The Stoichiometry Roadmap

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After teaching introductory and college prep. chemistry for a couple of decades now, I am still fascinated by the "unproductive creativity" of students when they come to answer simple, logical, calculation questions in chemistry.
I have realized that much of their confusion stems from the fact that **they don't see what I think they see** when I write things on the board that illustrate the chemical processes we are discussing.

Consider the chemical equation arrow " $\longrightarrow$".

In introductory chem., we often use it as the arrow of time...

before mixing $\longrightarrow$ after mixing.

Later, we write two arrows in opposite directions to describe an equilibrium process. If the student's concept of a chemical reaction is based on "before and after", this second interpretation of the same symbol is difficult for them. Many have trouble remembering that both "reactants" and "products" coexist in the same beaker.

I have found that a simple diagram sequence solves this problem and several associated ones:

Consider a solution equilibrium: $PbI_2 \rightleftarrows Pb^{2+} + 2\,I^-$

We first deal with dissolving by drawing the beaker, crystal and separate ions in solution, using arrows to show the motion of ions leaving the crystal. Next, I add the precipitation process to the diagram. Then, I draw the chemical species as an equation, but keep the outlines of the beaker, water and crystal. Later, I just draw the beaker and put the equation inside. Finally, I can write the equation without the diagram and be confident that they have the mental concept of what is happening, as they use the standard equation.

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Of much more importance, I believe, is that when WE solve problems, we have already decoded the problem according to our own logical framework, and allocated the pieces of information to appropriate labels (usually the chemical formula of each compound). Students that can use symbolic logic easily, will also do this. But the majority of students are still struggling with interpreting Co as cobalt, CO as carbon monoxide and CO_3^{2-} as carbonate, when we introduce mole problems.
They need a logical framework, a road map, to decode the information. I have had great success with the following diagram, and I urge you to try it...especially with students that have inconsistent success in solving stoichiometry problems.

UP OVER AND DOWN!

I often tell my class that once they can write and balance a chemical equation, I can put the rest of the course on one page. Then I present this diagram.

		Gas n= PV/RT ↓		**Gas** PV=nRT ↑		
Solution Conc. Vol.	→	***moles***	→ **BALANCED EQUATION** →	***moles***	→	**Solution** Conc. Vol.
		↑ **Pure Solid or Liquid** (grams)		↓ **Pure Solid or Liquid** (grams)		

The main idea is to have them use this "road map" to organize their thinking and their analysis of the information presented by the problem.

The two statements to push are:

"What is the answer. That is not a question!"

and **"Every problem is the same....just go up, over and down".**

We start with weight-weight problems, progress through solution concentrations and end up, much later in the course with the ideal gas law, but every problem is solved in the same format. For each *individual* calculation, we use the "factor-label" approach as a guide.

Here is an example that many students would find very complicated without a road-map.

(a) What mass of magnesium phosphate will be produced if 10 g of magnesium carbonate react completely with H_3PO_4 ?

(b) What volume of CO_2 is produced at 100 kPa and 300 K?

(c) What volume of 2M H_3PO_4 solution is required?

1. First, we need a balanced equation...without it we can't get anywhere, so...

$$3\ MgCO_3 + 2\ H_3PO_4 \rightarrow Mg_3(PO_4)_2 + 3\ H_2O + 3\ CO_2$$

2. Now, **what is the answer... that is not a question**.
Place a "**?**" <u>well below</u> each compound that requires an answer.

3. Next, place the information given by the problem below the formula it applies to.

$3\ MgCO_3 + 2\ H_3PO_4$ □ $Mg_3(PO_4)_2 + 3\ H_2O + 3\ CO_2$

10 g	V= **?** L C= 2M	**?** g	V= **?** P=100 kPa T= 300 K

4. **It is "illegal" to solve a problem by starting with the answer,** so don't start where there is a "**?**". Here, we must start our calculations using the 10 grams.
The first step is to **go up to the equation**. The equation is written in moles, so the first step ALWAYS involves changing quantities into moles. If they are converting from mass, then beside the "up" arrow they write the weight of **ONE** mole.

Since we aren't "at the equation yet", the balancing number is NOT involved.

$3\ MgCO_3 + 2\ H_3PO_4$ □ $Mg_3(PO_4)_2 + 3\ H_2O + 3\ CO_2$

0.12 mol

84 g/mol ↑

10 g	V= ? L C= 2M	? g	V= ? P=100 kPa T= 300 K

5. We are now able to use the equation to calculate the number of moles of any of the desired compounds. We go **over** to the compound with a question mark under it. Let's deal with the phosphoric acid. We use the balancing numbers as a ratio.

[for the numerically challenged..... cross-multiply and divide by the unused number].

Write the result just under the formula it applies to.

3 $MgCO_3$ + **2** H_3PO_4 □ $Mg_3(PO_4)_2 + 3\ H_2O + 3\ CO_2$

0.12 mol □ **0.08 mol**

84 g/mol ↑

10 g	V= ? L C= 2M	? g	V= ? P=100 kPa T= 300 K

6. Finally, we have to focus our attention on how we can get "**down** to the answer". Because of the positioning on the diagram AND because they decoded the information before "getting confused" by calculations, students can **see** what is needed, and what other information is available. For this question, we have moles and concentration (in moles per litre) so:

$3\ MgCO_3$ +	$2\ H_3PO_4$	→	$Mg_3(PO_4)_2$	+ $3\ H_2O$	+ $3\ CO_2$
0.12 mol →	**0.08 mol**				
84 g/mol ↑	↓				
10 g	**V= ? L** **C= 2M**		? g		V= ? P=100 kPa T= 300 K

V= 0.08 mol X $\frac{\text{1 litre}}{\text{2 mol}}$

V= 0.04 L or 400 mL

The numbers for $Mg_3(PO_4)_2$ and CO_2 are waiting under the formula for each compound and they can clearly see that the moles of $MgCO_3$ do not need to be recalculated.

This structure avoids problems such as confusing Volume of gas with Volume of solution as students quickly learn to decode the given information and place it in the appropriate location before beginning any calculations.

With a "road-map", students know where they are in the problem, where they are trying to go, and they can see that the next step involves just one calculation.... a calculation that they have done before, in other simpler problems. This framework gives security and consistency to all of your students, so that they are able to progress to more complex calculations like "limiting reagents" with confidence.

Numerically-confident students soon internalize the logic and see the concepts behind the calculations. The less confident ones are not left behind in a pool of frustration. As their confidence grows, so does their ability to see the chemistry behind the calculations.

Limiting Reagent Problems:

What mass of CO_2 is produced if 10 g of $MgCO_3$ are mixed with 10 g of H_3PO_4 ?

$3\ MgCO_3$	+ $2\ H_3PO_4$	→	$Mg_3(PO_4)_2$	+ $3\ H_2O$ +	$3\ CO_2$
10 g	10 g				**?** g

Now we have two numbers and one "?"...where to start?

Only one of the two compounds will be used up completely...which one?
STOP HALFWAY UP AND CHECK!
[The student is visually and mentally focussed on just that one aspect of the problem.]

3 $MgCO_3$ + 2 H_3PO_4 □ $Mg_3(PO_4)_2$ + 3 H_2O + 3 CO_2
0.12 mol □□□□□□□□□□□□□□□□□□ □ **0.12 mol**
↑

0.12 mol **0.10 mol** □

1 mol = 84 g ↑ ↑ 1 mol = 98 g

10 g **10 g** ? g

Students can see <u>where</u> to calculate the needed amount of H_3PO_4 . When they do, they can easily compare the 0.08 moles needed with the 0.10 moles available. Since there is more than enough H_3PO_4 they now know <u>why</u> they can go ahead. If they chose the wrong compound, they can <u>see</u> that there is not enough of the other one to use it all up and they must start again.

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The general structure works for **dilution problems**:

H_2SO_4 (concentrated) □ H_2SO_4 (dilute)
moles □□□□□□□□ moles
↑ □
C= 2.5 M C = **?**
V= 0.5 L V = 3.5 L

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Boyle's and Charles' Law problems:

CO_2 (cold) □ CO_2 (hot)

n= moles □□□□□□□ n= moles

↑ □
P= 100 kPa R= 8.31 P= ? R= 8.31
V= 2.5 L T= 273 K V= 4.0 L T= 373 K

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AND **water of hydration problems**:

$MgSO_4 \cdot$ □ H_2O □ $MgSO_4$ + □ H_2O
0.1 mol □□□□□□ 0.1 mol
□
? g/mol ↑

↑
26.4 g 12.0 g

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"What" **is** the answer!