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.

For my research 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. 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 [doctor@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.

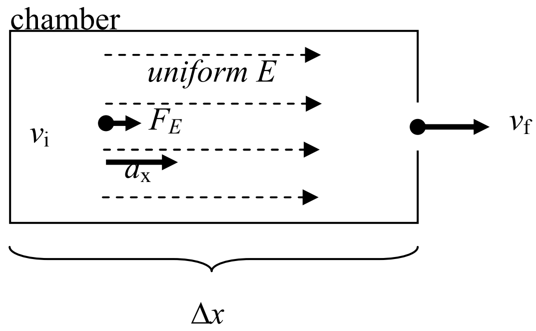
Logical Organization assesses the solver's skills at communicating reasoning, staying focused toward a goal, and evaluating the solution for consistency (implicitly or explicitly). It checks whether the entire problem solution is clear, focused, and organized logically. The term *logical* means that 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 1:

You are designing part of a machine to detect carbon monoxide (CO) molecules (28 g/mol) in a sample of air. In this part, ultraviolet light is used to produce singly charged ions (molecules with just one missing electron) from air molecules at one side of a chamber. A uniform electric field then accelerates these ions from rest through a distance of 0.8 m through a hole in the other side of the chamber. Your job is to calculate the direction and magnitude of the electric field needed so that CO^+ ions created at rest at one end will have a speed of 8×10^4 m/s when they exit the other side.

Instructor solution:

Description

	v_i= 0; initial velocity of the CO^+ molecule v_f=8x10^{4}m/s; final velocity of the CO^+ molecule E: uniform electric field in the chamber Δx =0.8m; distance to hole in chamber q=1.602x10^{-19}C; charge of a CO^+ molecule m=mass of a CO^+ molecule a_x=acceleration of the CO^+ molecule F_E=force on the CO^+ molecule in the uniform electric field

Target: calculate the electric field, *E*

Solution Approach 1: Use Newton's Second Law to relate the force on the molecule to its acceleration; use kinematics to write an expression for acceleration in terms of velocity and distance. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$\sum F_X = ma_X : \qquad qE = ma_X \qquad solve\ for\ the\ electric\ field: E = \frac{ma_X}{q}$$

$$v_f^2 = v_i^2 + 2a_X \Delta x \qquad solve\ for\ acceleration:\ a_X = \frac{v_f^2 - v_i^2}{2\Delta x}$$

$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1\,mol}{6.022 \times 10^{23}\,molecules} \approx 4.65 \times 10^{-26}\,kg / molecule\,CO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65 \times 10^{-26}\,kg\left(\left(8 \times 10^4\,m/s\right)^2 - 0\right)}{2\left(1.602 \times 10^{-19}\,C\right)\left(0.8m\right)} = \boxed{1160\,N/C} \quad direction\ is\ same\ as\ v\ (to\ the\ right.)$$

Solution Approach 2: Use conservation of energy to relate the electric potential energy transferred to the molecule and its final kinetic energy. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$E_{final} - E_{initial} = E_{in} - E_{out} : \qquad \frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2} = q\Delta V - 0 \quad OR \quad \frac{1}{2}mv^2 - \frac{1}{2}mv_i^{\ 2} = \int \vec{F} \cdot d\vec{s} - 0$$

$$for\ uniform\ electric\ field:\ \Delta V = \int \vec{E} \cdot d\vec{s} = E\Delta x \qquad and \qquad \int \vec{F} \cdot d\vec{s} = F_E \Delta x = qE\Delta x$$

$$\frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2} = qE\Delta x \quad solve\ for\ electric\ field$$

$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1\,mol}{6.022 \times 10^{23}\,molecules} \approx 4.65 \times 10^{-26}\,kg / molecule\,CO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65 \times 10^{-26}\,kg\left(\left(8 \times 10^4\,m/s\right)^2 - 0\right)}{2\left(1.602 \times 10^{-19}\,C\right)\left(0.8m\right)} = \boxed{1160\,N/C} \quad direction\ is\ same\ as\ v\ (to\ the\ right.)$$

Check: The units are correct for electric field. We expect that for a particle with larger mass or higher final velocity the electric field would need to be stronger, which is consistent with the equation obtained.

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
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.				

 Jennifer Docktor [docktor@physics.umn.edu]

Category Descriptions:

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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.

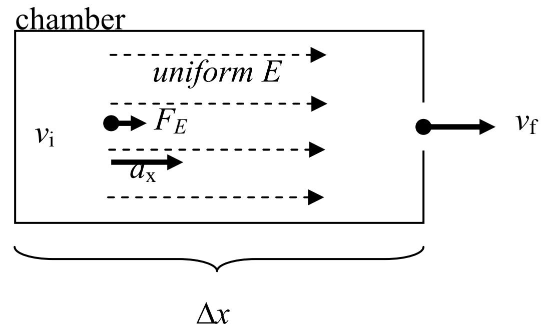
Logical Organization assesses the solver's skills at communicating reasoning, staying focused toward a goal, and evaluating the solution for consistency (implicitly or explicitly). It checks whether the entire problem solution is clear, focused, and organized logically. The term *logical* means that 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 1:

You are designing part of a machine to detect carbon monoxide (CO) molecules (28 g/mol) in a sample of air. In this part, ultraviolet light is used to produce singly charged ions (molecules with just one missing electron) from air molecules at one side of a chamber. A uniform electric field then accelerates these ions from rest through a distance of 0.8 m through a hole in the other side of the chamber. Your job is to calculate the direction and magnitude of the electric field needed so that CO^+ ions created at rest at one end will have a speed of 8×10^4 m/s when they exit the other side.

Instructor solution:

Description



v_i= 0; initial velocity of the CO^+ molecule
v_f=8x10^{4}m/s; final velocity of the CO^+ molecule
E: uniform electric field in the chamber
Δx =0.8m; distance to hole in chamber
q=1.602x10^{-19}C; charge of a CO^+ molecule
m=mass of a CO^+ molecule
a_x=acceleration of the CO^+ molecule
F_E=force on the CO^+ molecule in the uniform electric field

Target: calculate the electric field, *E*

Solution Approach 1: Use Newton's Second Law to relate the force on the molecule to its acceleration; use kinematics to write an expression for acceleration in terms of velocity and distance. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$\sum F_X = ma_X : \qquad qE = ma_X \qquad solve\ for\ the\ electric\ field: E = \frac{ma_X}{q}$$

$$v_f^2 = v_i^2 + 2a_X \Delta x \qquad solve\ for\ acceleration: a_X = \frac{v_f^2 - v_i^2}{2\Delta x}$$

$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1\,mol}{6.022 \times 10^{23}\,molecules} \approx 4.65 \times 10^{-26}\,kg / molecule\,CO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65 \times 10^{-26}\,kg\left(\left(8 \times 10^4\,m/s\right)^2 - 0\right)}{2\left(1.602 \times 10^{-19}\,C\right)\left(0.8m\right)} = \boxed{1160\,N/C} \quad direction\ is\ same\ as\ v\,(to\ the\ right.)$$

Solution Approach 2: Use conservation of energy to relate the electric potential energy transferred to the molecule and its final kinetic energy. Assume gravity is negligible. Convert the mass of CO into kilograms per molecule.

$$E_{final} - E_{initial} = E_{in} - E_{out} : \qquad \frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2} = q\Delta V - 0 \quad OR \quad \frac{1}{2}mv^2 - \frac{1}{2}mv_i^{\ 2} = \int \vec{F} \cdot d\vec{s} - 0$$

$$for\ uniform\ electric\ field: \Delta V = \int \vec{E} \cdot d\vec{s} = E\Delta x \qquad and \qquad \int \vec{F} \cdot d\vec{s} = F_E \Delta x = qE\Delta x$$

$$\frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2} = qE\Delta x \quad solve\ for\ electric\ field$$

$$m = \frac{28g}{mol} = \frac{0.028kg}{mol} \bullet \frac{1\,mol}{6.022 \times 10^{23}\,molecules} \approx 4.65 \times 10^{-26}\,kg / molecule\,CO^+$$

$$E = \frac{m\left(v_f^2 - v_i^2\right)}{2q\Delta x} = \frac{4.65 \times 10^{-26}\,kg\left(\left(8 \times 10^4\,m/s\right)^2 - 0\right)}{2\left(1.602 \times 10^{-19}\,C\right)\left(0.8m\right)} = \boxed{1160\,N/C} \quad direction\ is\ same\ as\ v\,(to\ the\ right.)$$

Check: The units are correct for electric field. We expect that for a particle with larger mass or higher final velocity the electric field would need to be stronger, which is consistent with the equation obtained.

Scoring Template Part II Name:______________________

Student # 1	Score	Notes
Physics Approach	2	Use of Newton's second law is appropriate; missing use of kinematics to find acceleration
Useful Description	2	Direction of force from horizontal E-field is incorrect; velocity is unclear from picture (constant?) and distance undefined
Specific App. of Physics	1	Should neglect the force of gravity; missing analysis of motion in the horizontal direction – missing key specific relationships
Mathematical Procedures	2	Missing procedure to convert molar mass to kg
Logical Organization	2	Electric field value is unreasonable; direction of force and E-field are inconsistent; answer independent of v and distance

Student # 2	Score	Notes
Physics Approach	1	Explicit use of "Newton's law" to equate forces; calculates acceleration and kinetic energy (but approach unclear)
Useful Description	1	Velocity is unclear from picture (constant?) and distance not labeled; direction of E-field incorrect; B-field incorrect
Specific App. of Physics	1	Incorrectly assumes B-field present; missing analysis of motion in the horizontal direction; missing important relationships
Mathematical Procedures	1	Missing procedure to convert molar mass to kg; procedures to solve for target are left unfinished
Logical Organization	1	Target variable unclear / inconsistent (B or E?); parts of the solution are inconsistent and unfocused – doesn't reach answer

Student # 3	Score	Notes
Physics Approach	3	Stated approach is appropriate but actual approach is missing kinematics or energy
Useful Description	2	Inconsistent use of variables L and R; should indicate direction of E-field and force on the picture; should label R
Specific App. of Physics	1	Incorrectly assumes circular motion; assumption to use 1 mol unjustified; assumes neg. charge; missing important relationships
Mathematical Procedures	2	Missing an appropriate procedure to convert molar mass to kg
Logical Organization	3	Answer unreasonable and unnoticed; stated approach does not match actual approach

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?