

Physics Approach (PA):

The solver has clearly selected appropriate physics concepts and principle(s) to use in solving the problem. Here the term *concept* is defined to be a general physics idea used to designate an entity, event, or relation. Examples include the concepts of “force” and “energy”. 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 or Newton’s second law. To identify a solver’s approach, it might be necessary to look at the entire solution (basic equations, specific equations, diagrams, etc.) for evidence of physics concepts and principles used. If there is no explicit statement of an approach in words or basic equations and specific equations are correct, then an approach statement was not necessary for this solver to be successful and the PA category should be coded as NA-solver. If the relevant physics concepts and principle(s) are obvious from the problem statement or textbook heading, then choosing an approach is not necessary for the problem and should be coded as NA-problem.

Evidence of a solver’s Physics Approach:

- statement of physics concept(s) in words: “Use Energy”, “Use Momentum”, “Use forces”
- statement of physics concept(s) as equations:
 - $F_{up} = F_{down}$ indicates a “forces approach”
 - $\vec{p} = m\vec{v}$ indicates “momentum” approach
- statement of basic physics principle(s) in words:
 - “Use Newton’s Second Law” ; “Use conservation of angular momentum”
- statement of basic physics principle(s) as equations:
 - $E_{initial} - E_{final} = E_{in} - E_{out}$; $\vec{P}_{initial} = \vec{P}_{final}$
- abstracted physics diagram
 - free-body diagram indicates “forces” approach
- specific equations:
 - $KE = \frac{1}{2}mv^2$ indicates an energy approach
 - $m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$ indicates conservation of momentum

Examples of difficulties in a solver’s Physics Approach:

- trying to solve a problem with an inappropriate concept / principle (one that will not lead to a correct solution)
- missing an important concept / principle
- approach is unclear
 - set a force equal to an energy: $F_{spring} = \frac{1}{2}kx^2$
 - equation is incorrect, such as stating “weight”: $W = Fd \cos \theta$ or “work” $W = mg$

Useful Description (UD):

The solver has organized information from the problem statement into an appropriate and useful representation that summarizes essential information required to solve the problem. The description is considered “useful” if it guides further steps in the solution process. A *problem description* could include assigning appropriate symbols for variables, defining variables, restating known and unknown information, stating a goal or target, a visualization (sketch or picture), stating qualitative expectations, an abstracted physics diagram (force, energy, motion, momentum), stating a coordinate system, and choosing a system. If a visualization is given in the problem statement and/or variables have already been defined for the solver, then solution(s) should be coded as NA-problem because representation skills constitute a very small part of the problem.

Evidence of a Useful Description:

- coordinate system is clearly defined
- appropriate symbols are assigned to variables (clearly distinguished from each other)
- symbols used for variables are clearly defined
- statement of “given/known” and “unknown” quantities
- visualization (picture or sketch) of the problem situation
- abstracted physics diagram (force, energy, motion, momentum)
- explicit statement of target variable
- appropriate and clear choice of system

Examples of difficulties in a solver’s Description:

- coordinate system is missing and/or unclear
- variables used are not clearly defined; defined variables are not distinguished from each other (same symbol for two variables; such as masses or “E” for both energy & electric field)
- a visualization (sketch or picture) of the problem situation is missing and would have been useful for the solver
- sketch/picture drawn is not useful for the solver
- sketch/picture is missing important objects, events, or interactions
- physics diagram (force, energy, motion, momentum) is missing and would have been useful for the solver
- diagram is missing important objects, events, or interactions
- diagram includes irrelevant objects or interactions
- quantities are not labeled on or near the picture or diagram
- important unknown variables are not defined on the physics diagram(s)
- target variable is not made explicit
- choice of system unclear
- description indicates misinterpretation of the problem statement
 - visualization(s) do not match the information given in the problem
 - spatial relationships between objects are confused
- description indicates fundamental misunderstanding of physics
 - straight-line trajectory drawn for a projectile

Specific Application of Physics (SAP):

The solver has correctly applied 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 including definitions, relationships between the defined variables, initial conditions, and assumptions or constraints.

Evidence of Specific Application of Physics:

- equations that include specific variables defined in the problem
 - $\sum F_x = \mu N - mg \sin \theta = ma_x$, $\sum F_y = N - mg \cos \theta = 0$
 - $\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = mgd \sin \theta - f_k d$
- explicit statement of assumptions / constraints
 - assume contributions from friction (surface, air resistance) are negligible
 - treat the projectile as a point particle
 - neglect the mass of the string or spring
 - assume a frictionless and massless pulley

Examples of difficulties in a solver's Specific Application of Physics:

- application of concepts / principles is inappropriate
 - using static friction coefficient when object is in motion
 - Using Coulomb's Law to find the force on a particle in an electric field
- incorrect relationship between variables is assumed
 - normal force $N=mg$ is always true (even when object is on an incline)
 - $T=Mg$ for an accelerating object
 - $kx=mg$ for an oscillating mass on a spring
- important relationship between variables is overlooked
 - accelerations $a_1=a_2$
 - tension force $T_1=T_2$
- simplifying approximations are not stated or are inappropriate
 - Ignoring friction when it should be included as a force
- there are not enough specific equations to solve the problem (one or more equations missing)
- sign errors in specific equations
 - direction of net force does not match direction (sign) of acceleration
 - sign of "g" does not match coordinate system
 - direction of forces indicated on picture/diagram does not match signs in specific equations
- SAP indicates misunderstanding of physics
 - mixing directions for kinematic equations: $x = v_o t + \frac{1}{2}gt^2$
 - confusing velocity and acceleration: assumes constant velocity for free fall motion instead of constant acceleration
 - vector quantities are treated as scalars (missing components)
 - Sets the normal force $N=mg$ even if the object is on an incline

Mathematical Procedures (MP):

The solver has followed appropriate and correct mathematical procedures during the solution execution. The term *mathematical procedures* refers to techniques that are used to isolate target variable(s) from specific equations of physics. For example, if a solver is faced with two equations and two unknown variables, appropriate techniques are used (such as substitution, matrix operations, etc.) to solve for the target in terms of known quantities. If the course instructor or researcher using the rubric values/expects a symbolic answer prior to numerical calculations, this could be considered an appropriate mathematical procedure. Similarly, if the instructor or researcher considers the numerical calculation step to be of low importance, then a calculation mistake could be considered a “minor” error.

Evidence of Mathematical Procedures:

- the solver has followed rules of arithmetic, geometry, trigonometry, algebra, calculus, etc. in the solution process
 - uses correct trig identities when finding vector components
 - follows appropriate algebra strategies, such as the “isolate” strategy (get unknown variable on one side of equation and all other variables on other side; subtract/add terms before multiply/divide)
 - correctly states and uses the Pythagorean theorem
 - correctly states and uses the quadratic formula
 - follows calculus rules of integration and differentiation
- the solver employs appropriate techniques to isolate the target variable(s) in terms of known quantities
 - when faced with multiple equations and unknown variables, the solver uses appropriate techniques: substitution, matrix operations, etc.
 - uses a “guess” and check method to solve a differential equation

Examples of difficulties in a solver’s Mathematical Procedures:

- the solver has violated rules of arithmetic, geometry, trigonometry, algebra, calculus, etc. in the solution process
 - sloppy use of parentheses for distribution, factoring, etc.
 - line-to-line inconsistencies, such as dropping a factor of 2 or a minus sign
 - multiplying/dividing some terms in an equation by a factor instead of all terms
 - incorrect trig identity used (sine instead of cosine or vice versa)
 - neglecting to use the chain rule when taking a derivative
 - separating terms under a square root sign
- inappropriate substitution of variable values into equations
- conversion difficulty (value(s) not in appropriate SI units)
- calculation error (numerical operation stated does not match resulting value)
- solver makes use of an unjustified relationship to reach a solution (set $m=1$)
- numerical values substituted too soon (if the instructor/researcher values a symbolic answer)
- calculations are left unfinished

Logical Organization (LO):

The solver's 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). If the problem being scored is actually a one-step exercise, then logical progression constitutes a small part of the solution and it should be scored as NA-problem.

Evidence of Logical Organization:

- solution order is clear and logical (internally consistent)
- relevant solution steps are shown
- steps are free from logical errors
- the solution progresses to an answer in symbolic and/or numerical form
- all the wanted information has been found
- the answer is expressed in terms of known quantities
- units are specified
- important results are clear (highlighted)
- consistency (absence of contradictions)
 - units are consistent throughout the solution
 - answer agrees with qualitatively expected functional relationships between parameters of the problem
 - answers are consistent with special cases or extreme values for parameters in the problem
 - values are sensible

Examples of difficulties in a solver's Logical Organization:

- solution order cannot be understood from what is written
 - haphazard manipulation of equations
 - significant unnecessary steps
- reasoning is unclear
- the same relationship was used more than once (circular reasoning)
- solution includes logical inconsistencies
 - specific equations do not match the approach and description
 - the stated target variable does not match the information in the problem statement
 - the stated target variable does not match the final answer
 - the answer is of unreasonable magnitude and unnoticed