Description		
Specific App. of Physics		
Mathematical Procedures		
Logical Organization		

Scoring Template Part II Name:________________________

4. What difficulties did you encounter while using the scoring rubric?

5. Were the example scores useful? Why or why not?

6. What further changes, if any, would you recommend making to the rubric?