Reactants, Products and Leftovers

Leading title ideas:
Chemical Equation Cafe
Reactions and Ratios
Reactants-to-Products
Reactants, Products, and Leftovers

PhET Sim Design Document

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Contents

Learning Goals

"The student will be able to... *verb noun*."

1. Recognize that atoms are conserved in a chemical reaction
2. Describe the difference between coefficients (e.g. 3 in $3A_2$) and subscripts (e.g. 2 in $3A_2$) in a chemical equation
3. Predict the products and leftovers after reaction
4. Identify the limiting reagent in a chemical reaction

Synergistic goals
5. Relate chemical reactions to everyday experiences like making sandwiches
6. Translate from symbolic (e.g. CH_4) to molecular representations of matter

Note for Teaching Tips:
Sim does NOT address the concept of moles!

Common Misconceptions

1. Limiting reagent = lowest coefficient
For the balanced equation $2A + B \rightarrow A_2B$, students pick B as the limiting reagent without using the *amounts* of the reactants.

2. Limiting reagent = least amount
Students use the amount of each reactant (e.g., A = 3 moles, B = 2 moles) but ignore the *molar ratio* in the balanced equation; i.e., they pick B as the limiting reagent.

TL: the idea below comes from the NDSL Science literacy map
http://strandmaps.nsdl.org/?id=SMS-MAP-1349
Middle- and high-school student thinking about chemical change tends to be dominated by the obvious features of the change. For example, some students think that when something is burned in a closed container, it will weigh more because they see the smoke that was produced. Further, many students do not view chemical changes as interactions. They do not understand that substances can be formed by the recombination of atoms in the original substances. Rather, they see chemical change as the result of a separate change in the original substance, or changes, each one separate, in several original substances. For example, some students see the smoke formed when wood burns as having been driven out of the wood by the flame.

Basic Sim Operation

Students use slider to enter reactants into "before reaction" box - can see all reactants in the box
Based on chemical equation, products and/or leftovers appear in "after reaction" box
Rationale: important to show before & after at same time, so students can see that number of atoms is conserved

Students can also vary reactant coefficients in chemical equation (except in 3rd tab) - this changes what appears in "after reaction" box
Rationale: gives students immediate feedback on the effect of molar ratio

Each tab operates in a similar manner, but with different representations (and allowances)
Rationale: students familiar with controls when they reach the more abstract tabs, can focus more on concept; scaffolds

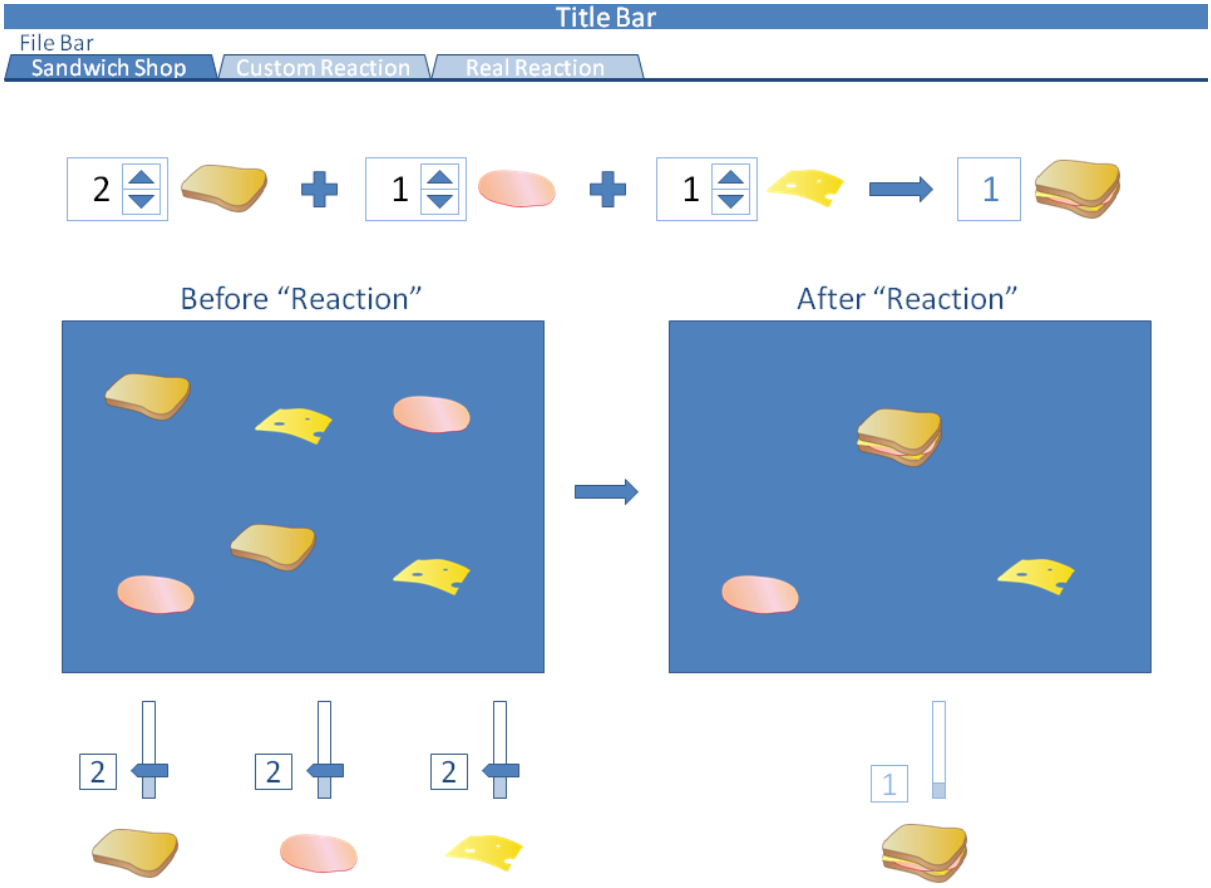
Order of tabs:
1. "Sandwich Shop" = real-world analogy
2. "Custom Reaction" = generic microscopic representation
3. "Real Reaction" = real-world, relevant chemical equations with symbolic representation

1st tab: "Sandwich Shop" aka real-world analogy

Students can vary the coefficients of the sandwich "equation" to make different sandwiches
Analogy = sandwich recipe is like chemical equation; can have leftover ingredients due to "limiting reagents"

Note for Teaching Tips:
The analogy relates the *amount* of food to the number of *molecules* (or moles) of reactants – not to the number of *grams* of reactants!

Example of case with limiting reagent:



Due to finite size of "before reaction" box, need to set an upper limit on number of "reactants" that students can add to box.
Range for slider: 0-10? (Same for each tab)

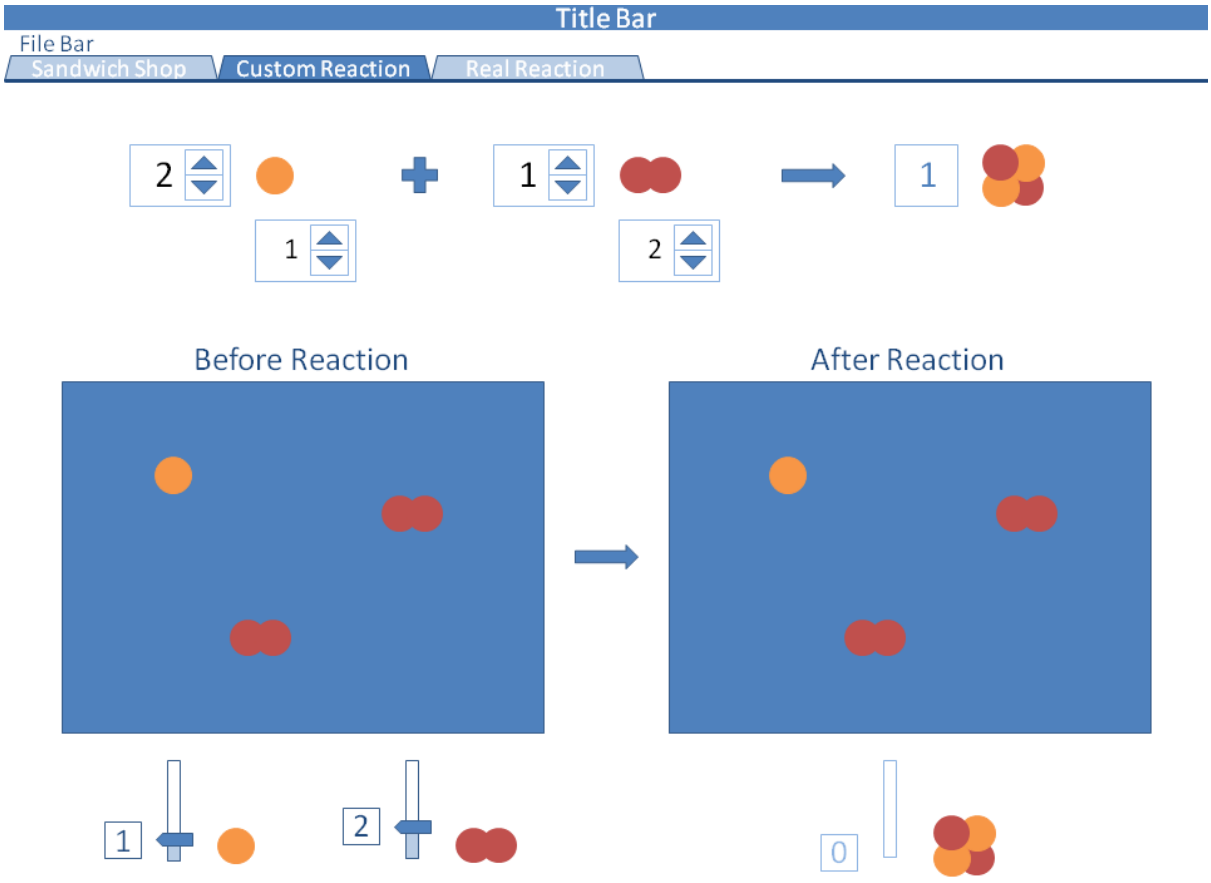
Size of sandwich will vary with coefficients - need to limit range of coefficients.
Range for spinner: 0-3? (Same for each tab, except 3rd)
Note: all coefficients can go to zero. In the case of no reactants, no products will show in the equation.

2nd tab: "Custom Reaction" with microscopic representation

This tab was dropped because this representation didn't really add anything. -Chris 11/17/09 5:54 PM

Students can vary both:
1) coefficients of chemical equation
2) identity of reactants (aka subscripts)
Rationale: gives students immediate feedback on difference between coefficient and subscript

Example of case where reaction cannot occur:



Can show motion in sim; but should we? Answer: NO!
Reasoning is because the sim is to emphasize the before and after snapshot to allow students to easily compare how things add up to determine what is left over. Motion would make it much more difficult to follow and see that the number of "atoms" is conserved. -Katherine Perkins 9/28/09 10:57 AM

Size (and shape) of product will vary with subscript - need to set a limit on subscript
KP: let's just do 1-3 ... 0 doesn't make sense and 4 seems excessive

Why are we using spinners to change coefficient/subscripts and sliders for changing quantities in the boxes? Why aren't we consistently using the same control for the same purposes (ie, to change value)? I suggest using spinners everywhere. - cmalley@pixelzoom.com 9/23/09 11:43 AM

KL: important to show amount in box *visually* (as well as numerically)
CM: it would be better to create our own histogram widget, a vertical bar (much like a slider's track) that fills up with a color based on the value (sort of like a rectangular thermometer). The widget under the Reactants box would have a handle (similar to a slider knob) that lets you increase/decrease the histogram value. The widget under the Products box would look the same, but without the knob.

Suggestion: Position the subscript values where they would normally be in an equation; that is, slightly (but not fully) below and to the right of the "balls". Imho, their current position doesn't clearly say "I am a subscript". -cmalley@pixelzoom.com 9/23/09 11:53 AM
KL: good idea, but subscript hard to define using ball representation

Balls will look more 3D - aka, spheres
CM: can implement using SphericalNode from PhET common code

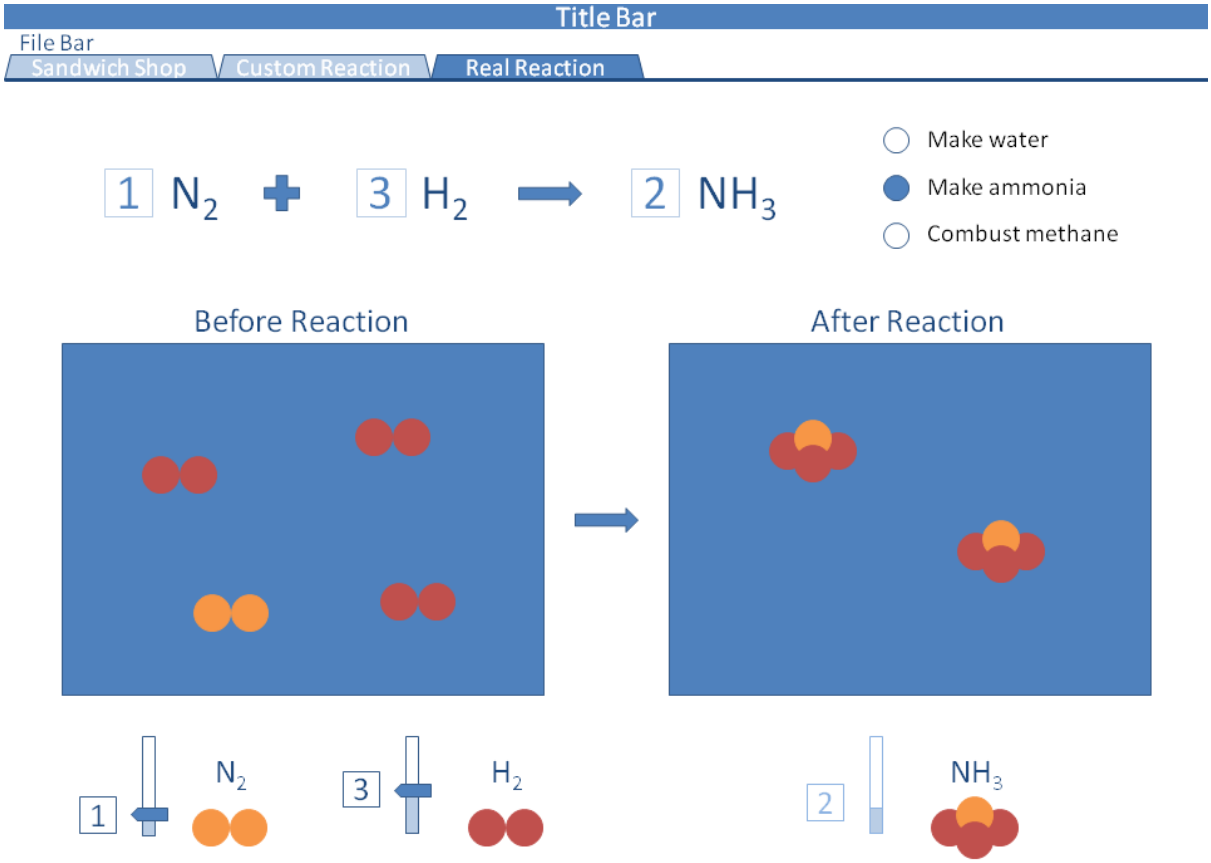
3rd tab: "Real Reaction" with symbolic representation

Students can choose among 3 *real* reactions; cannot change chemical equation

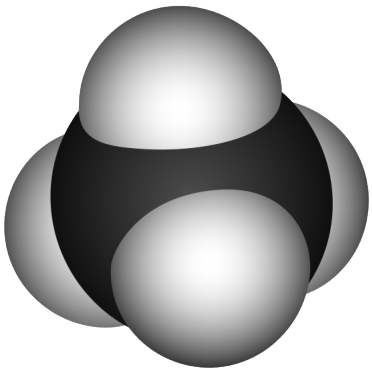
Chemical equations:
1. Make water: $2H_2 + O_2 \rightarrow 2H_2O$
2. Make ammonia: $N_2 + 3H_2 \rightarrow 2NH_3$
3. Combust methane: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$; NEW: 2 products!

Are 3 choices sufficient? If you think you'll want to have more, use a combo box (aka, option menu) instead of radio buttons. -cmalley@pixelzoom.com 9/23/09 12:23 PM
KL: good question for advisory board

Example of case where both reactants are fully consumed:



Will use *real* (or at least more realistic) molecular images - i.e., balls not all same size, correct geometry
CM: must implement using image files
Example of space-filling model of CH_4 from Wikipedia:



Game tab

2 types of challenges:
A. given the reactant quantities, guess the product and leftover quantities
B. given the product and leftover quantities, guess the reactant quantities (more difficult than A.)

2 levels of difficulty:
1. reactions with 1 product, mostly challenges of type A.

2. reactions with 2 products, mostly challenges of type B.

Scoring:
- shows # correct guesses, # incorrect guesses
- no points system

User interface:
- Looks very much like the "Real Reaction" tab.
- Score and level controls appear at bottom of play area.
- Reactions are automatically selected based on level control setting.
- Reaction appears at the top, with an indication of how many challenges have been generated (eg, "Reaction 8")
- Editable spinners appear below the box (Before or After) that the user will be guessing.
- Instructions and buttons appear in the box above the editable spinners.

Not included:
Timer: The goal is accuracy and understanding, not speed.

We'll describe this interface via a user scenario, which will reference screen mockups. The scenario is is for a type-A challenge; the scenario for type B-challenges is similar.

Presenting a challenge to the user (see Figure "Game 1")
1. A reaction and challenge type are automatically selected based on the Level control setting. Assuming that a type-A challenge is generated...
2. The Before box shows randomly-generated quantities of reactants. Reactant images are in the box, and below the box is a read-only histogram display showing reactant quantity values.
3. The After box has spinners below it, all set to zero. Instructions appear in the After box.

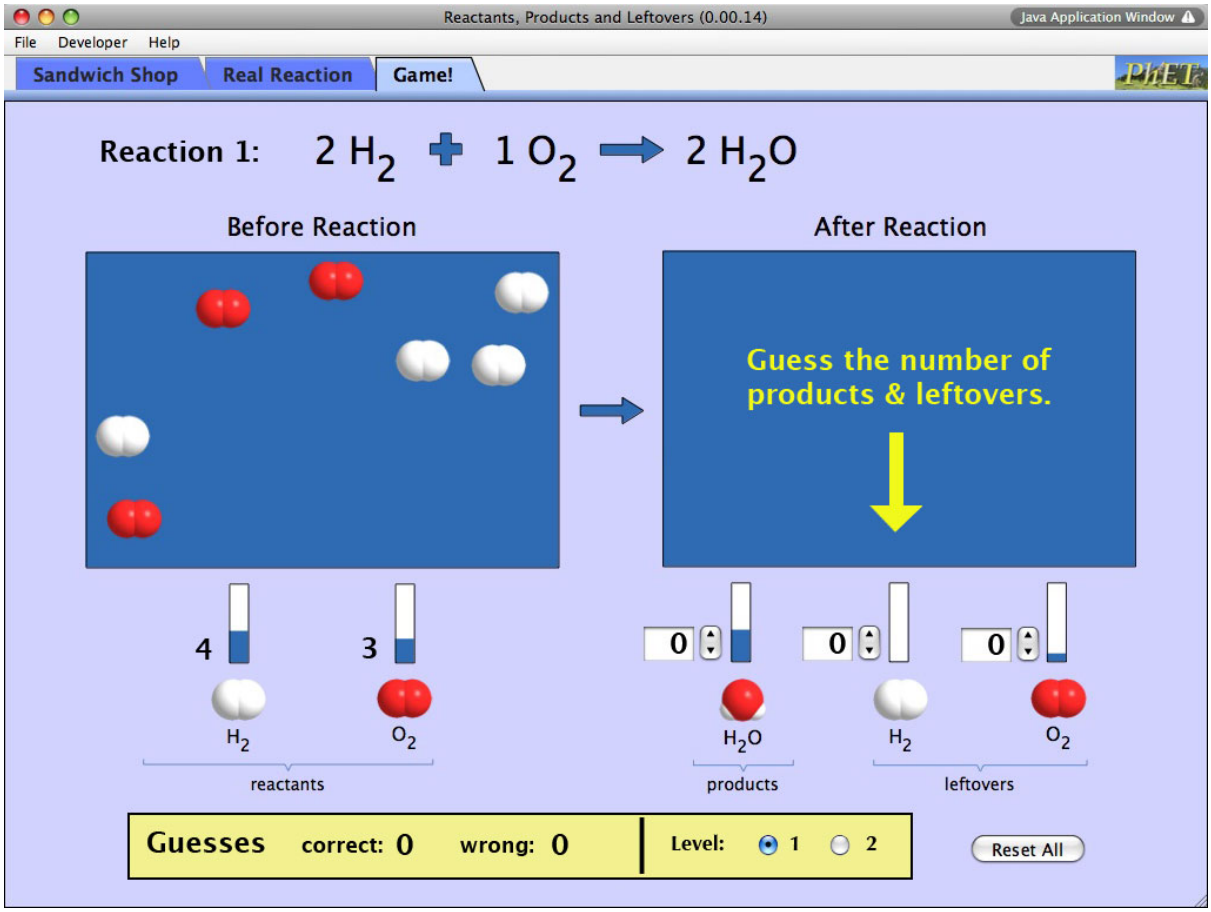


Figure "Game 1" - starting a challenge

Making a guess (see Figure "Game 2")
1. When a value is entered into any of the spinners, the instructions disappear, and images appear to match the quantity entered. A button labeled "Check my guess" appears at the bottom center of the box. This button and the images in the box will not overlap.
2. The user enters quantity values using the spinners. They can change values as often as they want.
3. When the user is done entering values, they press the "Check My Guess" button.

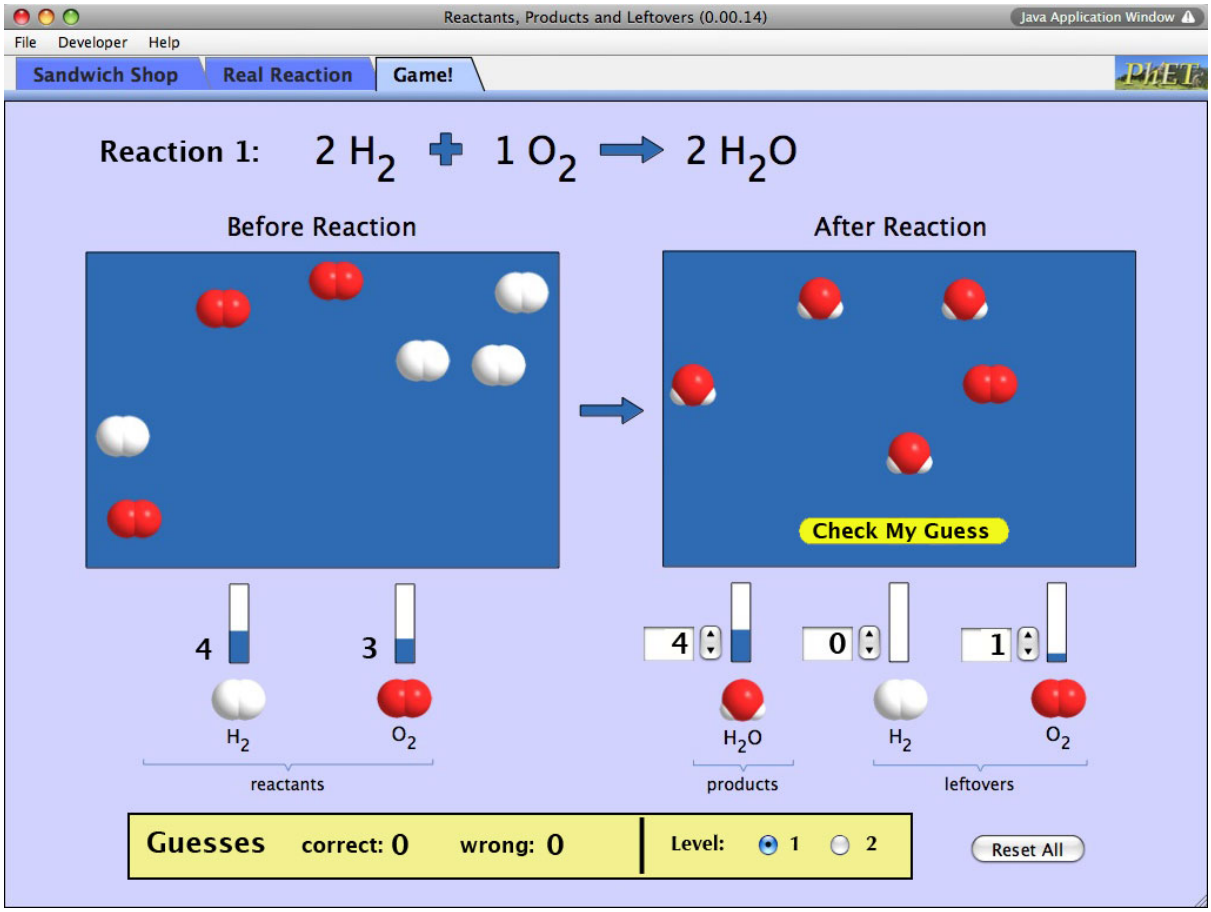


Figure "Game 2" - ready to check a guess

Correct guess (see Figure "Game 3")
1. The quantities become uneditable.
2. "Correct!" is superimposed on the top of the After box contents.
3. The number of correct guesses is incremented by 1.
4. The "Check my guess" button is replaced by a "Next Reaction" button. This allows the user to spend some time looking at what they did before going to the next challenge.

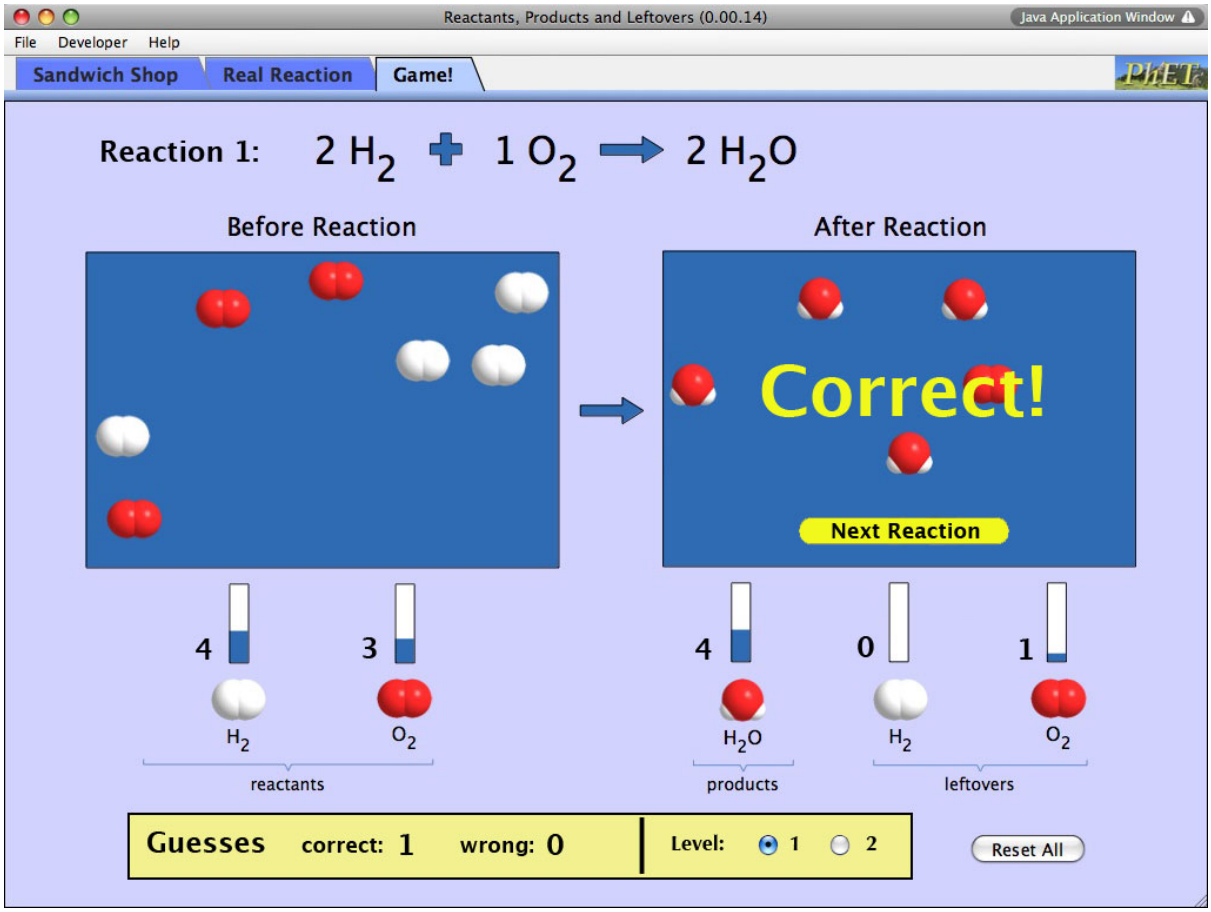


Figure "Game 3" - correct guess

Wrong guess (see Figure "Game 4")
1. The quantities become uneditable.
2. "Wrong" is superimposed on the top of the After box contents.
3. The number of incorrect guesses increments by 1.
4. The "Check my guess" button is replace by 2 buttons: "Try again" or "Skip".
5. Pressing "Try again" makes the "Check my guess button" comes back and they can try again.
6. Pressing "Skip" generates a new challenge.

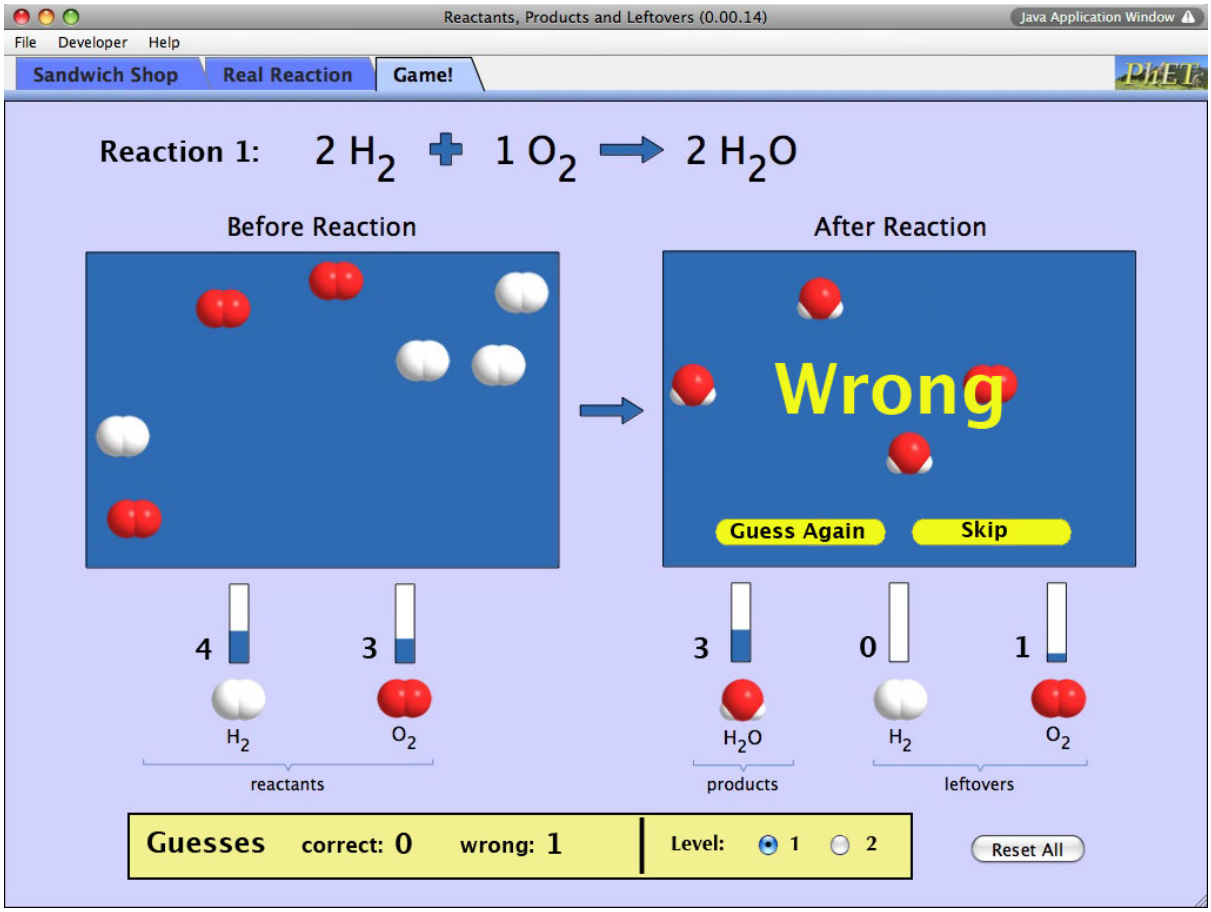


Figure "Game 4" - wrong guess

Misc:
- If the Level control is changed at any point, the current challenge is skipped and a new challenge is generated that corresponds to the new Level setting. This does not affect the score.
- Pressing "Reset All" resets the game, clearing the score.

Open issues:

1. Need a name for this game.

2. As designed, the game has no "end". It was proposed that a "game" should have a finite number of challenges (let's say 10), and after 10 we start a "new game". If we want to take this approach, then the following issues need to be resolved:
(a) What do we do to signify that the game is over? Open a dialog with a summary of how they did? What new information to we show them about how they did that's no already displayed in the play area?
(b) After a game is over, what choices does the user have? Start a new game? Don't start a new game? If they don't start a new game, what does that mean and what does the interface do?
(c) For a correct guess on the 10th challenge, it makes no sense to have a "Next Reaction" button. But we still want them to be able to have time to reflect on their answer. How do we start a new game? Does pressing "Next Reaction" automatically start a new game? (confusing) Is the "Next Reaction" button replaced with a "New Game" button for the 10th challenge? (confusing)
(d) For an incorrect guess on the 10th challenge, what happens if the user presses the "Skip" button? Does it automatically start a new game? (confusing) Is the Skip button replaced with a "New Game" button for the 10th challenge? (confusing)
(e) Create user scenarios for related to ending and starting a game.

Online Resources

1. $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$
http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/limitr15.swf
Animation of gas molecules with superfluous male narrator. **By far the most popular.**

2. $N_2(g) + O_2(g) \rightarrow 2NO(g)$
http://www.deciencias.net/proyectos/0cientificos/Tiger/paginas/LimitingReactant.html
Animation of gas molecules. Reaction very slow.

3. $C_xH_y(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/stoichiometry/stoic_select_both.html
Simulation with some feedback to user, but non-intuitive interface design. Reaction hard to follow, and not very clear how sim relates to concept.

4. $2NH_3 + CO_2 \rightarrow (NH_2)_2CO + H_2O$
http://ir.chem.cmu.edu/applets/stoich.php
Interactive bar graph of reactant and product amounts, but only shows one case.

5. $Zn(s) + 2HCl(l) \rightarrow ZnCl_2(l) + H_2(g)$

http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/015_LIMITREAGENT.MOV
Movie with female narrator. Very traditional, but does show states other than gas.

6. Bl + 2Nt → BlNt2
http://faculty.washington.edu/dwoodman/LimitingReagent/dswmedia/limitingReagent.html
Tutorial uses nuts ("nuttigen") and bolts ("boltium") to illustrate concept. Little interaction or animation, mostly male voice instruction.

7. 2 bread + 1 cheese + 1 meat → 1 sandwich
http://www.gautamsaha.com/file.php/7/limiting_reactant.swf
Click and drag to make a sandwich. Loud voice says "nice" on each drag. Nice interface, but error in function.

References

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4. Rojas de Astudillo, L.; Niaz, M. *J. Sci. Educ. Tech.* **1996**, *5*, 131-140.
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7. Haim, L.; Corton, E.; Kocmur, S.; Galagovsky, L. *J. Chem. Educ.* **2003**, *80*, 1021-1022.
Title: Learning Stoichiometry with Hamburger Sandwiches

8. Wood, C.; Breyfogle, B. *J. Chem. Educ.* **2006**, *83*, 741-748.
Title: Interactive Demonstrations for Mole Ratios and Limiting Reagents

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Research Ideas

1. Interview: Can remove 2nd "microscopic" tab and see if students can still understand

analogy

2. Recitation: General chemistry course at CU uses recitation material that follows the same sequence: 1. analogy, 2. microscopic representation; 3. traditional symbolic problem; can see if simulation (vs. written instruction) promotes more engagement, better learning

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Meetings

9/4/09
Kathy, Jack, Kelly
Let's do limiting reagent sim!

9/15/09
Kathy, Noah P, Robert, Kelly
Need to make sim more interactive - change click-and-drag to sliders, pull-down menu to spinners

9/17/09 part 1
Trish, Kelly
Need to refine learning goals

9/17/09 part 2
Kathy, Trish, Noah P, Kelly
Sim needs new name - concept larger than limiting reagent
Will students fully explore 1st tab? Need to interview.

9/22/09
Kathy, Noah P, Robert, Kelly
No need for motion in 2nd & 3rd tabs

9/25/09
Kelly, Noah P, Chris, (Kathy briefly)
Chris' comments, emailed to the team after the meeting:

Choose one representation for spinners. Best would be to use an actual spinner, so you can be convinced that it really works in the formula interface. Next best would be to use the representation in the design doc that has up-&-down arrows.

I asked why we're using sliders instead of spinners to set quantities in the boxes. The answer is that the sliders are supposed to serve as both a value control and a sort of histogram representation. There are several problems here. First, I think it's a bad idea to use a permanently-disabled slider for this purpose below the Products box, users will always be wondering when it will become enabled and it's a bad use of this control. Second, I don't recommend trying to overload Swing sliders as histograms, it will be a nightmare to make them line up. It would be better to create our own histogram widget, a vertical bar (much like a slider's track) that fills up with a color based on the value (sort of like a rectangular thermometer). The widget under the Reactants box would have a handle (similar to a slider knob) that lets you increase/decrease the histogram value. The widget under the Products box would look the same, but without the knob. If the "histogram widget" idea doesn't work for you, then consider separating the value control from the histogram representation (Kelly, this is what we started to sketch out on the blackboard.)

Having radio buttons for selecting coefficients or subscripts creates a usability problem. If (like Kathy) you intend to set all of your coefficients first, then all of your subscripts, you have to click one radio button. But (if like me, and I suspect many others) you work left-to-right and configure each term, then you have to click radio buttons many times. It's not worth arguing over which way of using the interface is correct; the point is that both ways are equally valid (and possible!), and this user interface makes one of those approaches a royal pain. Also consider the accessibility issues for disabled users. Kathy mentioned that removing these radio buttons would make the interface more complicated, but I don't see how that is the case; both the coefficient and subscript controls are always visible, the radio buttons simply control which ones are editable. So I think we should ditch the radio buttons, and allow simultaneous editing of coefficients and subscripts.

The boxes show reactants and products. Is there any need to represent "left overs"? For example, suppose my formula for a sandwich is "2 bread + 1 cheese + 1 turkey". I put 2 bread, 1 cheese, and 1 turkey in my "Reactants" box, and I see 1 sandwich in my "Products" box. Now suppose I increase cheese to 3. I have 2 left-over pieces of cheese, but those left-overs aren't shown or represented anywhere. In fact, I can change the quantity of cheese all day long, and (other than the cheese quantity control) nothing in the sim will change. I don't know if this is an issue, but I thought I should bring it up.
Kelly pointed out that left-overs do appear in the Products box, as shown in the sandwich screenshot. And I see left-overs in other screenshots, too. Do we need to include the left-overs in the histogram below the Products box? - cmalley@pixelzoom.com 9/24/09 6:28 PM

9/28/09
Kathy, Kelly
Will NOT show leftovers in histogram below "after reaction" box - may cause visual overload