Problem solving SiQuENC (similar to Larkin, Knight, and Etkina)

Neatly and graphically represent situation(s)

1. Read the problem with careful attention.
2. Represent the problem statement in a visually navigable format.

Organize items like these	Using tools like these
a. Described situation(s) b. Given information/quantities c. Requested unknowns	a. Sketch(es) b. Table(s) c. List(s)

   Make sure that your representation is complete so that you do not need to refer back to the original problem statement.
3. Use dashed bubble(s) to identify system(s) (set(s) of focal point(s) of analysis).
4. Label situations (e.g. initial and final, A and B, etc.).
5. Identify requested unknowns.

Graphically represent quantities and their relationships

Ways to represent quantities	Specific examples of types of diagrams
a. Lengths b. Directions c. Countable copies of icons	a. Motion diagrams and graphs of kinematics quantities b. Vector component decomposition diagrams c. Free body diagrams d. Bar charts e. Standing wave diagrams

Identify relevant allowed starting point (in)equation(s)

1. Look at cribsheets in which allowed knowledge has been organized into categories.
2. Try to identify (a) relevant categor(y)ies.
3. Look again at your representations of the problem statement and of quantities.
4. Write down relevant (in)equation(s).

Analyze

Deductively reason	Check whether result is reasonable
a. Manipulate algebraic equations. b. "According to the law of ____, [X] is (proportional to | inversely proportional to | etc.) [Y]. Because [X] _____, [Y] _____." c. Recognize an equation of a line $y = mx + b$ and interpret its slope and y-intercept. d. Recognize what is being held constant and what is being changed. e. Design an experiment with correctly identified independent, dependent, and control variables.	a. "[X] has dimensions/units of _____, which is (not) expected." b. Check order of magnitude. c. Functional dependence: "According to this result, as [X] increases (by _____), [Y] _____. This is (not) reasonable because _____." d. Limiting cases: "According to this result, as [X] gets very _____, [Y] _____. This is (not) reasonable because _____."

Communicate

1. Label each key logical point in your work with a number.
2. Following the order of your labels, translate each numbered key point into a sentence.

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Identify relevant quantities that permit efficient reasoning

The following flowchart can be used after kinematics, dynamics, momentum, and energy are studied. The flowchart is loosely based on ideas from the principles-of-mechanics flowchart on p. 137 of (Chi, et al., 1981) and the table of cues on p. 144 of the same reference.

If visualizing situation(s) does not organically lead to identification of relevant quantities to represent, ask, in a scenario (experiment), **how many snapshots** can be identified?

↓ ↓

Can identify a "**before**" snapshot and an "**after**" snapshot

↓

Can **work/energy** principles be used?

- Are the complicated ΔW_{OUF} and ΔU_{INT} terms both zero?
- Are we explicitly asked to study ΔW_{OUF} and/or ΔU_{INT}?

$$KE_i + U_{\text{G},i} + U_{\text{S},i} + \Delta W_{\text{OUF}} = KE_f + U_{\text{G},f} + U_{\text{S},f} + \Delta U_{\text{INT}}$$

$$KE = \frac{1}{2}mv^2 \qquad \Delta U_{\text{G}} = mg\Delta h \qquad \Delta U_{\text{S}} = \frac{1}{2}k(\Delta x)^2 \qquad \Delta W_{\text{F}} = (F_{\text{AVG}}\cos\theta)\Delta\ell$$

$$P_{\text{F,AVG}} = \frac{\Delta W_{\text{F}}}{\Delta t} = (F\cos\theta)v$$

↓

Can **impulse/momentum** principles be used?

- Is the complicated $\Delta\vec{\mathbf{J}}_{\text{EXT}}$ term zero?
- Are we explicitly asked to study $\Delta\vec{\mathbf{J}}_{\text{EXT}}$?

$$\Sigma\vec{\mathbf{p}}_i + \Delta\vec{\mathbf{J}}_{\text{EXT}} = \Sigma\vec{\mathbf{p}}_f$$

$$\vec{\mathbf{p}} = m\vec{\mathbf{v}} \qquad \Delta\vec{\mathbf{J}} = \vec{\mathbf{F}}_{\text{AVG}}\Delta t$$

↓

Can **kinematics** relationships be used?

- Is the acceleration directly stated in the problem statement (or almost directly stated, as would be the case for free-fall motion)?

$$v_{x,\text{AVG}} = \frac{v_{x,i} + v_{x,f}}{2}$$

$$x_i + v_{x,\text{AVG}}\,\Delta t = x_f \qquad x_i + v_{x,i}\Delta t + \frac{1}{2}a_x\Delta t^2 = x_f$$

$$v_{x,i} + a_{x,\text{AVG}}\,\Delta t = v_{x,f} \qquad v_{x,i}^2 + 2a_x\Delta x = v_{x,f}^2$$

Can only identify a **single snapshot** of interest

↓

Can **force** concepts be used?

Free-body diagram: BETA

$$\vec{\mathbf{a}} = \frac{\sum\vec{\mathbf{F}}}{m}$$

$$\sum\vec{\mathbf{F}} = \vec{\mathbf{0}} \Leftrightarrow \text{constant } \vec{\mathbf{v}} \qquad a_{\text{IN}} = \frac{v_{\text{TAN}}^2}{r}$$

There exists $\vec{\mathbf{F}}_{\_\_,\ 2\text{ ON }1}$ ⇒ there also exists $\vec{\mathbf{F}}_{\_\_,\ 1\text{ ON }2} = -\vec{\mathbf{F}}_{\_\_,\ 2\text{ ON }1}$

In simple problems, direct calculation of instantaneous values of quantities listed in the flashcards at the left might be requested.

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Analysis can be performed quantitatively and qualitatively

Features of qualitative reasoning are related to features of quantitative reasoning. Qualitative reasoning is distinct from quantitative reasoning, but qualitative reasoning can still be highly mathematical.

	Quantitative reasoning	**Qualitative reasoning**
Elements for representing snapshot features	Precise values	Zero Positive Negative
Comparisons	Precise differences (including a difference of zero)	Relatively large Relatively small Greater than Less than Equal to
Relationships	Algebraic association rules (formulas)	So-and-so's law states that y is proportional to x. Additional examples "y is inversely proportional to x" "Changing y does not change x" "y increases with x"
Operations for deducing solution sets	Arithmetic operations to simplify expressions and manipulate equations based on laws of algebra (e.g. addition property of equality, etc.)	According to so-and-so's law, y is proportional to x. Because (blah-blah-blah previous deduction), x is decreasing in this situation. This means that y is also decreasing.

Problem solving SiQuENC (similar to Larkin, Knight, and Etkina)

Presentation in the form of prose does not automatically confer upon reasoning the status of being qualitative.

Both of these are examples of **quantitative**, not qualitative, reasoning		This is a **mixture** of qualitative and quantitative (mostly qualitative) reasoning
Traditional **algebra**	Natural-language **narration of algebra**ic reasoning (looks like qualitative reasoning, but isn't)	Natural-language **narration of mostly qualitative reasoning**
$U_{G,i} = K_f$ $mgh = \frac{1}{2}mv^2$ $gh = \frac{1}{2}v^2$ $v = \sqrt{2gh}$ Try $h = 1$ $v = \sqrt{2g}$ Try $h = 2$ $v = \sqrt{2g \cdot 2} = \sqrt{4g}$ $\sqrt{4g} > \sqrt{2g}$ So v increased	I set the initial gravitational potential energy equal to the final kinetic energy. The formula for gravitational potential energy is mgh, and the formula for kinetic energy is $\frac{1}{2}mv^2$. I divided the mass m out from both sides of the equation. I multiplied both sides of the equation by 2 and then took the positive root of both sides to solve for v. I substituted an example height of $h = 1$ and found that the resulting speed was $\sqrt{2g}$. When I substituted a greater example height of $h = 2$, I found that the resulting speed was now $\sqrt{4g}$, which is greater than $\sqrt{2g}$. This means that the v increased. Final velocity increases with increasing initial height.	Gravitational potential energy is mgh and, thus, proportional to h. This means that increasing the initial height from which the ball is dropped increases the initial gravitational potential energy. Air resistance is neglected, so the work performed on the ball-Earth system by external forces is zero. This means that mechanical energy is conserved so that all of the initial gravitational potential energy is converted to final kinetic energy at the bottom of the ball's fall. Thus, increasing the initial gravitational potential energy results in increasing the final kinetic energy. Because kinetic energy is $\frac{1}{2}mv^2$, increasing kinetic energy at a constant mass corresponds to increasing speed v. Thus, increasing the height from which the ball is dropped results in increasing the ball's speed at the bottom.

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Textbook correlation

This step sheet is based on problem-solving processes similar to the one described by Larkin *et al.* in 1980.[1,2] The chart below illustrates correlations between the SiQuENC steps and problem-solving steps from Larkin,[1,2] Etkina[3] (978-0-321-87972-1), and Knight[4] (978-0-321-87972-1).

Larkin *et al.*[1,2]	Knight[4]	Etkina[3]	**SiQuENC**
"(i) If the problem statement is not accompanied by a picture, . . . sketch one."	Prepare	Sketch and translate	**Neatly and graphically represent situation(s)**
"(ii) Selecting tentatively a set of principles to use, . . . construct an abstract problem representation containing physical entities (such as forces and energies) relevant to those principles."		Simplify and diagram	**Graphically represent quantities and their relationships**
"(iii) . . . rerepresent the problem as a set of equations."	Solve	Represent mathematically	**Identify relevant allowed starting point equations**
		Solve and evaluate	**Analyze**
	Assess		
			Communicate

This table illustrates only four examples of the many references[1,2,5,6,7,8,9,10,11,12,13,14,15,16,3,17,4] that students and teachers can use to support the use of multiple representations and qualitative reasoning in problem-solving in physics.

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