1. **Sketch** scenario.
   a. If phrase-by-phrase translation of problem statement into figure and/or table is unreliable, fill out optional phrase-translation table as you carry out substeps below.
   b. **Read** a short phrase containing one of the following items (a phrase might play multiple roles).
      i. **Object/person** (possibly with characteristics)
      ii. **Action** (possibly with characteristics)
      iii. **Location/time** (possibly with characteristics)
      iv. **Quantity** (dimension or count)
   c. **Draw** a simple representation of the phrase (unless meaning of phrase has already been sketched).
   d. **Underline** the phrase. If phrase required no additional sketching, dash-underline the phrase.
   e. Go back to step (a) and analyze **next** phrase.
2. Draft a **force diagram** using **BETA**. This first draft is just for figuring out force directions.
   a. **B**ubble the system (try one object or a combination of objects moving together rigidly).
   b. **E**arth nearby? If so, use **Table 1**, row 1 to draw $F_{\text{E on SYS}}$.
   c. **T**ouching? Run your finger along system's bubble. Announce each external object in contact with the system. For each external object, draw appropriate force(s) using **Table 1** rows 2-5, as applicable.
      i. Use N3L to uncover hidden information about forces on the system:
         1. If the problem describes a force the system exerts on an external object, copy and fill in the N3L template below. Draw the corresponding force on the system.

	$\vec{F}_{\text{SYS on EXT OBJ}}$	Relationship	$\vec{F}_{\text{EXT OBJ on SYS}}$
Direction		Opposite	
Strength		Sane	

   d. **A**xis system: In force-components table, record $+x$ and $+y$ directions.
3. Sketch system's **motion diagram**.
   a. Draw **current position dot**. From this dot, extend **current velocity arrow** $\vec{v}_i$.
   b. Draw **slightly later position dot**. From this dot, extend **slightly later velocity arrow** $\vec{v}_f$.
   c. In empty workspace nearby, **paste** a copy of **current velocity arrow** $\vec{v}_i$ (don't draw dot).
   d. **Paste** a copy of **slightly later velocity arrow** $\vec{v}_f$ (don't draw dot) with the **tails** of the pasted $\vec{v}_i$ and $\vec{v}_f$ arrows **touching** (leave tiny gap if readability requires).
   e. Draw **segment connecting arrowheads** of pasted $\vec{v}_i$ and $\vec{v}_f$. Draw **segment's arrowhead** where segment touches **arrowhead of slightly later velocity arrow** $\vec{v}_f$. **Label** this segment $\Delta\vec{v}$.
4. Fill in **Newton's Tripod**.
   a. Were you told the direction of the net force $\sum\vec{F}$?
   b. Were you told all relative sizes of forces in your force diagram?
   c. Were you told (or figured out) the direction of the acceleration $\vec{a}$?
   d. Do you know the direction of the $\Delta\vec{v}$?
   e. If you answered "Yes" to any of questions (a), (b), (c), or (d) above, write in Newton's Tripod the direction of $\sum\vec{F}$, $\vec{a}$, or $\Delta\vec{v}$ you determined.
5. Update **lengths of force arrows**.
   a. What's the direction of the net force $\sum\vec{F}$ based on your force diagram? Does the direction of $\sum\vec{F}$ your force diagram implies match the direction of net force $\sum\vec{F}$ in Newton's Tripod? If not, edit force sizes in your force diagram to eliminate the inconsistency.
   b. (You can skip this step if you're not given a grid for your force diagram): If problem statement discloses numerical force strengths, tweak force-arrow lengths accordingly.
6. Fill in rest of **force-components table**.
   a. Copy direction of each force in force diagram into direction column of force-components table. Copy full sizes (strengths) from problem statement or **Table 1**, column D.
   b. Use direction and full-size columns to fill in x-direction, x-sign, x-size, y-direction, y-sign, and y-size columns.
   c. Write 0 for each a net-force component ($\sum F_x$ or $\sum F_y$) known to be 0.
   d. For each net-force component remaining blank, fill in the entry by adding up contributions from preceding rows.
7. Set up algebraic **equations** using **N2L**.
   a. Under force-components table, write $a_x = \frac{\sum F_x}{m}$ and $a_y = \frac{\sum F_y}{m}$ in appropriate columns.
   b. If a_x is known to equal 0, slash a_x "out to 0" and, on the next line, write $0 = \sum F_x$, with $\sum F_x$ replaced by the sum over appropriate x-components of forces from the force-components table.
   c. If a_x is not known to be 0, write a new copy of N2L, with $\sum F_x$ replaced by the corresponding entry from the force-components table.
   d. Go through (b) and (c) for a_y.
8. Carry out **algebra**.
9. You might need to use kinematics knowledge for additional calculations.

Table 1. Objects and forces they can exert

<table>
<tr><th></th><th>A. External object</th><th>B. Name & label</th><th>C. Direction</th><th>D. Memorized magnitude formulas (if any)</th></tr>
<tr><td>1.</td><td>Earth</td><td>Gravitational (name isn't important)
$F_{\text{E on SYS}}$</td><td>Rule: Down (toward Earth's center)
Write: "The Earth attracts the system, so the force of the Earth on the system is downward."</td><td>$F_{\text{E on SYS}} = mg$
$F_{\text{E on SYS}}$: Strength of Earth's pull on system
m: System's mass
g: Gravitational acceleration near Earth's surface, $9.8\,\frac{\text{N}}{\text{kg}} = 9.8\,\frac{\text{m}}{\text{s}^2}$</td></tr>
<tr><td>2.</td><td>Tight string</td><td>Tension (name isn't important)
$F_{\text{STR on SYS}}$</td><td>Rule: From system back into string
Write: "Tight strings pull, so the force of the string on the system points toward the …."</td><td>(No memorized formula)</td></tr>
<tr><td>3.</td><td>Surface</td><td>Normal
$F_{\text{N,SURF on SYS}}$</td><td>Rule: From surface directly back into system
Write: "Surfaces provide perpendicular presses, so the surface presses on the system in the … direction."</td><td>(No memorized formula)</td></tr>
<tr><td rowspan="2">4.</td><td>Surface threatening to scrape a face of the system.</td><td>Static friction
$f_{\text{S,SURF on SYS}}$</td><td rowspan="2">Rule: Bristles of surface "toothbrush" strive to unbend themselves
Write: "Friction opposes slippage, so the static friction force the surface exerts on the system points toward the …."</td><td rowspan="2">$f_{\text{S,SURF on SYS,max}} = \mu_{\text{S,SURF \& SYS}} F_{\text{N,SURF on SYS}}$
$f_{\text{S,SURF on SYS,max}}$: Maximum possible strength of static friction force surface could exert on system
$\mu_{\text{S,SURF \& SYS}}$: Coefficient of static friction (property of system and surface)
$F_{\text{N,SURF on SYS}}$: Strength of press surface exerts on system

$f_{\text{S,SURF on SYS}}$: Strength of static friction force surface exerts on system

<table><tr><th>Algebraic situation</th><th>Surface and system</th></tr><tr><td>$f_{\text{S,SURF on SYS}} < f_{\text{S,SURF on SYS,max}}$</td><td>Remain securely stuck</td></tr><tr><td>$f_{\text{S,SURF on SYS}} = f_{\text{S,SURF on SYS,max}}$</td><td>Remain stuck, but on verge of slipping
- OR -
Just barely starting to get unstuck</td></tr><tr><td>$f_{\text{S,SURF on SYS}} > f_{\text{S,SURF on SYS,max}}$</td><td>Not actually stuck. Scraping is ongoing. Presumption of absence of scraping is refuted.</td></tr></table></td></tr>
<tr><td colspan="2">* Unsure whether a surface is threatening to scrape or already scraping the system? Presume scraping is threatened and look out for results refuting your presumption.</td></tr>
<tr><td>5.</td><td>Surface scraping a face of the system</td><td>Kinetic friction
$f_{\text{K,SURF on SYS}}$</td><td>Rule: Bristles of surface "toothbrush" strive to unbend themselves
Write: "Friction opposes slippage, so the kinetic friction force the surface exerts on the system points toward the …."</td><td>$f_{\text{K,SURF on SYS}} = \mu_{\text{K,SURF \& SYS}} F_{\text{N,SURF on SYS}}$
$f_{\text{K,SURF on SYS}}$: Strength of kinetic friction force surface exerts on system
$\mu_{\text{K,SURF \& SYS}}$: Coefficient of kinetic friction (property of system and surface)
$F_{\text{N,SURF on SYS}}$: Strength of press surface exerts on system</td></tr>
</table>

Table 2. Newton's Laws

Law	Wordy statement	Convenient statement
Newton's 1st Law (**N1L**)	Unless acted upon by a non-zero net force $\sum\vec{F}$, an object at rest stays at rest and an object in motion stays in constant-velocity motion.	For a system, precisely one of the following options is true: a. The net force $\sum\vec{F}$ on the system and the acceleration $\vec{a}$ of the system are both 0. b. The net force $\sum\vec{F}$ on the system and the acceleration $\vec{a}$ of the system are both non-zero.
Newton's Tripod (don't write this unofficial name; instead say "as a consequence of N2L")	The directions of the net force $\sum\vec{F}$ on a system, acceleration $\vec{a}$ of the system, and change in velocity $\Delta\vec{v}$ of the system are all the same.	$\vec{a}$ Direction: $\sum\vec{F}$ $\Delta\vec{v}$
Newton's 2nd Law (**N2L**)	System acceleration $\vec{a}$ equals the ratio of net force $\sum\vec{F}$ on the system to system mass m.	$a_x = \frac{\sum F_x}{m}$ $a_y = \frac{\sum F_y}{m}$
Newton's 3rd Law (**N3L**)	When two objects interact, they exert a pair of forces on each other of equal strength and opposite direction.	| | $\vec{F}_{\text{A on B}}$ | Relationship | $\vec{F}_{\text{B on A}}$ | | Direction | | Opposite | | | Strength | | Sane | |
Definition of **N3L force pair**	If two forces are of the same type and the exerter of each is the exertee (recipient) of the other, the forces are called a N3L force pair.	1. Write names of two forces. Use subscripts to reveal exerter and exertee for each force. 2. Are the forces of the same type (example: both frictional)? 3. Do objects listed in subscripts "swap" (exerter of first force is exertee of second and exerter of second force is exertee of first)? 4. If you answered "Yes" to 2 and 3, the forces are a N3L force pair.

Writing an explanation

Table 3. Parts of an explanation

Component	Instructions	Example of wording style
Flashcard knowledge	Cite a rows from **Table 1** or **Table 2**.	N2L says that the horizontal acceleration of the car equals the net horizontal force on the car divided by the car's mass.
Evidence	Cite facts from problem statement (or information previously determined with very few steps from problem statement).	The net horizontal force on the car is provided exclusively by the rightward static friction the road exerts on the car, of strength 4000 N. The car's mass is 1000 kg.
Claim	State conclusion.	So, the car has a rightward acceleration of $4\,\frac{\text{m}}{\text{s}^2}$.

Arguing in the midst of contention

1. Fill in a column of Error! Reference source not found. w ith a correct argument.
2. Fill in other column(s) with other people's arguments.
3. Use your correct argument to "grade" other people's arguments.
4. Summarize your critiques of other people's arguments.

Table 4. Contention chart

	Correct argument	**Alice says**	**Bob says**	**Charlie says**
Flashcard knowledge				
Evidence				
Claim				