

# Balancing Chemical Equations

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Balancing Equations

Balance the Equation

## Balancing Chemical Equations

Balance Chemical Equations

Balancing Chemistry

Balancing Act: Chemistry!

Chemistry Balancing Act

## PhET Sim Design Document

*Design team:*

Kelly Lancaster (lead)

Chris Malley (developer)

Trish Loeblein

Emily Moore

Robert Parson

Kathy Perkins

**Public URL:** [https://docs.google.com/document/pub?id=1UgvPv\\_mPXxiDtAduYYe3KUIReFN1OcQBii5sA6\\_eSxA](https://docs.google.com/document/pub?id=1UgvPv_mPXxiDtAduYYe3KUIReFN1OcQBii5sA6_eSxA)

### Abstract:

What does it mean for an equation to be balanced? How do you know if an equation is balanced? What can you change to balance an equation? Play a game to test your ideas.

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## Learning Goals

Students can balance chemical equations, but:

- do not understand the meaning of symbols  
e.g., 3 A<sub>2</sub> is given by: OOOOOO (where A = O) rather than: OO OO OO
- think chemical reactions are additive  
e.g., A<sub>2</sub> + B<sub>2</sub> → 2 AB is given by: OO + **OO** → OOOO (where B = **O**) rather than:  
OO + **OO** → **OO** + OO
- change subscripts when balancing equations

After using the sim, students will be able to:

- balance a chemical equation
- recognize that atoms are conserved in a chemical reaction
- describe the difference between coefficients (the 3 in 3 A<sub>2</sub>) and subscripts (the 2 in 3 A<sub>2</sub>) in a chemical equation
- translate from symbolic to molecular representations of matter

## Teaching Tips

- We expect least coefficients, but do not specify in the sim

The sim does NOT address:

- the concept of moles
- stoichiometric conversions (but the teacher can build such an activity around the sim)
- the misconception that matter is static

## Mockup

### First Tab: Balance Equation

#### Before Balance

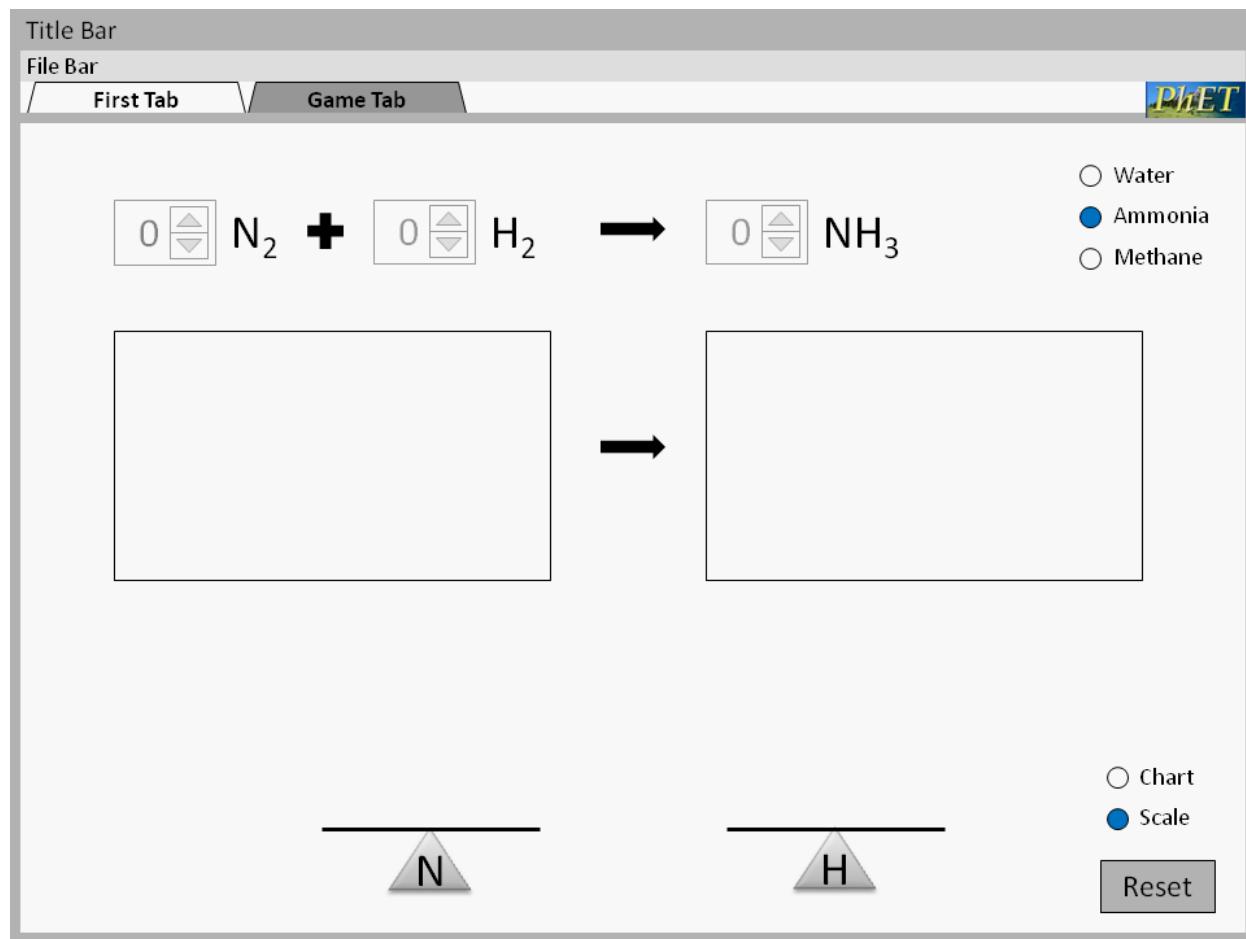
The student can choose among 3 (unbalanced) reactions:

- 1 N<sub>2</sub> + 3 H<sub>2</sub> → 2 NH<sub>3</sub> (make ammonia)
- 2 H<sub>2</sub>O → 2 H<sub>2</sub> + 1 O<sub>2</sub> (separate water)

- $1 \text{ CH}_4 + 2 \text{ O}_2 \rightarrow 1 \text{ CO}_2 + 2 \text{ H}_2\text{O}$  (combust methane)

The reactions are the same as those used in the 2nd tab of RPAL. The default reaction is to make water. UPDATE: we reversed the water reaction, so the default is make ammonia.

The student can balance the equation by using spinners to change the coefficients. The default spinner value is 0.

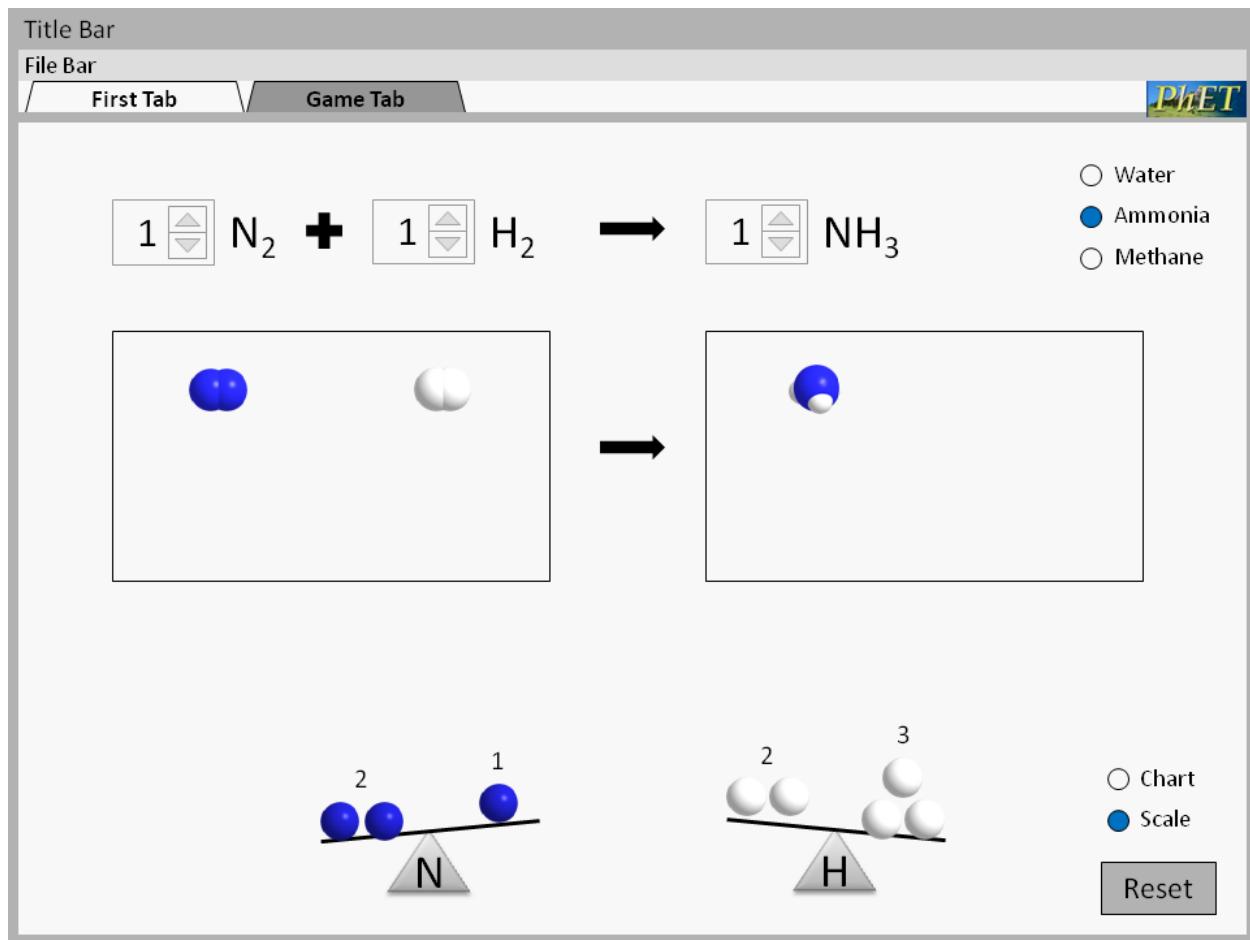


### During Balance

As soon as the student enters a value for a coefficient, the molecule appears in the box below the symbol. The molecules stack down, and the max value for the spinner is 3.

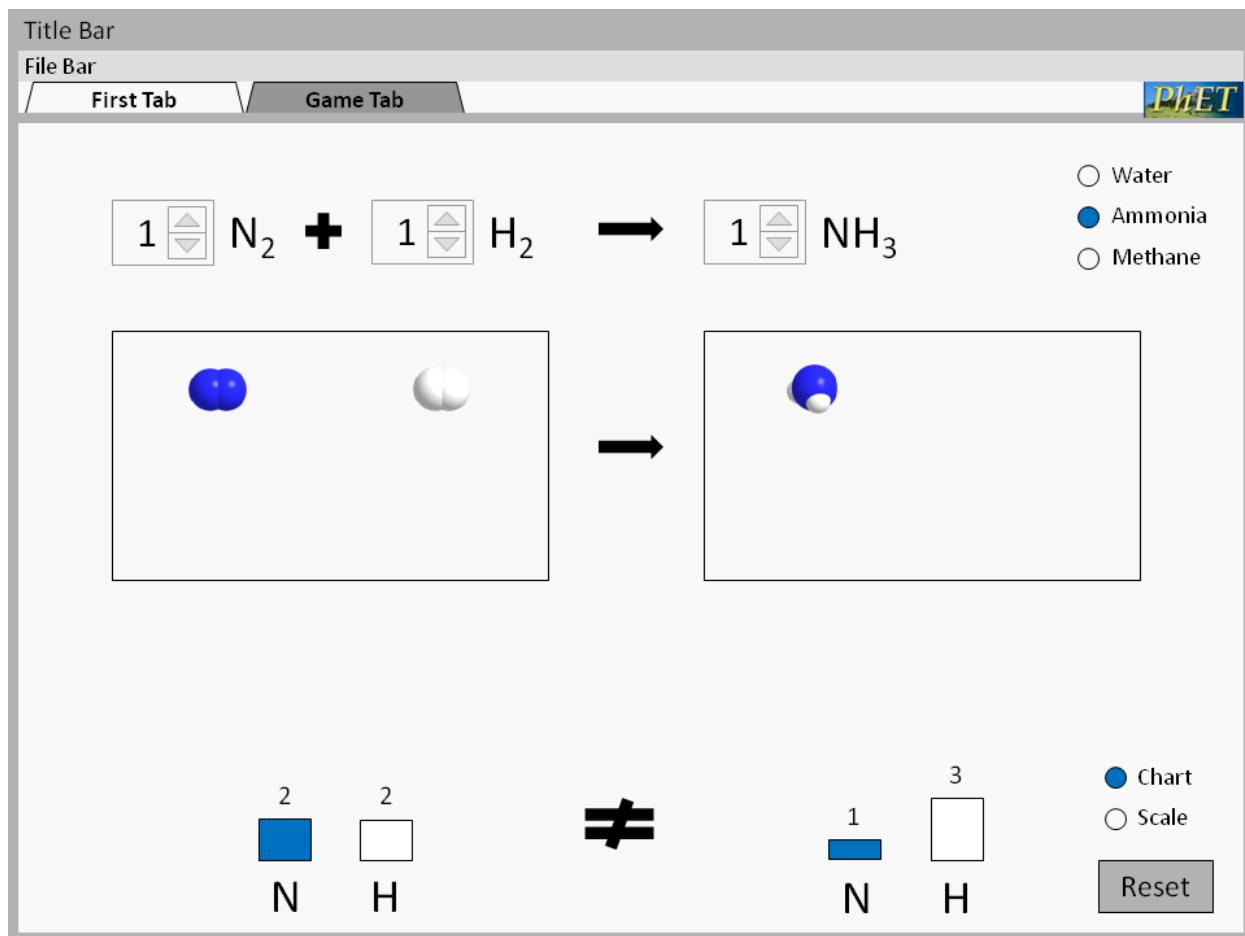
The student can also choose between two representations of balance. If the scale view is selected, the number of atoms on each side of the equation is given for each element. The max number of scales is 3, and the max number of atoms on one side of the scale is 12 ( $3 \text{ CH}_4 = 12 \text{ H atoms}$ ).

*Scale view:*



If the chart view is selected, the total number of atoms on each side of the equation is given. The max number of bars is 3, and the max value of a single bar is 12. The arrow in the chemical equation and the equal sign in the chart view are always aligned.

*Chart view:*



KP: Maybe in chart-view show a blue ball below the N and a white ball below the H.

KL: Tested with 4 chem students and 1 chem TA, all thought both views were valuable. It did seem like the more chemistry experience they had, the more they preferred the scales. One student thought this would be better as a means to check answer, otherwise too easy if there while balancing equation.

CM: I know you're trying to indicate "balance", but the use of scales makes me think "mass" or "weight measurement", which isn't at all relevant. How many students will have this same problem?

KL: Actually, mass is relevant (conservation of matter). All 4 chem students liked the idea of scales. The chem TA loved the balances, said it was intuitive.

In chart view, reactants vs. products (R vs. P); in scale view, atoms vs. atoms (RP vs. RP)

CM: When "Chart" is selected, you're comparing things on the left and right sides of an equals (or not equals sign), similar to the equation. When you switch to "Scale" you have to look on the left and right of each scale, and the scales are horizontally arranged. It would be better if the scales were vertically stacked, so that you still had the left-and-right relationship, but there's no room to vertically stack scales. As presented, I think the organization of the scales

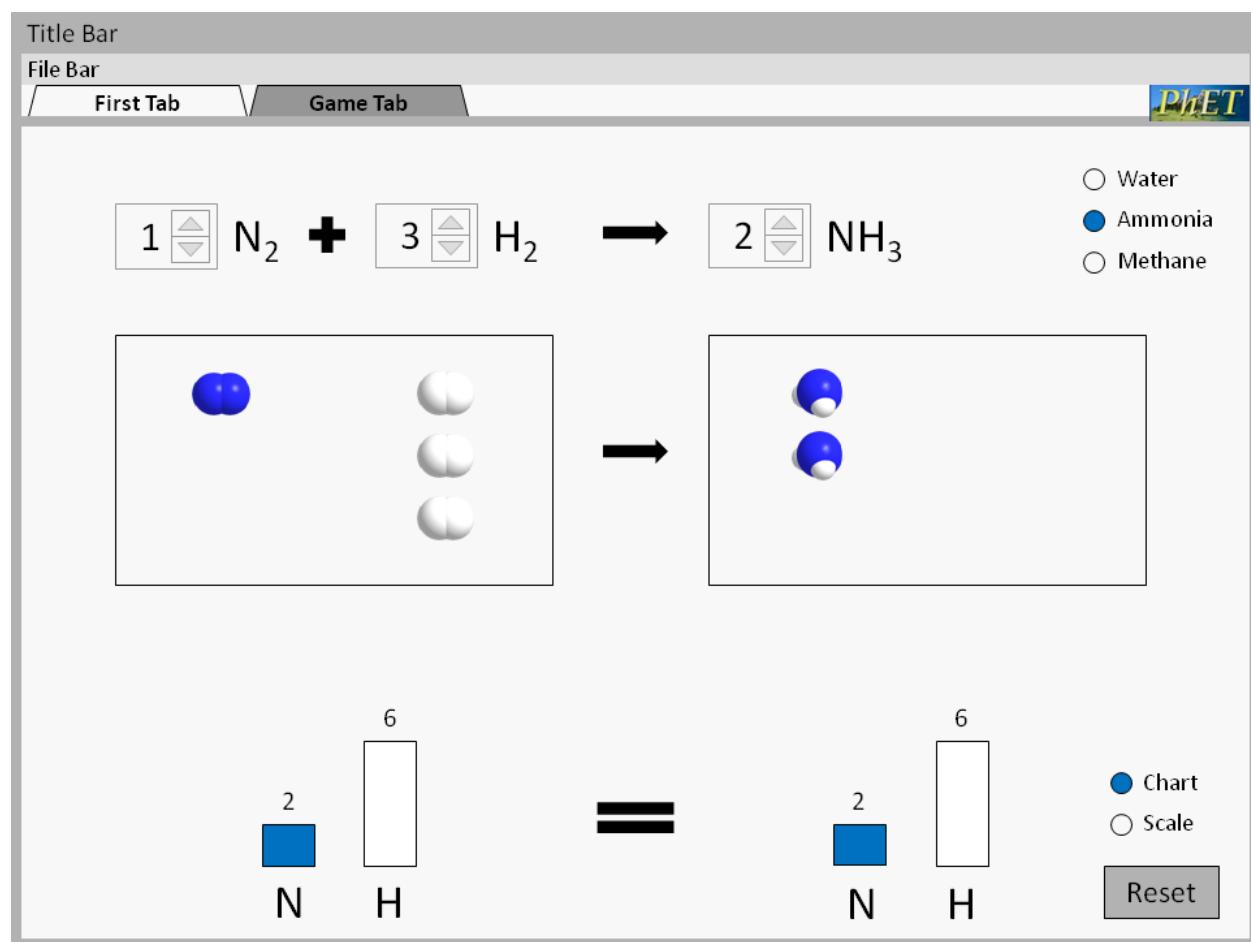
representation is going to cause confusion. When there are 2 scales, I think that students will try to connect the left scale to the left side of the equation, and the right scale to the right side of the equation.

KL: All 4 chem students understood what the scales represent (when shown a static picture). Will watch for any confusion in interviews.

LJ: I like being able to switch between the chart and balance views, but I have concerns about the balance view. In the ammonia synthesis example, the N balance is on the reactant side and the H balance is on the product side. Either the two sides of the balance should be labeled or they should be one above the other. Also, why call a balance a scale? That would have raised the hairs on my old analytical prof's head.

### After Balance

After the student balances an equation, they can choose a new reaction. After they explore all 3 equations, they can move on to the game tab.



KP: Show smiley face and “Balanced” when achieve balance. KL: A smiley face seems a bit much here. The point is not to just balance the equation, but to understand what it *means* for an

equation to be balanced. Plus, a smiley face is associated with a correct answer in the game. We want students to *explore* here, not just get to the “correct” answer and stop.

KP: Menu item .. hide molecular view.

KP: Add radio buttons: Chart, Scale, None.

UPDATE: all signs turn yellow when balanced

## **Second Tab: Game**

(See the Game tab in the RPAL sim.) The game will give students practice at balancing equations.

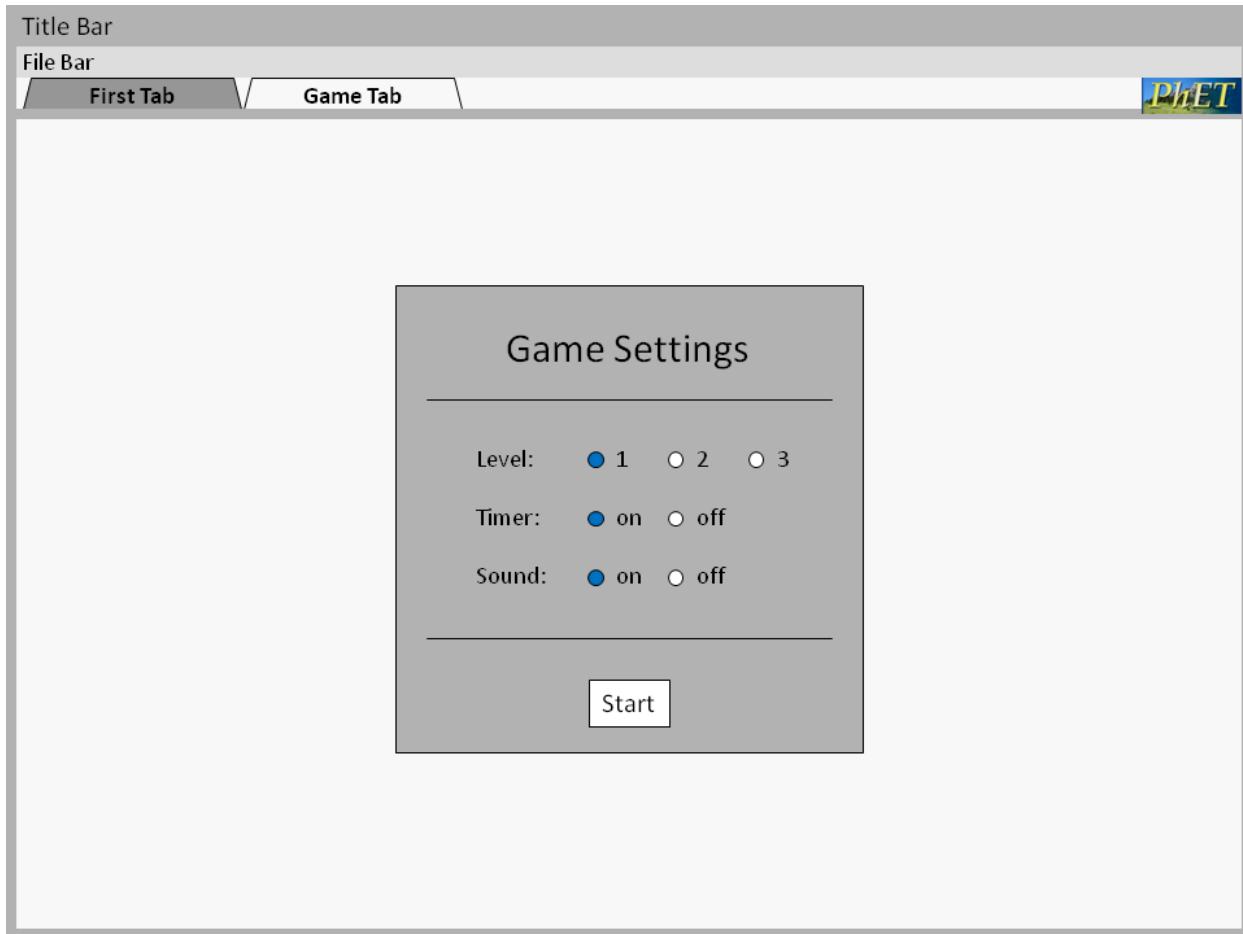
### Before Game

The tab opens in “Game Settings” mode; here, the student can select the game level (1, 2 or 3), can elect to turn OFF the timer/sound (both are ON by default), and can click the “Start” button to begin the game.

We need to determine the 3 levels of difficulty!

Do we want to let students hide the molecules below the equation, as we did in RPAL? We could add radio buttons in the Game Settings dialog for Hide: “Nothing” or “Molecules”.

UPDATE: this feature is in the Options menu.



### During Game

Each level will consist of 5 problems. When a student enters the correct answer, they will see a smiley-face, hear a pleasant sound, and get points added to their score. When a student enters the wrong answer, they will see a frowny-face, hear an unpleasant sound, and get NO points added to their score. Below is a flow-chart:

Enter answer, click "Check"

If correct: get 2 points, click "Next"

If wrong: get 0 points, click "Try Again"

    Enter NEW answer, click "Check"

        If correct: get 1 point, click "Next"

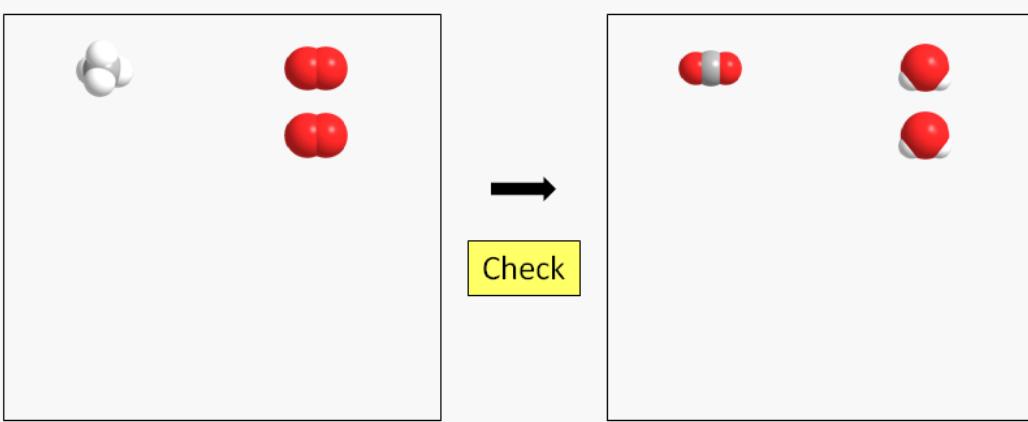
        If wrong: get 0 points, click "Show Answer", then click "Next"

A box at the bottom of the play area will keep track of the current level, the score, and the time (the clock starts at 0:00 and counts UP). The box will also include a "Start Over" button, which will take the student back to the "Game Settings" screen.

The max value for the spinner is now 10. UPDATE: 7.

Title Bar  
File Bar  
First Tab Game Tab PlEET

Reaction 1 of 5: Balance the equation

$$1 \begin{array}{c} \triangle \\ \square \\ \triangledown \end{array} \text{CH}_4 + 2 \begin{array}{c} \triangle \\ \square \\ \triangledown \end{array} \text{O}_2 \rightarrow 1 \begin{array}{c} \triangle \\ \square \\ \triangledown \end{array} \text{CO}_2 + 2 \begin{array}{c} \triangle \\ \square \\ \triangledown \end{array} \text{H}_2\text{O}$$


**Check**

Level: 1 Score: 0 Time: 1:00 Start Over

KP: Add scale at level 1 and 2?

TL: Ask MS teachers about having scales in with game at the lowest level

Group: Ideas that were discussed .... show different options for representations in the game ... possibly have radio buttons that let you choose representation - charts, molecular view, scales. Teacher still can hide representations.

KL: How is this any different from the first tab? The chart and scale views give away the correct answer! There would be no point to "Check" your answer, and students would never learn from mistakes. If we must do this, need space for a max of 60 atoms.

Group: Can be off-scale if more than 20 atoms

UPDATE: in pop-up window

What if the equation is balanced, but not with the lowest coefficients?

For example:  $2 \text{A} + 2 \text{B} \rightarrow 2 \text{AB}$

KP: ask advisory board what feedback to give students

Group: too many big words to say "lowest coefficients" in game question - give feedback during check answer: frowny face with "X Balanced", straight face with "V Balanced, X Simplified" or a smiley face.

## After Game

After the student has gone through all 5 problems, a “Game Over” box will appear with a summary of the level, the score, and the time. The student can click the “New Game” button to return to the “Game Settings” dialogue and try a new level.



## **Chemical Reactions**

Same as RPAL (but not limited to 2 reactants)

**Need to assign level of difficulty!** Equations in Level 3 are the most difficult (for KL) to balance. Otherwise, hard to say - we should ask students! KL made a worksheet of unbalanced equations to give students.

CM on difficulty: larger subscripts, more atom types

LJ: In your Level 1 list of reactions, how about including a few decomposition reactions, with one reactant and two products?

KL: We are recycling the reactions from RPAL, which had to have 2 reactants. But we can

reverse some of the reactions in level 1, if you think that would help.

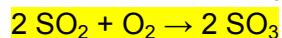
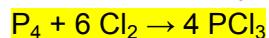
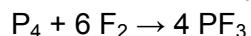
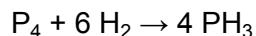
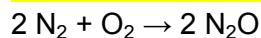
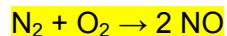
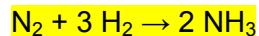
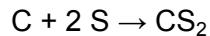
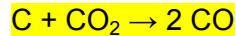
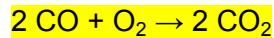
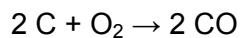
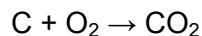
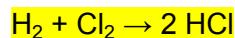
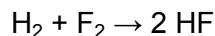
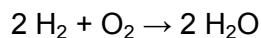
LJ: In some research studies it was found that if students see only certain types of systems they have a harder time extending their learning to other types of systems. So if it isn't too difficult to do, there is a pedagogical advantage, even if it is only in part of the program.

### Level 1 (one product)

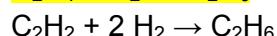
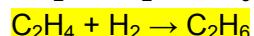
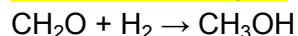
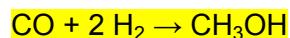
The highlighted equations are reversed in the game. Thus, there are 10 synthesis reactions and 11 decomposition reactions (reverse the ones shown in yellow), for a total of 21 reactions.

For each game, choose 5 with no duplicates. Do not allow equations with big molecules to be first.

#### **Small molecules**

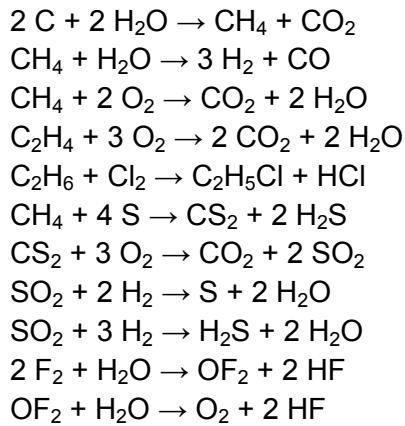


#### **Big molecules** (more than 5 atoms per molecule)



### Level 2 (two products)

For each game, choose 5 with no duplicates.



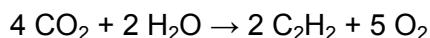
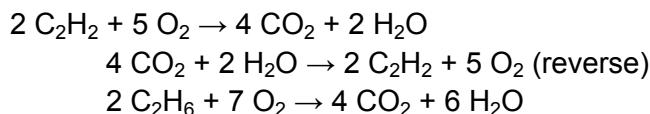
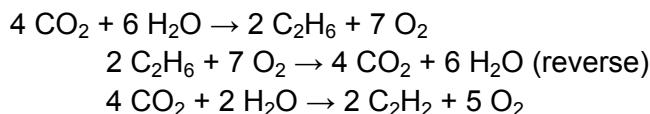
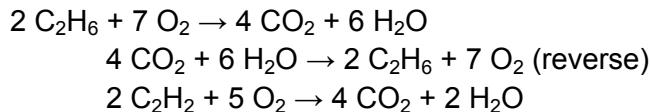
### Level 3 (hard to balance)

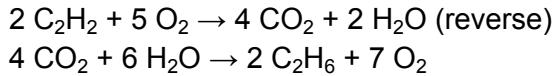
Level-3 uses a more complicated selection strategy. For each game, choose 5 equations from a pool of 14 equations, consisting of 7 equations and their reverse equations. Inclusion of an equation in the game causes exclusion of zero or more other equations from the game.

Below is the list of 14 equations and their exclusions. The exclusions for each equation are shown indented below the equation. There are 5 general heuristics contained in these exclusions:

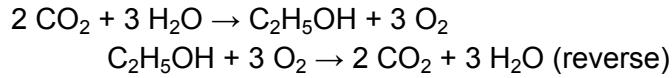
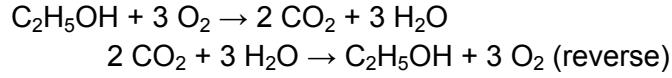
- (1) don't include the forward and reverse versions of the same equation
- (2) include at most 1 equation that has 4 NH<sub>3</sub> as a reactant and 6 H<sub>2</sub>O as a product
- (3) include at most 1 equation that has 4 NH<sub>3</sub> as a product and 6 H<sub>2</sub>O as a reactant
- (4) include at most 1 equation that has C<sub>x</sub>H<sub>x</sub> as a reactant
- (5) include at most 1 equation that has C<sub>x</sub>H<sub>x</sub> as a product

#### C<sub>2</sub>H<sub>x</sub>:

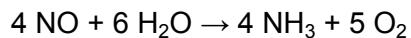
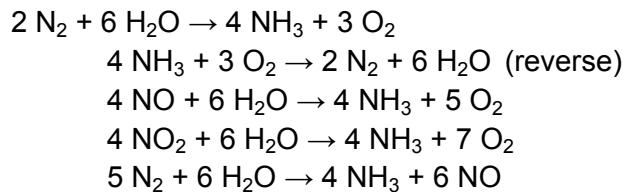
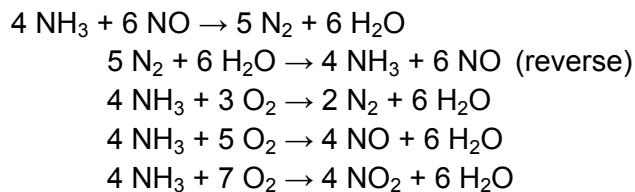
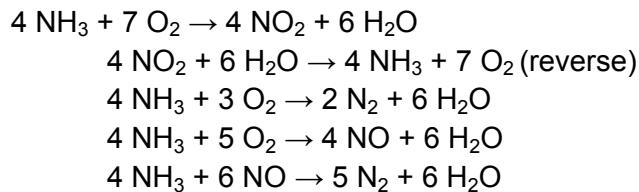
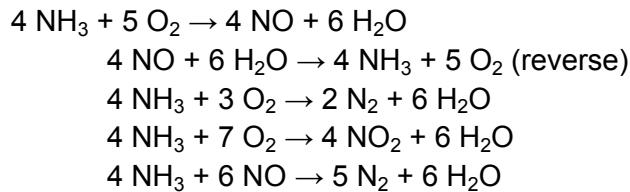
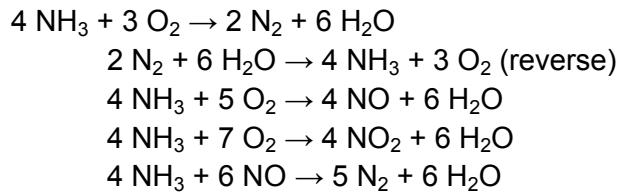


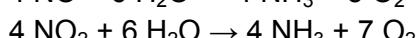
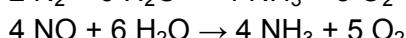
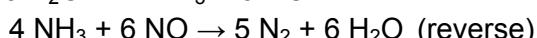
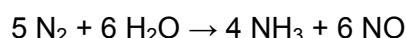
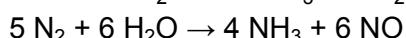
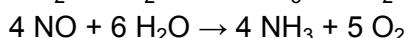
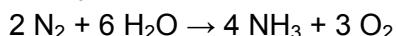
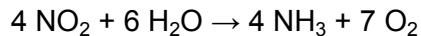
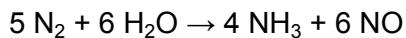
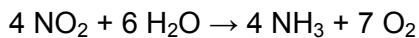
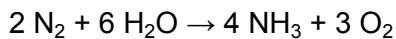


**C<sub>2</sub>H<sub>5</sub>OH:**



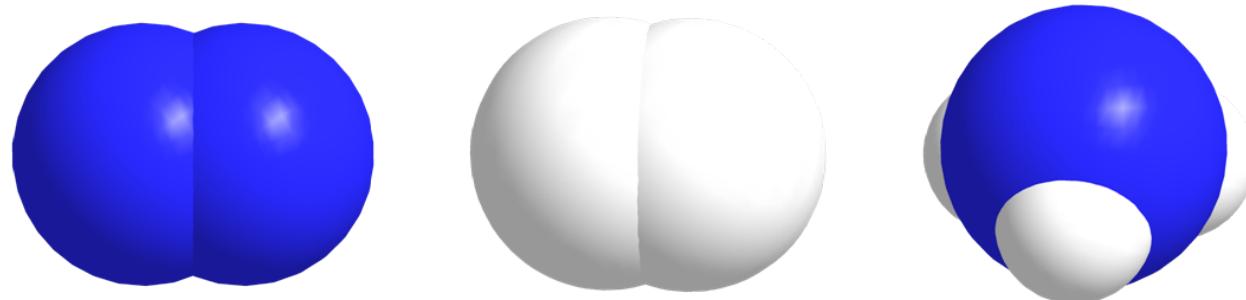
**4 NH<sub>3</sub>, 6 H<sub>2</sub>O:**





### Images

Each image is about the same size, so the *atoms* in different images are not always the same size. Thus, the H atom in H<sub>2</sub> looks bigger than the H atom in NH<sub>3</sub>. Also, the H<sub>2</sub> and N<sub>2</sub> molecules look similar. Since atom size is not a learning goal, we can watch for any confusion in interviews. If need be, we can always resize the images.



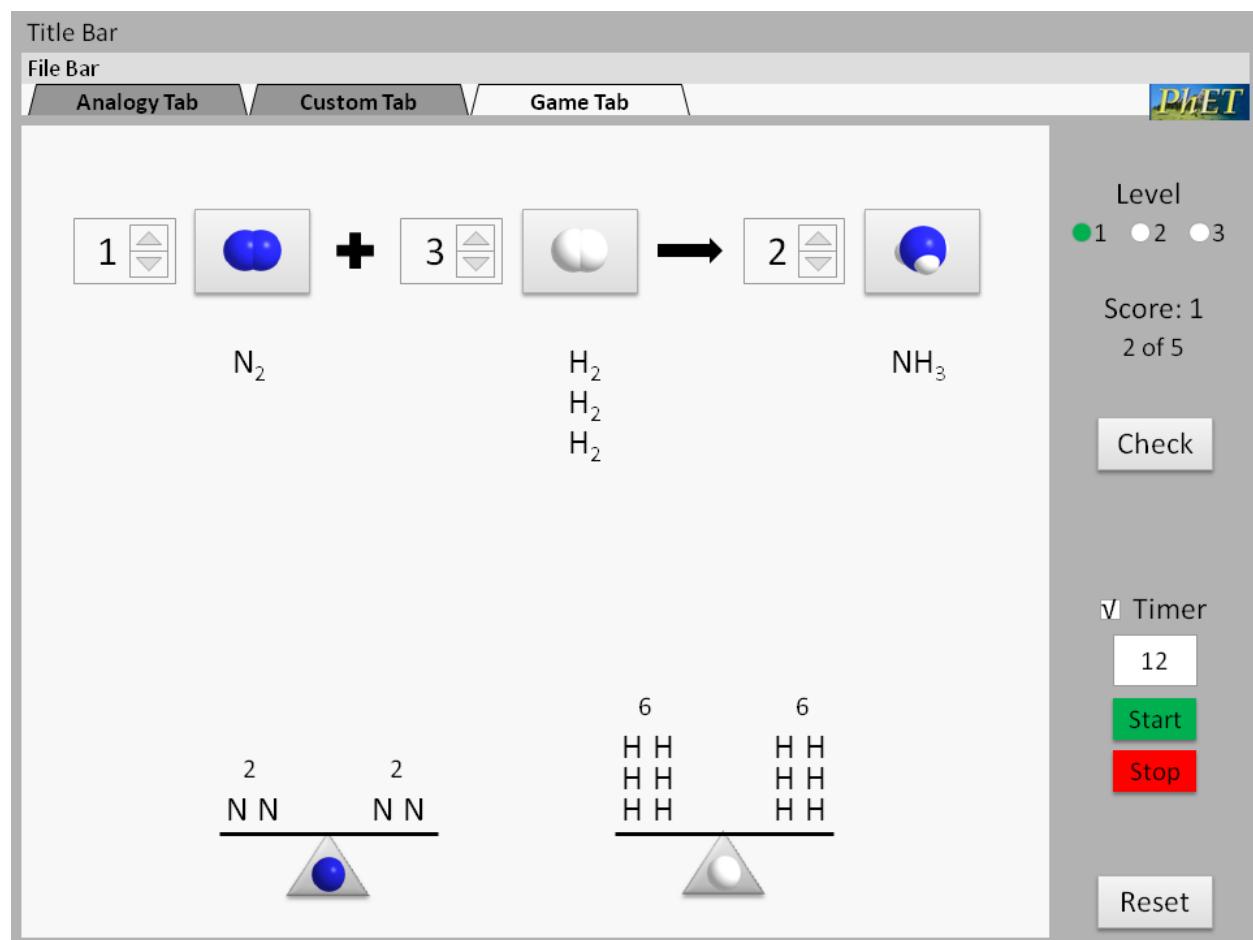
CM: If you try to resize the images so that the atoms have consistent sizes, I guarantee that we're going to run into screen layout problems. The user-interface design is based on the assumption that molecule images have similar sizes. So don't plan on being able to do this. If you think this is might be an issue, investigate it NOW.

RP: I think it's ok to have the atom sizes be inconsistent. These pictures are intended to be \*schematic\* representations of molecules, not realistic ones, and we want students to be able to deal with such representations since they will encounter them elsewhere, for example in textbooks.

UPDATE: the atom sizes are now consistent

## History

### Microscopic Mode



KL: The chem helproom students liked the other representation better. They said the molecules would help more when under the symbols.

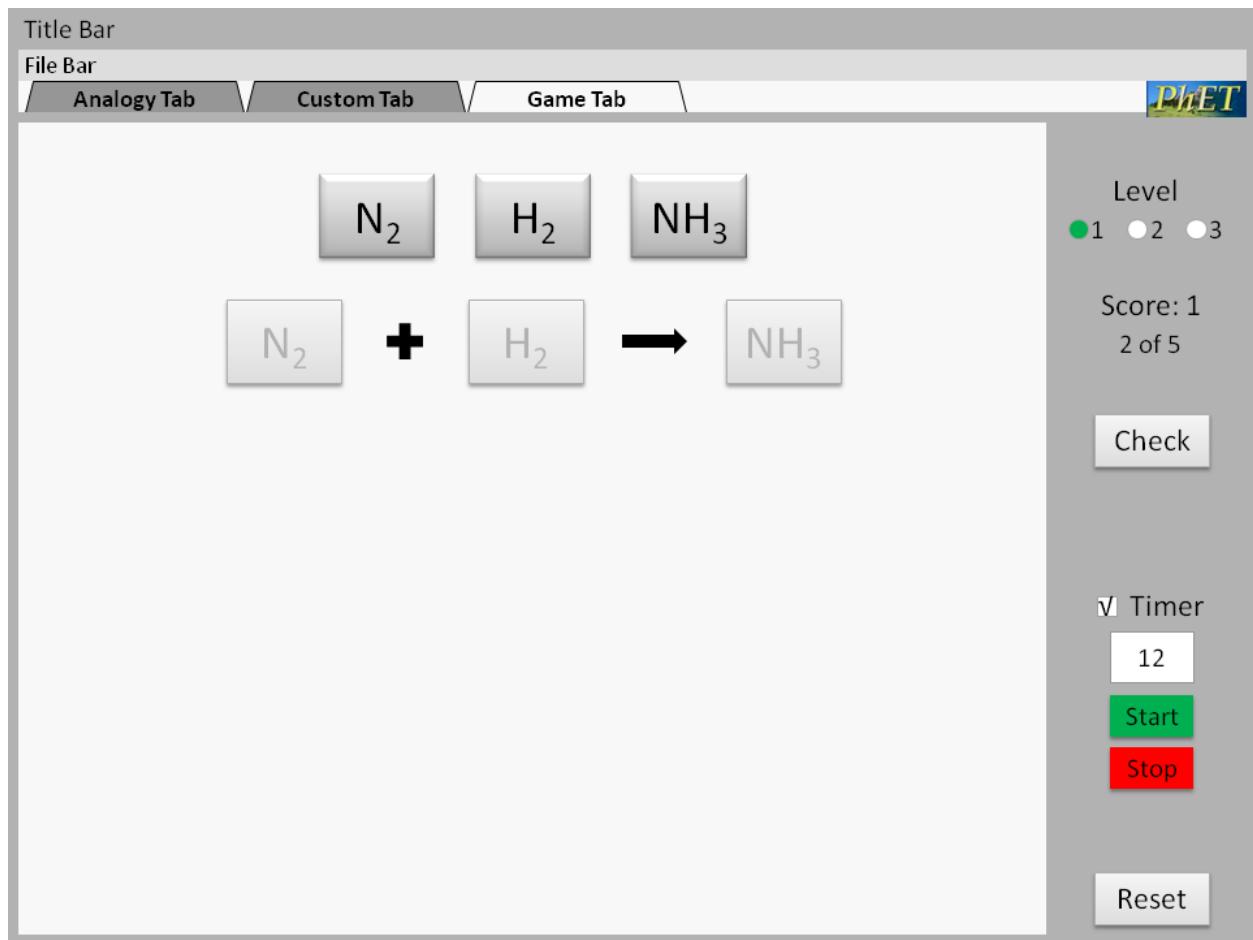
### Solitaire Mode

The student can drag in the symbol or use a spinner to change the coefficient.

- In solitaire mode: drag card into or out of equation
- In spinner mode: click up or down arrow as usual, or type in number

KL: The spinner mode seems more authentic.

*Solitaire mode:*



*Spinner mode:*

Title Bar

File Bar

Analogy Tab    Custom Tab    Game Tab    PhET

Level  
• 1   • 2   • 3

Score: 1  
2 of 5

Check

✓ Timer  
12  
Start  
Stop

Reset

The screenshot shows a PhET simulation interface. At the top, there's a title bar and a file bar with tabs for 'Analogy Tab', 'Custom Tab', and 'Game Tab'. The 'PhET' logo is in the top right. On the left, there's a large white area for the simulation. In the center, there's a chemical equation:  $\text{N}_2 + \text{H}_2 \rightarrow \text{NH}_3$ . Each molecule is represented by a box with two spinners inside. To the right of the equation are buttons for 'Check', 'Timer' (set to 12), 'Start', and 'Stop'. Below the timer are 'Reset' and 'Score: 1 / 2 of 5'. On the far left, there's a 'Level' section with three radio buttons for levels 1, 2, and 3.

KL: The chem helproom students preferred the spinners. One student said must use mouse more if click-and-drag. The chem TA saw no benefit to click-and-drag.

### Custom Tab

The student can make an equation to balance, and can try any number of combinations.  
KL: This is not a common practice in chemistry! It could distract from the learning goals, and the student can make an equation that is impossible to balance.

Title Bar

File Bar

Analogy Tab   Custom Tab   Game Tab   PhET

The screenshot shows a PhET simulation interface. At the top, there's a title bar and a file bar with tabs for 'Analogy Tab', 'Custom Tab', and 'Game Tab'. The 'PhET' logo is in the top right. Below the tabs is a scrollable menu with symbols:  $A_2$ ,  $B_2$ ,  $AB$ ,  $AB_2$ , and  $AB_3$ . The main area displays a chemical equation:  $1 \begin{array}{c} \uparrow \\ \downarrow \end{array} A_2 + 1 \begin{array}{c} \uparrow \\ \downarrow \end{array} AB_3 \rightarrow 1 \begin{array}{c} \uparrow \\ \downarrow \end{array} AB + 1 \begin{array}{c} \uparrow \\ \downarrow \end{array} B_2$ . Below the equation are molecular models: two green spheres for  $A_2$ , three green and three purple spheres for  $AB_3$ , one green and one purple sphere for  $AB$ , and two purple spheres for  $B_2$ . There are 'Show' and 'Hide' radio buttons next to these models. At the bottom, there are two sets of colored squares labeled 'A' and 'B': one green square with '3' above it and one purple square with '3' above it on the left; and one green square with '1' above it and one purple square with '3' above it on the right. A double-headed arrow between the first set indicates they are equal.

CM: About the Show/Hide radio buttons... Are these buttons really needed? While playing "what if", I kept asking myself "why would I want to use show/hide?" I finally decided to ignore them, and I'll bet students will too, so they're just taking up valuable space. If this feature is for a research project, we could always generate a special research version that has no icons visible, rather than bothering all users with a show/hide control.

If you must have a Show/Hide feature... The purpose of the show/hide radio buttons isn't obvious. You said it only shows/hides the icons. If we must use radio buttons, you'll probably want to label these "Show icons" and "Hide icons". I don't like using two radio buttons for what is essentially an on/off control -- a single check box labeled "Show icons" is more appropriate and economical.

How to use control at top of play area?

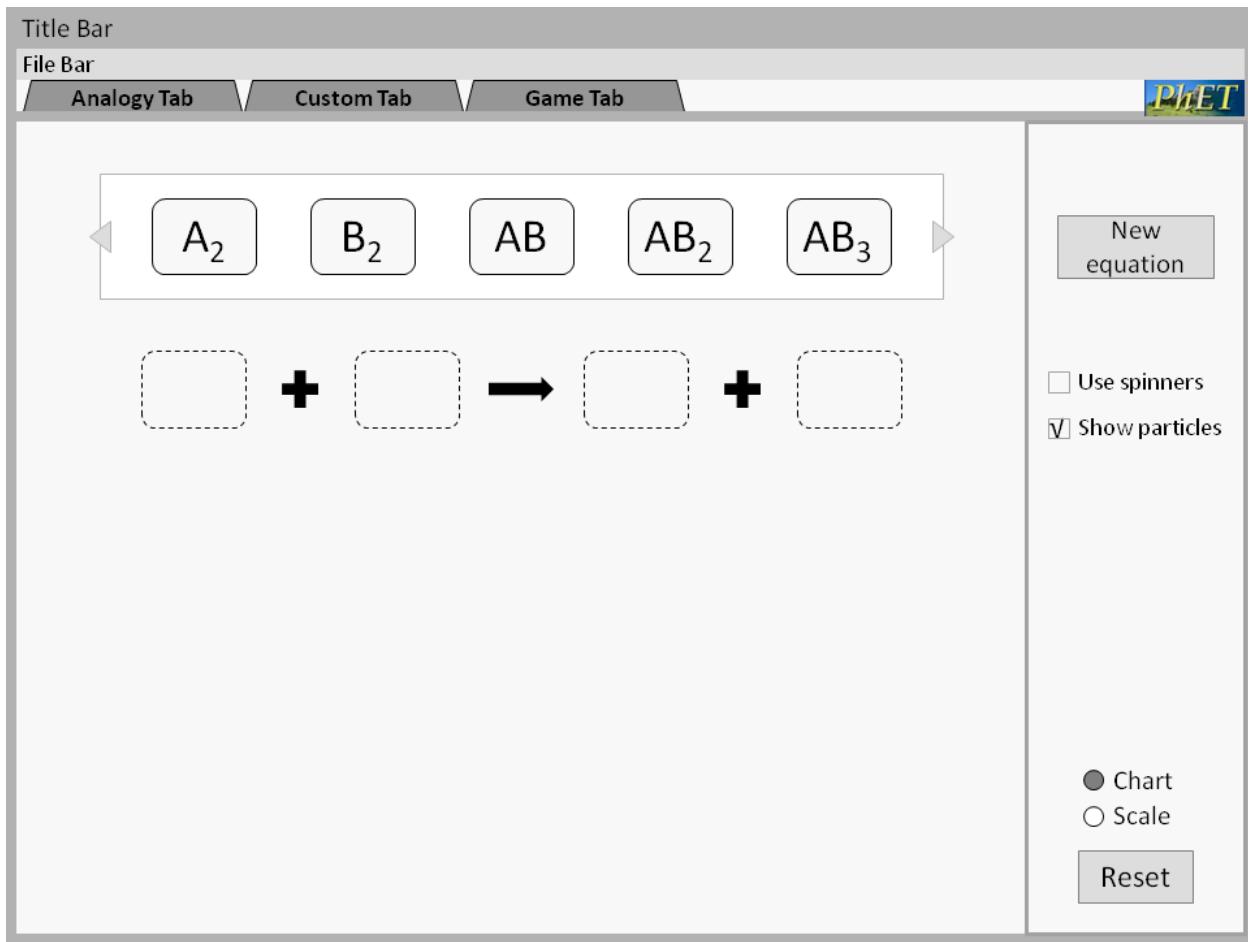
Left and right arrows allow user to scroll horizontally to see more symbols

Order: A, B,  $A_2$ ,  $B_2$ ,  $AB$ ,  $A_2B$ ,  $AB_2$ ,  $AB_3$ ,  $AB_4$

The student must click on symbol and drag down to equation area

How to make control intuitive?

Place symbols on "cards"; in equation area, the student will see empty boxes with same shape as cards:



How to prevent the student from making uninteresting (e.g.  $A+B \rightarrow A+B$ ) or nonsensical (e.g.  $A+A2 \rightarrow B+B2$ ) equations?

In "solitaire" mode: symbol card will \*bounce\* back if not valid equation

In spinner mode: once user has selected a symbol, they cannot select that symbol again (it becomes grayed out)

CM: The behavior of the box at the top is going to be difficult to specify, and probably even more difficult to use. I don't know how the user is going to figure out this control. And how are we going to keep them from creating bogus equations? (I'm afraid that I'm not convinced by your explanation.) How does the user make a new equation or modify an existing equation? Etc. etc. I recommend that we play "what if" with this control, and then either address all of the issues that come up, or investigate other interface options.

WA: I agree. I can't see students using this productively and vote for starting with an equation already in place.

TL: I understand Chris's comment that it would be difficult to specify, but I do see value in students being able to play with compounds and see that some combinations are nonsense.

On the AP test, students are given only the reactants and are supposed to generate the products. Many students struggle with this. I think if they were given interactive situations and they were able to test some of their own ideas about what situations are reasonable, it could help them make some more sense of reactions. Most students who are successful on the AP test have simply memorized the most common reactions from a table. I think that before the cards "bounce back" the students should have some time to look at what they selected so they can try to understand why the designed reaction is not reasonable. I see that the design plans appear to have dropped this option, but I would like to consider this for a future tab or an advanced game.

### Analogy Tab

The goal of the analogy was to introduce the symbolic representation with a real-world object.

The screenshot shows the PhET Analogies simulation interface. The title bar says "Title Bar" and the file bar has tabs for "Analogy Tab" (selected), "Custom Tab", and "Game Tab". The logo "PhET" is in the top right. The main area displays a chemical-like equation:

$$T + L_2 \rightarrow TL_3$$

Below this, another equation is shown:

$$1 \begin{array}{|c|} \hline \triangle \\ \backslash \\ \triangledown \\ / \\ \hline \end{array} T + 2 \begin{array}{|c|} \hline \triangle \\ \backslash \\ \triangledown \\ / \\ \hline \end{array} L_2 \rightarrow 1 \begin{array}{|c|} \hline \triangle \\ \backslash \\ \triangledown \\ / \\ \hline \end{array} TL_4$$

Icons below the equations represent the symbols: a black rectangle for T, two brown rectangles for L<sub>2</sub>, and a black rectangle with four brown legs for TL<sub>3</sub>. There are also "Show" and "Hide" buttons for these icons. At the bottom, there's a "Chart" or "Scale" section with icons for T and L.

CM: I figured out that T=table and L=leg, but it wasn't immediately obvious, even though the screenshot shows a typical 4-legged table. It's going to be even less obvious with a TL3, and whatever other mutant tables are lurking in the options. The "T" and "L" abbreviations will need to be translated for different languages. "Table" and "Leg" start with different characters in English, but what about other languages? 3-legged and 4-legged tables typically have different

top (T) shapes, round for 3-legged, rectangular for 4-legged. I guess we can put 3 legs under a rectangular top, but it doesn't make for a very stable design (table design, that is ;-)

## Online Resources

*Many simply balance equation for student.*

<http://balance-equation.appspot.com/>

Type symbolic formula for reactants & products, get balanced equation.

*Most only provide practice.*

<http://funbasedlearning.com/chemistry/chembalancer/default.htm>

Practice balancing equations. Enter coefficients; shows structures (symbolic) below equation. When check answer, get pop-up window with trivia. Some errors with structures. Classic: 11 exercises. Review: 10 exercises. Brain boggle: 5 exercises.

TL: I thought this one had an interesting solution to the balance display. They chose to put all the reactants on one side and the products on the other and not isolate each element. I am not really sold on the idea, but I did think it provided something to think about. I personally like separating the elements because that is the strategy we usually use and that is what is taught in texts. They also have some interesting tidbits about the chemicals in the reactions if you get the problem right, but I really found those more annoying than interesting, but I am not a trivia lover.

[http://www.chempractice.com/drills/java\\_balancing.shtml](http://www.chempractice.com/drills/java_balancing.shtml)

Practice balancing equations. Click arrow to increase coefficient, get feedback (right or wrong) on answer. All symbolic. 10 exercises. Error toward end.

<http://richardbowles.tripod.com/chemistry/balance.htm>

Interactive tutorial with 10 practice exercises. Enter coefficients & click to check; get pop-up window with answer.

<http://www.wfu.edu/~ylwong/balanceeq/balanceq.html>

Interactive tutorial on balancing equations. Enter atom amounts on each side of equation. Symbolic, only one example!

<http://www.wfu.edu/~ylwong/redox/>

Interactive tutorial on balancing **redox** equations in acid or base. All symbolic; focuses on order of steps. Trish favorite, but not goal of this sim.

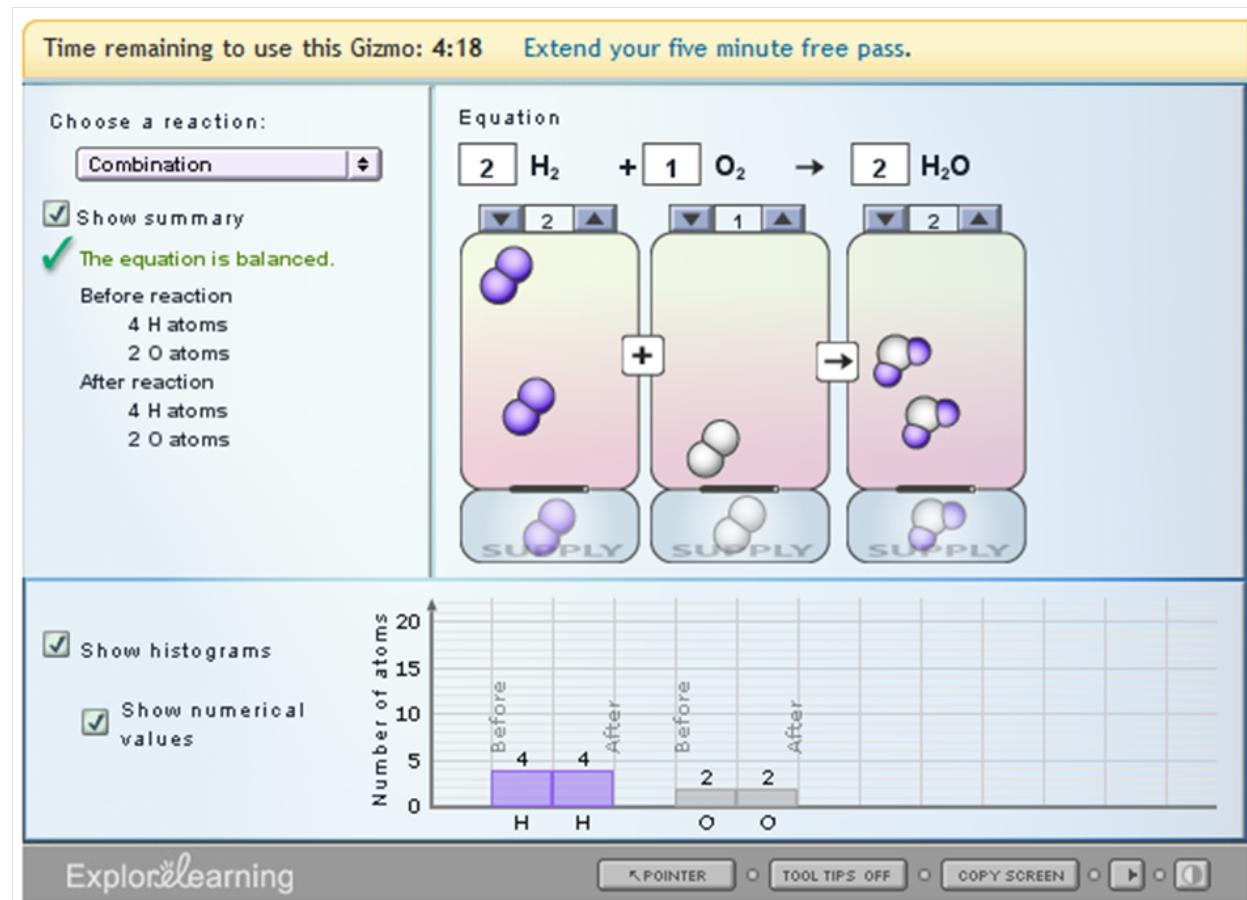
*Some have other features.*

<http://www.quia.com/rr/100887.html>

Multiple-choice game modeled after "rags to riches".

<http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=408>

Interactive simulation (5 minute free pass). Shows symbolic equation, molecular representation of reactants and products (with motion), before & after histogram of atom amounts. 4 types of reaction.



<http://www.chemfiles.com/flash/formulas.html>

TL: I received a link to a site that uses a scale to help with formula writing. I think it has a pretty nice interface.

## References

Yaroch, W.L. *J. Res. Sci. Teach.* **1985**, 22, 449-459.

Title: Student understanding of chemical equation balancing

Students can balance equations, but do not understand chemical symbols

Nurrenbern, S.C.; Pickering, M. *J. Chem. Educ.* **1987**, 64, 508-510.

Title: Concept Learning versus Problem Solving: Is There a Difference?

Students can solve problems without understanding concepts

Sanger, M.J. *J. Chem. Educ.* **2005**, 82, 131-134.

Title: Evaluating Students' Conceptual Understanding of Balanced Equations and Stoichiometric Ratios Using a Particulate Drawing

Common student errors: left excess reactants in the equation, confused subscripts & coefficients

## Discussion

### **10/09/09 - Click & Drag**

Click & drag symbols to make equation, then balance

Why? To make sim more interactive

### **10/16/09 - Scales**

Make scale for each atom, rather than reactants vs. products

Why? Can get equal # of atoms w/out balance, plus atoms not same mass

### **10/20/09 - Solitaire interface**

Make interface like Solitaire card game

Why? To make sim more intuitive

*One year later...*

### **12/13/10 - Game tab**

We talked about being able to select different views in the game, and what to do when the equation is balanced but not with the lowest coefficients.

#### CM notes:

- add a global Options menu item to show/hide molecules in both tabs
- pick a random representation for Game (bar chart, balance scale, molecules) then allow user to change via 3 radio buttons
- in "Game", two possible labels below frowny face, depending on whether lowest coefficients are used:

X not balanced

✓ balanced

X not simplified"

- tilt of balance scale: compute N = left - right. Choose some N that hits the ground, have N scale angles.
- OK to overlap atoms on balance scale (range is 0-60)
- limit bar charts height (to 15?), label each bar's value, show up-arrow for bars off scale (range is 0-60)

### ***01/11/11 - Images***

CM: For BCE, I'm going to need a few additional image files. Attached is a screenshot showing the images that I can reuse from RPAL. I believe that you created these with ChemDraw, correct?

I looked though the list of equations in the doc, and I think all I need are these 6 atoms: Cl, F, H, N, O, P

Could you create these for me? Hi-res transparent PNG would be great. For example, the C.png you gave me for RPAL was 1830x1830, and I shrunk it down.

KL: I no longer have access to ChemDraw (I got it through Georgia Tech, not CU), but Emily might have a license.

If not, I can look into other programs, or see if Kathy will buy a ChemDraw license. The other thing we could try is to use Piccolo for the single atoms.

CM: We'll never match the look of ChemDraw with Piccolo, so atoms and molecules would look different. So we shouldn't mix the 2 approaches (image files and Piccolo). I could apply what I did in Acid-Base (Piccolo atoms and molecules) if everyone is OK with atoms not quite looking as "embedded" in other atoms, which will be more obvious with the larger-looking molecules in BCE.

If we're going to keep doing chem sims, I think we need to either (a) invest in a drawing tool and use it for all chem sims or (b) create molecules/atoms in Piccolo and accept the limitations. And stick with a consistent approach. I'm a big fan of using Piccolo wherever possible because it's generally easier to change colors (as we saw in Acid-Base), and image files bloat the JAR file size.

ChemDraw Std download is \$130 for a 1-year license.

KL: I was actually using ChemDraw Ultra - which comes with Chem3D - which is a bit more expensive (\$380 for 1 year with academic pricing). It also comes with a bunch of other stuff that I don't need anymore. There must be a free program out there...

CM: Lots of options listed here: [http://en.wikipedia.org/wiki/Molecule\\_editor](http://en.wikipedia.org/wiki/Molecule_editor)

KL: I tried a couple of programs that looked promising, but no luck. I did find some of the images you asked for in my files.

### **01/25/11 - Images, Part 2**

CM: A question about Balancing Chemical Equations (BCE)...

This sim currently uses image files for molecules and atoms, most of which are being reused from RPAL. If we ever want to change the colors, that's going to mean changing a whole bunch of images, or changing the sim to draw molecules using Piccolo (as we did in Acid-Base Solutions). I would switch to Piccolo now, but that approach has a limitation that you should be aware of, and which I will describe via an example. In both of the attached images ( $O_2$ ,  $H_2O$ ), the atoms are pressed together so that they merge (I believe "smooshed" is the technical term :) I can't duplicate this look with Piccolo, I can only overlap shaded spheres.

There is also an issue of inconsistency across sims, ie:

- RPAL uses the image files shown.
- Acid-Base Solution uses overlapping spheres drawn using Piccolo.
- Molecules & Light uses a yet-another representation, with no overlap of atoms, showing the bonds between atoms, drawn using Piccolo but without the same degree of 3D shading that Acid-Base has.

Opinions on how to proceed for this sim?



KL: I am fine with Piccolo images - i.e., no smoosh - but if others prefer the images in RPAL, we need a ChemDraw license (and we should probably mention the company in our credits.)

I think Emily was going to ask Mindy to contact the ChemDraw people to see if they would give us a free license, like the Camtasia folks did. I am not sure how that went.

EM: Mindy has emailed ChemDraw, but there's been no response yet.

TL: I wrote this while Kelly was also replying:

I think I understand that the reason you had to re-draw Acid and Base was for color blindness; is that right?

I was looking through all the chem sims and wondered how some of the other molecules were drawn, but more importantly to me since I don't really grasp the programming ramifications,

I wonder which ones of the old ones wouldn't pass the color blindness test and how was the drawing programming chosen? Like pH, Salts, Reactions & Rates or the Nuclear sims? How about the one in design called Isotopes (tab 2) ? Should we make a decision that is applied as part of the Look and Feel for PhET, not just the present chem group. Should this be a programmer discussion instead of a chem group discussion?

Sorry I have more questions than opinions. Don't feel like you have to try to explain how all the chem sim images are drawn to me, I just want to add to your point that there are many ways we are trying to visualize particles. I think one thing that organizations like Molecular Modeling provide is a consistent look and feel. Also, I think when we made a decision about how photons would look in all the sims (or at least with few adjustments when needed), it helped teachers use the sims more easily because they were familiar images.

Now that Kelly has responded, I am interested in her idea to use ChemDraw. It that a nice solution?

CM: Yes Trish, there are quite a few representations for molecules and atoms. But I don't think it's up to us developers to decide which representation is right, whether having multiple representations is inappropriate, or whether consistency across all sims is desirable. I think that you educators need to decide that.

In terms of implementation... The Piccolo approach is easier to implement, modify and maintain, and (as a secondary consideration) results in smaller JAR files. So if we decide to use image files for BCE, we'll be paying a rather high price for the "smoosh".

TL: Thanks for helping me put this in perspective. I wasn't sure if we should be deciding on a long term look and feel to be more effective. I recognise that we use a variety of models in chemistry depending on the topic, so maybe a consistent model just isn't realistic.

For BCE, I am not sure how bad the smoosh effect will really be. The images are hard for me to judge out of context, but I like the idea that they are easier to implement, maintain and modify. I know in the past, near finishing a sim, we want to make changes to color or relative size of things and it is nice if the changes don't cost as much in terms of programming or turn around time. When the turn around time is long, we have talked about the fact that team members get "sim fatigue".

### ***02/01/11 - Images, Part 3***

CM: I have not heard from Kathy or Robert on this issue -- if either of you have opinions, please provide feedback by the end of today. The consensus so far is that using Piccolo would be fine, and the "smoosh" effect that we get from image files is not worth the extra cost and inflexibility of using image files. Unless I hear otherwise, I will be converting to a Piccolo approach, ala Acid-Base Solutions.

TL: FYI I answered that I thought the approach that provides the easiest changes was best. My understanding was that the piccolo was this solution.

KP: Picolo looks fine to me.

## 02/01/11 - Version 1

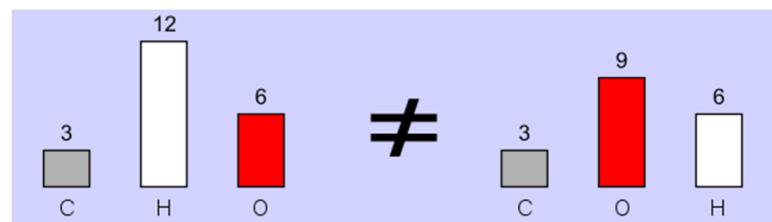
CM: Here's the first dev version of Balancing Chemical Equations (BCE):

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.01/>

All features in the first tab are implemented, as well as the global Options menu. There's no horizontal alignment of things in the play area yet, I'm working on that next. Anything you'd like me to change before showing this to the team?

KL: This is looking good! Here are a few comments:

The atoms in the bar chart for methane are not in the same order (both should be C, H, O).



There is a white box around both sets of radio buttons. And it might be better for them to be right-aligned (but we can discuss this with the team first, no need to change now).



If you balance an equation, go to a new equation, and then return to the original equation, can we keep it in the same configuration? Not sure what that is called in code-speak.

In addition to the alignment, we might need to use another visual cue to get students to connect the representations. Maybe the + signs can be black, and the arrows and = sign can all be the same color? Blue is fine.

Also, "balance scales" can just be "Balances", and "bar charts" can be "Bar charts" (capital B for both). Kathy wanted a radio button for "None".

CM: Thanks, all relatively easy changes.

I'll hold off on changing the alignment of radio buttons.

I thought Kathy wanted the "None" button in the Game, but I'll add it in the first tab, too.

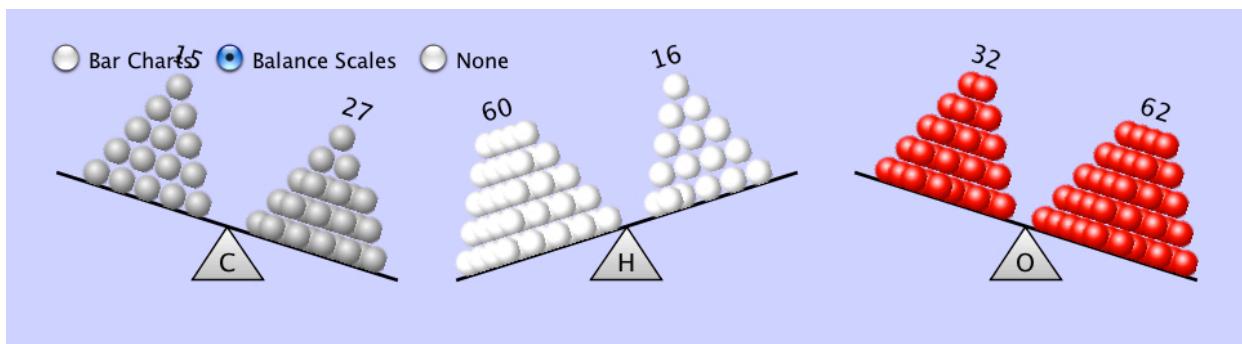
02/03/11 - Version 2

CM: All of the features for the 1st tab are implemented.

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.02/>

Issues to discuss:

- Should the "Bar Charts" view show "=" when all coefficients are zero? (It does now.)
- When "Options->Show molecules" is off, should the boxes contain "molecules are hidden", ala RPAL Game? (It currently does not.)
- Should "Reset All" prompt for confirmation? (It does now.)
- Should pressing "Reset All" in any tab reset the global "Options->Show molecules" menu item?
- We have a serious real estate problem in the Game tab. The coefficients go to 10 in the Game, so we need to fit many more molecules in the boxes. We need to fit a scoreboard across the bottom of the play area. And we've added the "Bar Charts" and "Balance Scales" views to the Game. Let's discuss how to address this, it must be resolved before I can continue with Game implementation.
- In "Balance Scales" view, atom piles contain a maximum of 15 atoms. The Game has a maximum of 60 atoms in a pile, so the plan is to build 4 piles ( $4 \times 15 = 60$ ), each pile slightly offset from the others. See attached mockup. Do you think this will be effective?



TL: Just as an observation: Because the Bar charts were on by default, I really focused on using them to balance the equation. Then I tried the Scale. It was not until I had tried all the reactions that I even noticed that the molecules were displayed. Maybe this is because I was focused on the numbers like a game as opposed to understanding the underlying molecular model. There are lots of sims/games available that enable this type of guess and check. I think we lose some of our strength as "builders of expert models". But I am interested in what the interviews show and not recommending a change.

Notes from Dev meeting:

Lots of work on balance tab - if bar chart amount goes above 12 it shows arrow and amount #.

On balancing if amount goes above 15 it creates a new stack in front of old slightly offset. Need to address issue of size amount (and placement of scales/ bar chart) so if more molecules are added they will all fit. (Kathy is ok with molecules being smaller). Kathy suggested changing the color of equals sign and arrows when user balances equation. (Perhaps instead of smiley face).

Notes from Chem meeting:

- what if bar chart is 0?
  - SR ideas: no bar, no number, no equal sign
- default = "none"
- move radio buttons to bottom
- show bar chart or balances in game (but \*after\* student enters answer)
  - to show \*why\* correct or wrong
  - in pop-up window (on top of boxes), not at bottom

**02/04/11 - Version 3**

CM: Please inform the teacher who is planning to use this that a new version is available. This version contains changes to the 1st tab, as requested at yesterday's meeting:

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.03/>

Requested changes include:

- defaulted the view to "None"
- made atom symbol larger below bars
- added atom icon below bars
- removed the horizontal line for zero-height bars
- made arrows and equals-sign light up when equation is balanced  
(used yellow instead of green for tie-in with Game smiley face, and to avoid red-green colorblind issue)
- used a lighter color for the boxes
- removed the smiley face

Additional changes:

- made the balance scale beams highlight when the equation is balanced  
(it seemed odd that all other representation highlight but this one didn't)
- added Developer->Colors menu item  
(so you can experiment with different colors for the play area and boxes)
- added "Under Construction" to the Game tab play area

Feedback appreciated.

KL: I really like how the arrows turn yellow when the equation is balanced!

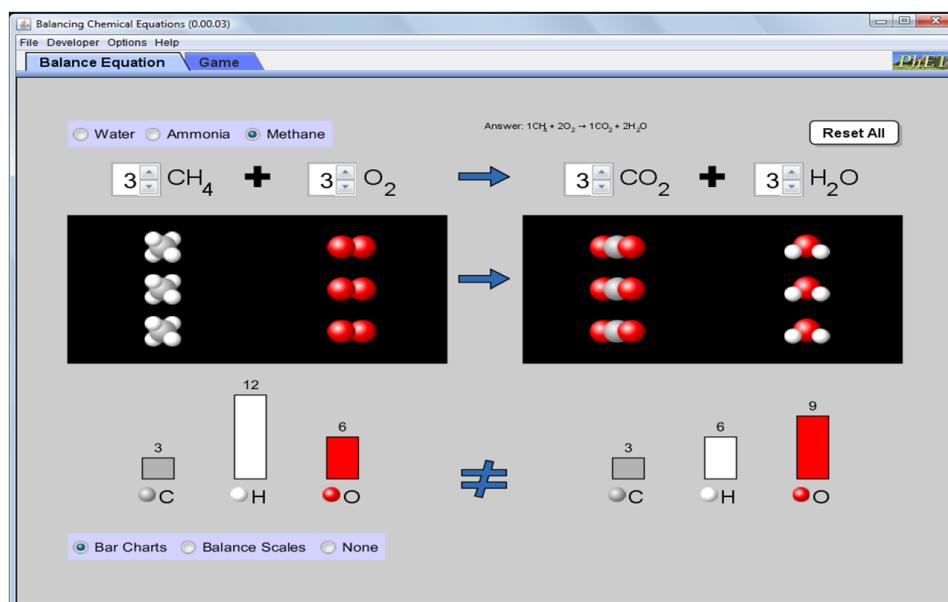
I find the radio and reset buttons at the top distracting. Can we move the reset button to the

bottom right, and try the radio buttons at the top right?

I like black for the boxes and gray for the play area. I think it draws more attention to the molecules and the arrows. (When I change the color of the play area, the box around the radio buttons returns.)

I think Emily is going to contact the teacher to see if she can observe the class on Monday. Maybe she can also send Jackie the link to the latest version?

Kathy D is going to contact parents so I can do some middle school interviews on the 1st tab next week.



CM: Which set of radio buttons are you suggesting moving to the top right? And doesn't having one set of radio buttons on the right and the other on the left seem odd?

The "Reset All" button should ideally (for usability) have a consistent location in all tabs. Moving it to the bottom right is problematic for the Game, unless you want to shrink the width of the scoreboard (Reset All will be to right of scoreboard, but close to the New Game button, where it might accidentally be pressed). Putting it below the scoreboard is not recommended because vertical space is precious.

I'll fix the boxes around the radio buttons, it reappeared when I gave you the ability to change the play area color. It's a Piccolo (PSwing) problem, and we developers seem destined to spend our lives working around it.

KL: 1. The ones that change the reaction. And yes, it is a bit odd. In the mockup, I drew both sets of radio buttons on the right. Maybe the buttons would distract from the equation less if they were farther away (closer to the top of the sim)?

2. We don't need a reset button in the game (and we did not use one in RPAL or Build an Atom), since the "new game" button has the same function.

CM: OK, I will:

- (1) move the reaction radio buttons to the right
- (2) move the Reset All button to the bottom right, at the same vertical position as the "None" radio button
- (3) remove the Reset All button from the Game tab

KL: Great! What do you think of the colors? (Emily said she likes the screenshot.)

### ***02/07/11 - Hiding molecules***

CM: About the "Options->Show molecules" menu item in BCE... I'm concerned that when molecules are hidden, people may become confused, especially since this menu item affects both tabs. In RPAL's Game, we put "molecules hidden" in the boxes when the molecules are hidden. Should we do the same in BCE, as a reminder?

KL: Yes, that is a good idea.

CM: OK, done.

### ***02/07/11 - Game reward***

CM: Will the BCE Game have a perfect-score "reward", like in RPAL? I don't see it mentioned in the design doc.

KL: I am indifferent - if it's not too hard to implement, then sure.

CM: If it's identical to RPAL ("tah dah" sound, and falling molecules) then it means reusing existing code, should be pretty straightforward. If we want something different, then cost is unknown. In either case, engineering the game to have this feature from the beginning is easier than adding it later. And since I'm just starting to implement the game....

Should we ask the team?

KL: Sure, let's ask the team.

CM: In RPAL, the student gets a reward for a perfect score. The reward is a special sound ("tah dah") and lots of molecules falling in the background (see attached screenshot). The BCE design doc doesn't say anything about a reward.

Options:

- (1) No reward. (Least expensive now, but more expensive to add later.)
- (2) Reward, same as RPAL. (Least expensive, reuse code. Familiar? Or boring because it's the same?)
- (3) Reward, something new. (Most expensive, need to design and implement. And keep in mind that it was expensive to design and implement for RPAL.)

Opinions?



TL: I vote for option 2.

KP: Option 2 is fine with me too. I don't have a strong opinion, except that definitely want a sound.

RP: I vote for option 2.

#### **02/05/11 - Version 4**

CM: Team,

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.04/>

Changes:

- moved equation radio buttons to upper right (I prefer them on the left)
- moved Reset All button to lower right (I like this change)
- removed Reset All button from Game tab

Fixes:

- changing play area color also changes background of radio button panels
- pressing and hold spinners caused a Java exception

TL: I realize I am a little behind in my comments because some of my comments reflect changes that happened in version .03, but I didn't have time on Friday or Sat to look at this sim: I like the

1. lighter box background for the molecule display because when you make a black and white version the molecules are still visible.
2. the icon of the particle next to the symbol and the removal of the line in the bar chart view.
3. I think I like the change of the color of the arrow, but I think just having a color change will not really tell the students that they have a right answer. I like the smiley face because we already use it in other places and I think it gives a nice positive reinforcement.

I am wondering if moving the radio buttons to change the reaction to the right corner is a good move, but I know there are some other things that we are not sure about. My understanding is that there will be interviews before much else is done.

KL: The point of the 1st tab is not for students to get the "right answer," but for them to explore the concept of coefficients.

I have 3 interviews with middle school students this week (on Tu, W and Th at 4pm). I can try versions with the smiley face, with the top set of radio buttons on the left, etc.

KL: Also, FYI: I am going to observe a middle school teacher using this sim with 3 of her 6th grade classes tomorrow.

KP: It's looking good to me. I'm mostly wondering how long it will take students to find and use the bar charts and scales. It will be interesting to see how the interviews go!

#### **02/09/11 - Version 5**

KL: For my next 2 interviews on BCE, can you make 2 new versions?

1. One with the top set of radio buttons on the left
2. One that shows a smiley face when the equation is balanced

(the interviews are today and tomorrow at 4pm)

Also, can you change the order of the bottom set of radio buttons to:

- 1) None, 2) Balance Scales, 3) Bar Charts?

How close is the game? (just curious)

CM: It's not clear from your email what combination of features you want in the 2 versions you requested. So here's 1 new version with all 3 changes that you requested:

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.05/>

If you want something different for tomorrow's interviews, I'll be happy to do that. Just let me know how each version should differ from 0.00.05.

KL: I am sorry I was not clear. I wanted to test the placement of the radio buttons and the addition of the smiley face separately, but this version will work.

CM: No problem. If you need anything else, just let me know, happy to create additional variations.

KL: Thanks! At this point, I've seen over 60 students use the first tab, so I'm not sure what else I can learn about that. It would be awesome to have a crude version of the game ready by 4pm today :) I will say that I am even more convinced that we should not put the bar charts and balances in the game.

Notes from Dev meeting:

KL: Middle school teacher on advisory board requested a sim do things similar to this. So she used it. Had to reserve computer lab – added an icon on desktop to all of the computers. While she was instructing – went around to all of the laptops and set up link.

They had used our sims before but they always use online. Before in MS classes we usually do an activity that takes entire class. Teacher started at the board and gave students a worksheet and let them play with the sim for 5-10min, students were really excited to get yellow arrow. Students found balancing scales... and students found balance through trial and error. After students had played for a while. Teacher told them to reset all and then asked them to balance without scale. But some students just played around until it was balanced. Kelly saw a couple of students point and count molecules on screen. Their goal was to get yellow arrow. Teacher thought it went really well. These are students with little experience with symbols and bar graphs.

Teacher went through steps with students... in her instruction she used bar graphs (without actually using bar graph on sim). I don't think scales should be used in game. But lots of other think scales should be used for 'help'. In 2 interviews gave them worksheet. It definitely gave them an idea that the symbols mean something.. but they aren't sure what the circles mean. The students had never seen molecules and atoms before. But one student was able to do everything correctly.. and drew out molecules to equalize equation. Can't say if sim helped him do that or if he was just ahead of his peers.

Did one last interview about happy face/ vs yellow arrows. And was happy with happy face. In terms of general MS stuff... we have been focused on really long activities... but teacher seems to do small activities and then does discussion then back to sim.

KP: hard to think of way for them to use balance scale without them only relying on the scale to

balance equation.

After the meeting, we talked about a click-and-drag interface instead of (or in addition to) spinners. Also, Kathy suggested a new type of problem in the game: no spinners, ask "Is this equation balanced?"

### **02/15/11 - Molecules and atoms**

CM: Attached is a screenshot showing all of the molecules and atoms used in BCE. These are all created using Piccolo code, no image files. They look very similar to the image files used in RPAL, but a few have been rotated to make it easier to see all of the atoms. Let me know if any of these look odd, or might cause misconceptions about molecule structure.

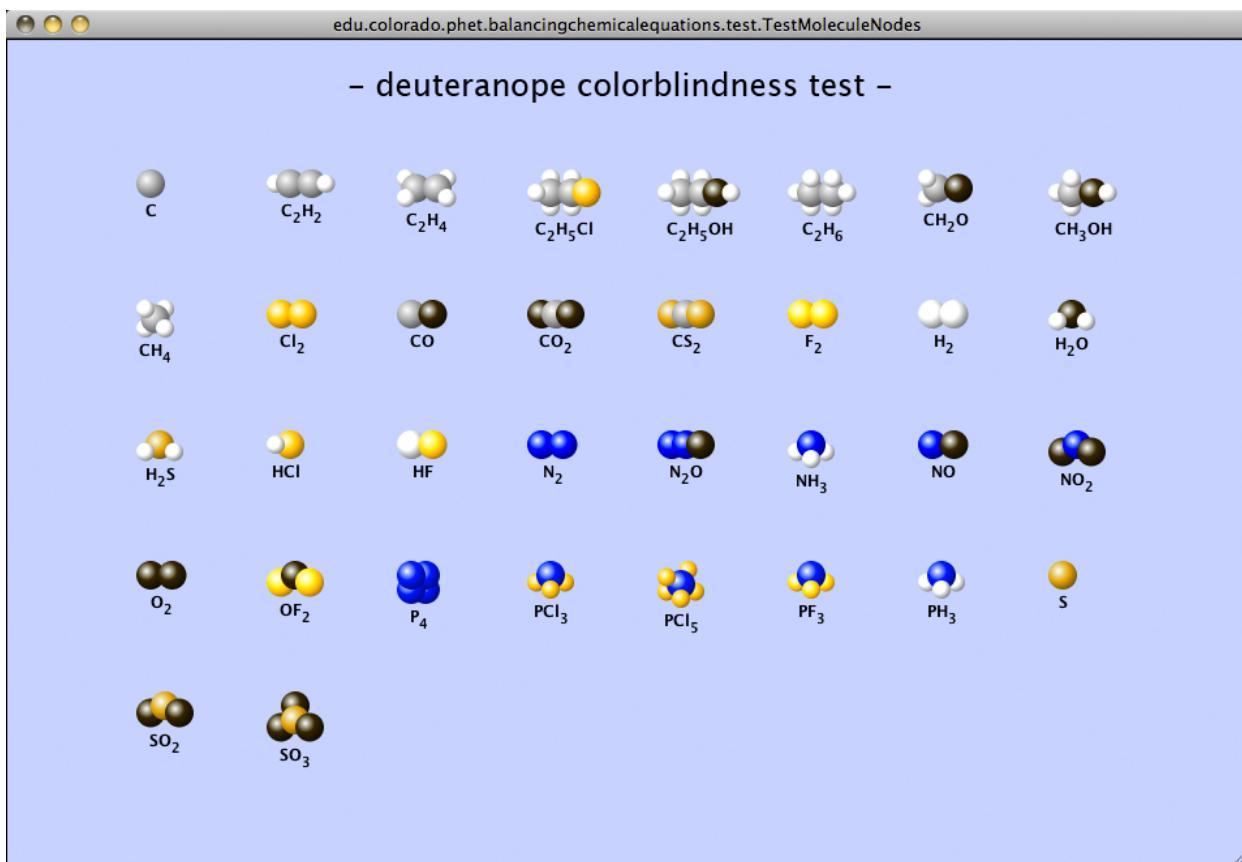
Also attached are colorblindness tests. Protanope and deuteranope are the common forms. We've been ignoring tritanope, but I've included it in case you're curious.

Protanope and deuteranope issues include:

- N and P look the same, but I don't see them used together in the same equation
- Cl, F and S look the same, but I don't see them used together in the same equation
- O looks black, but that's probably OK in this case

Colors used in BCE are the same as RPAL. If you want to change colors in BCE, it will take seconds; in RPAL it will take hours.





KL: Thank you for converting the images to code and for doing the colorblind test!

Structure is not a goal of this sim, but some of the 3D molecules do look odd to me.

- The conformations of CH<sub>3</sub>OH, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>5</sub>Cl, C<sub>2</sub>H<sub>5</sub>OH, and PCl<sub>5</sub> are not the most stable ones

CM: I tried to copy what was used in RPAL, while ensuring that all atoms are clearly visible (and therefore easily countable). You'll need to draw the stable conformations, or tell me what specifically needs to change.

KL: I think it would be easiest to tweak the molecules together.

- The H atom is too big in HF - it should look like HCl

CM: OK, will change.

- The F and Cl atoms in PF<sub>3</sub>, PCl<sub>3</sub> and PCl<sub>5</sub> should not be the same size as the H atom in PH<sub>3</sub>

CM: Why not? None of these appear together in the same equation, and are therefore never displayed at the same time. Should the H be smaller, or the others larger?

- Are you using the same size for each atom except H?

CM: No. There are 2 atom sizes, big and small, used to construct all molecules. See for

example PCI<sub>3</sub>, where P is big and Cl is small. Do we also need a "medium" size? If so, where?

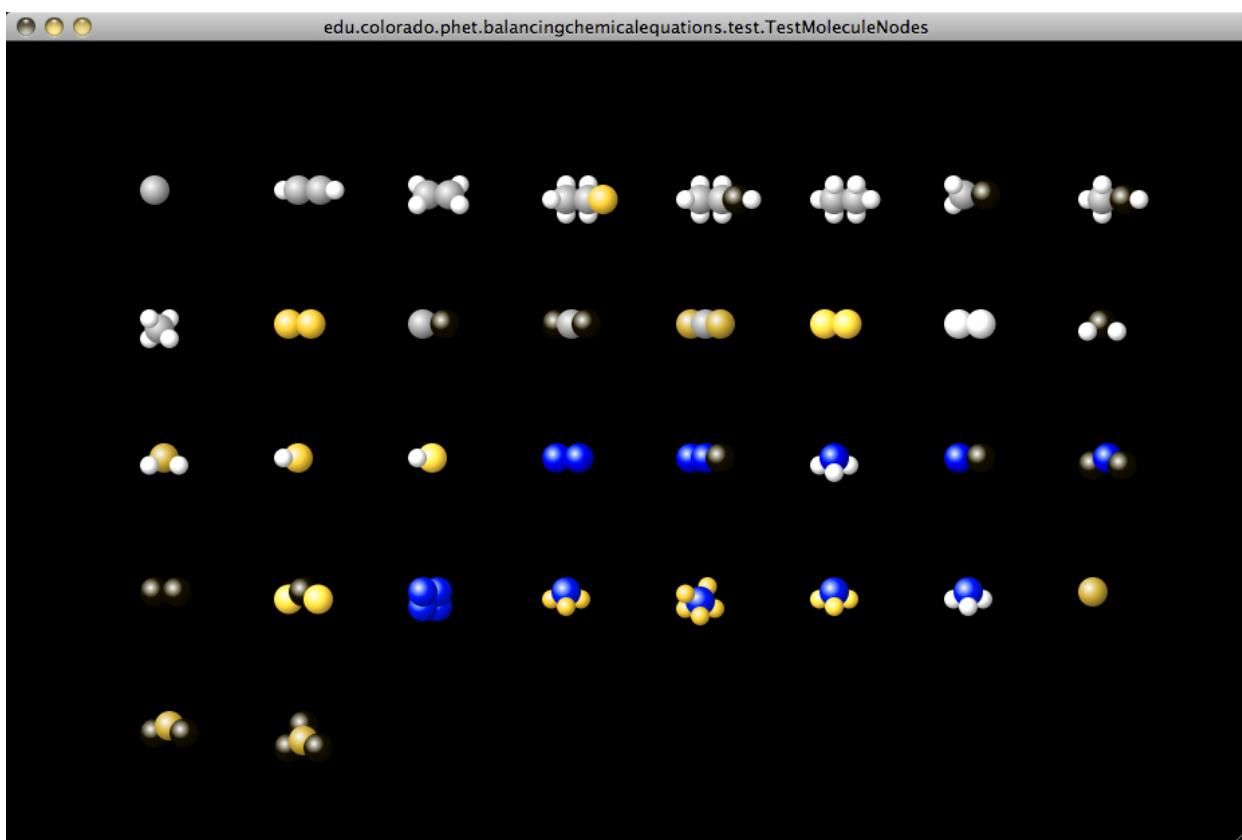
KL: Did we ever decide on the background color of the box? I suggested black, so a black O atom would be a problem.

CM: I gave you a Developer control for experimenting with the box color. The original color was a dark blue, and you requested a lighter blue. So I'm surprised that you're considering black.

KL: I suggested black for the box color and sent out a screenshot on Feb 4. I said, "I like black for the boxes and gray for the play area. I think it draws more attention to the molecules and the arrows." I asked for feedback on the colors, and Emily said she liked the color changes.

CM: Screenshots attached, showing all molecules on black background for normal and tritanope.

Red on black is definitely a problem.

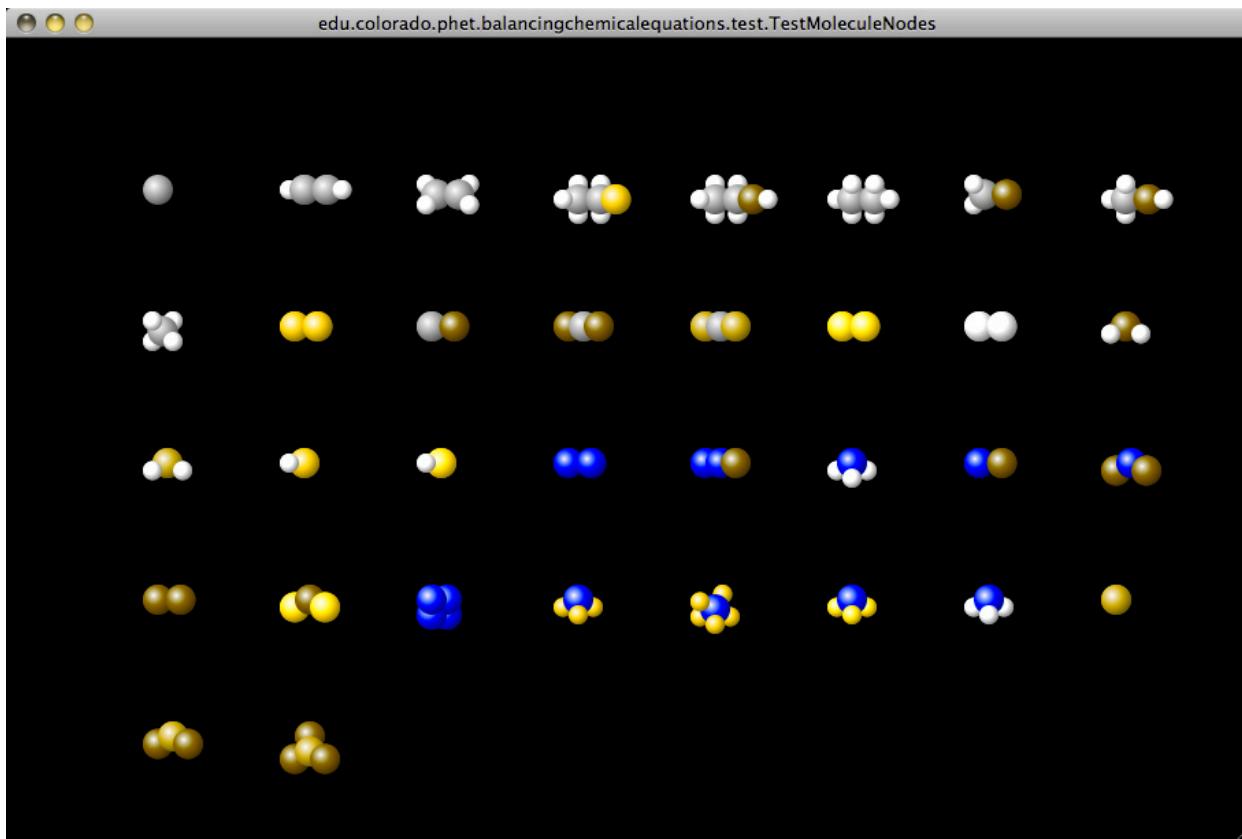


KL: The way we got around this in Molecules & Light was to make the pure red more of an orange-red. Maybe we should send another email to the team to ask for their opinion on the colors.

CM: Screenshots attached with the ABS orange-red (RGB=255,85,0) substituted for Oxygen.

Yes, we should ask the team about colors. But I think it would be less painful for everyone if you and I propose a color scheme that address all issues. Then if someone wants a different

color scheme, the burden is on them to prove that it also addresses all issues.



### 02/17/11 - Atom sizes

We decided to use the actual sizes for each atom. We think this could make it easier for students to connect the reactants to the products.

### 02/21/11 - Version 6 & 7

CM: Team,

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.06/>

This version includes "test-molecule-nodes", the test application that I demonstrated at last week's status meeting, which displays all of the molecules used in the sim. The colors used here are colorblind friendly, and molecule structures were adjusted based on Kelly's change requests. Also note the relative size of atoms is now correct and consistent. And, as requested, I've added a "play area color" control, so that you can experiment with background colors. Please let me know what color you'd prefer for the background, and please check your color choice with [Vizcheck](#).

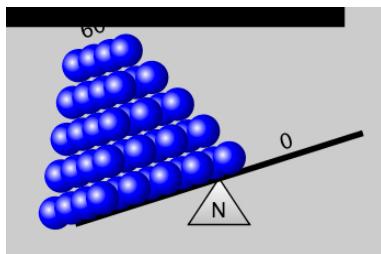
KL: I am going to let other team members suggest colors, but the new atom sizes make some of the atoms harder to count and some of the conformations look a bit off. Can we meet to do more tweaking?

TL: I agree with Kelly that the size of the particles do seem small. It is more important to me that the particles are visible than proportionate according to real scale, but I do not feel strongly about this. Thanks for doing all the color checking; I think it is important that the molecules pass color tests.

CM: We should also try to resolve the issue of larger atoms (eg, P) not fitting on the balance scales.

KL: Can you make the scales any wider?

CM: The scales could be made a tad wider (5%), but that's not enough to resolve the problem, and it makes the 3-scale case look crowded. Attached is a screenshot showing 60 atoms with diameter=110 (the max, same as P). And as you noted before, this would be a non-issue if we didn't use this representation in the Game.



KL: What is the maximum size an atom can be and still fit on the scale?

CM: The beam will currently accommodate atoms up to diameter=76pm, and that leaves no space on either end of the beam.

To accommodate the max atom diameter (P=110pm), the beam would need to be 1430pm long (a 43% increase).

Calculations:

The scale's beam is 1000 pm long, so one side of the beam is 500 pm.

The max number of atoms on one side of the beam is 60.

The max number of atoms in a triangular pile is 15, so we have a max of 4 piles.

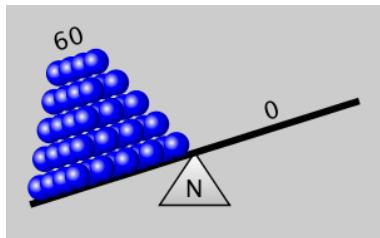
Each pile has 5 atoms along the bottom of the pile, and each new pile is shifted to the right by 1/2 of the atom diameter.

The width of 4 piles of 60 atoms =  $6.5 * \text{diameter}$ .

So the max diameter that will fit on one side of the beam is  $500/6.5 = 76$  pm.

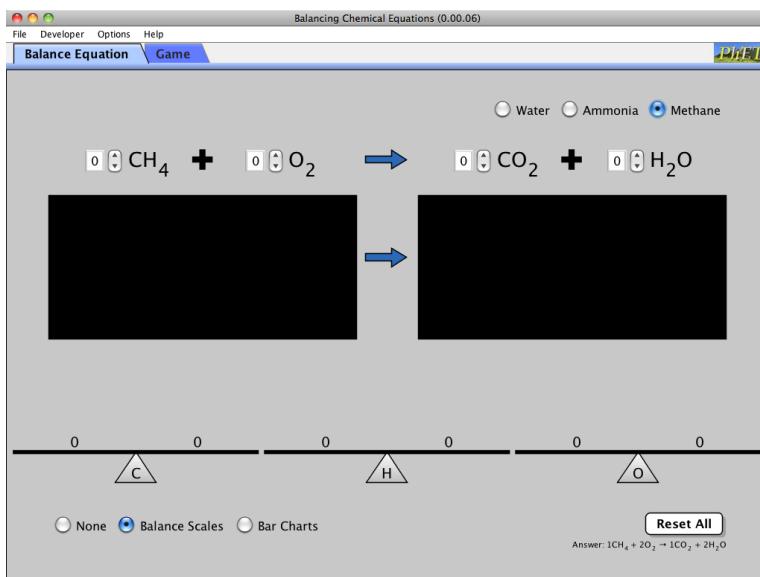
And the length needed to accommodate P=110pm is  $110*6.5*2 = 1430$  pm.

Attached is a snapshot showing 60 atoms with diameter=75pm.



KL: Can we just make the scales in the game larger? They are going to be in a pop-up window anyway.

CM: There's no way I can make the beam 43% longer, there simply isn't room. Attached is a screenshot showing the beams extended to the full width of the play area, and they are only 20% longer (1200pm). Besides the fact that this looks lousy/crammed, it will only accommodate atoms up to 92pm diameter -- so it addresses the problem for C (77pm) but not for Cl, S and P (all >100pm). And filling the play area so close to the edges is a really bad idea, since it tends to cause platform-specific layout problems.



KL: Another solution, without changing the size of the atoms, is to line the scales up vertically.

CM: Do you mean arrange the scales in a column? Each scale would need to be about 35% of the height that it is now, and I don't think that would be acceptable.

Other ideas:

- (a) Ignore the real atom sizes for the scales, and make all atoms the same size (eg, 50pm).
- (b) Use real atom sizes for the scales, but then rescale them to fit in some min/max range of display size.

KL: Yes, that is what I meant. I think it could be confusing if the atoms are the same size on the scale but not in the box, so I prefer option B.

CM: I'll hold off on implementing B until we have our discussion. I suspect that we may want to do something similar for molecules in the boxes, so that the difference between smallest and biggest atoms is not so great.

KL: How about something like this - we define P as 100pm, and scale accordingly:  
 $100 - (1/2) * (110 - x)$

So the new radii would be:

H 64  
C 84  
N 83  
O 82  
F 81  
P 100  
S 97  
Cl 95

CM: Yes, that's what I had in mind. Except that I'd keep the accurate diameters in the model, and apply the scaling in the view.

KL: One small note: the numbers we got from the textbook are radii, not diameters.

CM: Here's a version that uses this approach to scaling the atoms:

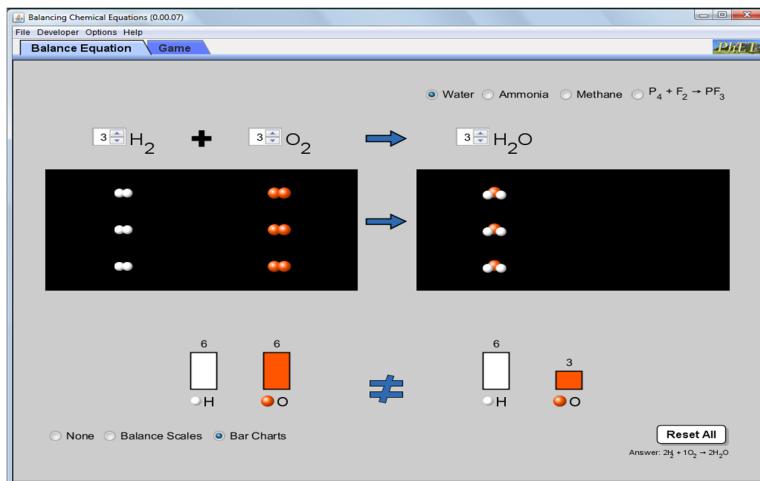
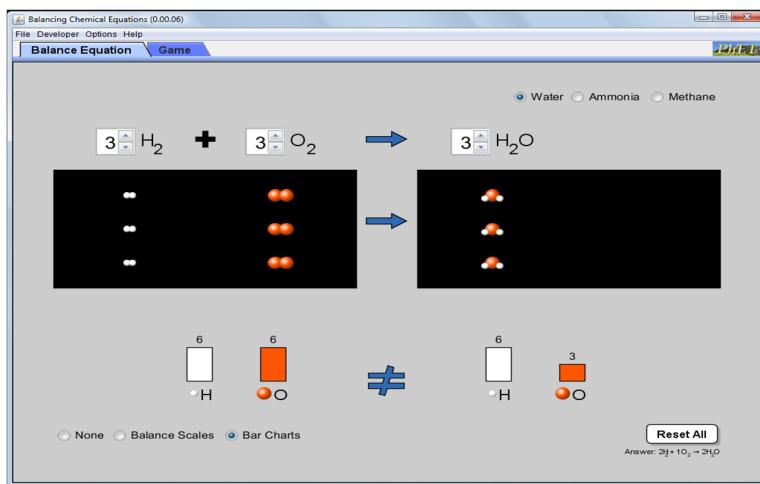
<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.07/>

We can play with the scaling factor when we meet.

Note that I added an equation involving P to the first tab in the "dev" version, so that you can see what the largest (P) and smallest (H) atoms look like in context.

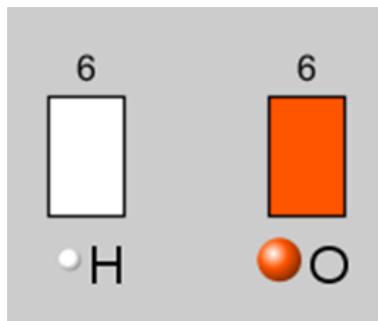
Also note that I tweaked the structure of CS2 so that the C is more clearly visible.

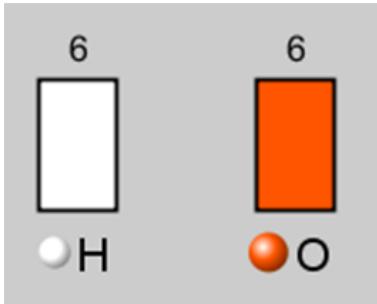
KL: Did you mean to scale other parts of the sim too? I attached a snapshot of v6 and v7. The spinners are smaller and the bar graphs look out of focus.



CM: I had to redo scaling in the entire view :-( I discovered that everything was being scaled up, and it was making the molecule images look fuzzy and jagged (see tops of molecules in your screenshot of 0.00.06). Making the spinners a little bigger is easy. I don't see a focus issue with the bar graphs in your screenshots, please elaborate.

KL: Yes, I see how the molecules are fuzzy in v6. In the same way, the edges of the arrows and bar graphs look fuzzy in v7. Switching between the two versions feels like an eye exam.





CM: Yes, I see the difference in the edges.

In v6, these things had a line of width 1, and were then scaled up 1.5x, so their effective width was 1.5.

In v7, they have a line of width 2, and are not scaled.

So v7 is 0.5 pixels wider than in v6.

In both cases the line is antialiased, but antialiasing is more noticeable when things are bigger.  
I'll try reducing the width to 1.5 or 1 and see if that is more acceptable.

#### **02/24/11 - Version 8**

CM: Here's a first look at the Game:

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.08/>

The Game is complete with the exception of 2 features:

- (1) Display balance scales or bar graphs when an incorrect answer is given.
- (2) Display a reward at the completion of a perfect game.

Feedback appreciated. Thanks!

TL: If we would like a tester, Stefan Johnson would appreciate logging some volunteer hours.

KL: The game looks great!

I'm going to wait on interviews until the first feature in your list is implemented. While you're at it, can you add a developer control to turn off this feature, so we can assess the impact of the feedback? Emily: did you still want to help with the middle school interviews?

Did anyone have an opinion on the background colors?

Loretta asked us to change some of the synthesis reactions to decomposition reactions (ie, swap the reactants and products) in the first level of the game. We may also want to do this for the water reaction on the first tab.

Based on my observations, we need more description of the reactions in the first tab: ie.,

Separate water (if we change it), Make ammonia, Combust methane.

Do we need the word "not" in front of "simplified"? It seems like the "X" implies the "not." Same for "not balanced." If we take out the word "not," the pop-up window can be narrower.

Kathy had suggested a new type of problem in the game: ie, no spinners, but ask "Is this equation balanced?" I wanted to bring this up again and get everyone's opinion.

Trish: would Stefan be testing for bugs, or to give us feedback on the design?

CM: Developer control, got it. What is your timeframe for needing this feature?

The background colors need to be neutral to keep focus on the atom colors, and to avoid ADA issues.

Molecules in the boxes look good on a dark background, it makes them stand out. But I'm not sure that black is the best choice. The 3D look of the atoms is based on a gradient between the atom color (eg, red) and black. So when the atom are put on a black background, we can't see the shadow. This makes the atoms look less 3D, and (in some cases) makes them appear less attached to the other atoms in a molecule.

It's easy to add new equations - as long as they have no more than 2 terms on either side. Just let me know what equations to add to which levels.

We would need to change to a vertical arrangement of radio buttons.

I think we have room to do this, but may need to decrease the font size a smidge.

I do think we need the word "not" in "not balanced" and "not simplified". It may be a bit redundant, but it is clear. And the checkmark and X icons may not translate to all locales. If you're concerned about the pop-up width, the savings by removing "not" is negligible, and could be gained other ways (smaller margin, smaller font,...) The popups are also moveable.

Ugh. When was this proposed? This is the first I've heard of it, and there's no mention of it in the Game section of the design doc. Adding another type of problem is going to be very costly at this point. The Game implementation is currently lean and mean, and was relatively inexpensive to implement -- but that's because it doesn't have a lot of flexibility built into it, and it can only handle one type of problem. If we introduce new problem types now, I'm going to be essentially starting over, and it's going to be more complicated. (Related note: In talking to Sam and JB, they said that the Build An Atom game was very costly and complicated. If we're going to continue implementing these types of Games, we should investigate a reusable framework.)

KL: Emily is going to be doing middle school interviews during Spring break, so before then.

We would use the same equations, but swap the reactants and products. For example,  $2 \text{ H}_2 +$

$1 \text{ O}_2 \rightarrow 2 \text{ H}_2\text{O}$  would become  $2 \text{ H}_2\text{O} \rightarrow 2 \text{ H}_2 + 1 \text{ O}_2$ . We only need to do this for some of the equations in the first level of the game.

Kathy suggested the new problem type a couple of weeks ago - I put it in the Discussion section. I only wanted the team to be aware of this, no need to implement.

EM: BCE Colors:

I don't have strong feelings about this, but after playing around I found two cases that I thought looked good.

- Boxes a light grey (RGB = 102, 102, 102), play area white
- Boxes a light grey, play area light blue (RGB = 204, 204, 255)

### **02/28/11 - Version 9**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.09/>

CM: New in this version:

- "Developer->Show bars/scales in Game" menu item, ON by default. This shows bar charts or balance scales in the Game when a "Not Balanced" answer is given. The charts/scales appear in the "Not Balanced" popup.
- "Developer->Show answers" menu item, OFF by default. The answer always appear below the left box. I made this a menu item in case you need to use the dev version for interviews.
- Equation choices in the first tab use the same verbose names that we used in RPAL (eg, "Combust Methane") and the radio buttons are vertically arranged. No one commented on Kelly's suggestion to do this, so I figured I'd try it. Easy to revert if you don't like it.

Finally... With the exception of the reward at the end of the Game, this sim is complete. Please take some time to provide feedback so that we can start to wrap this up.

TL: I like the changes.

EM: Everything you mention below looks good to me. Seems like grey is a rather drab color for the background, but if no one else objects I'm sure it's fine as it is.

CM: I realize that PhET generally thinks that more color = more fun, and I continue to strongly disagree. Every user-interface designer should be forced to read the "Color and Information" chapter of Edward Tufte's "Envisioning Information", one of the classic books on presenting information. Judicious use of color is the key to an effective user interface, not making things look like an angry fruit salad :-)

That said... Feel free to suggest a different color for the background. We already have quite an array of atom/molecule colors, and there are 2 very good reasons to stick with a drab background color: (1) The eye is drawn to color, so color should be reserved for things that you

want the user to focus on (ie, atoms, molecules, bar chars, etc. -- not backgrounds). (2) Colorful backgrounds complicate the ADA issues, both for colorblindness and for other forms of vision impairment, and we've already spent a lot of time developing a color palette that is colorblind friendly.

Btw Emily... I realize that you did suggest other background colors, and I appreciate the feedback. I haven't changed the colors because I don't think that consensus has been reached. If anyone else on the team has opinions on the colors, please speak up now.

KP: I respect your concerns, but I would also favor exploring alternative background colors. Perhaps we won't find one, but I'd like to explore some options. Emily, Kelly, do either of you have time to explore some options?

CM: Why not use the same colors as RPAL? We spent lots of time choosing those colors (light blue play area, dark blue boxes). RPAL and BCE use the same set of atoms colors, and have very similar interfaces (equations, 2 boxes, bar charts, Game, etc). So I'm wondering why we're going through this again -- Is the goal to make these sims look different? Did people not like the colors in RPAL?....

It's also too bad that we spent time tweaking the color palette for ADA compliance before getting this input. Everything will need to be run through Vizcheck again.

EM: While I haven't read the chapter you mention, I agree that color should be used judiciously. Of the two color options I suggested, my favorite is a white background, with the boxes a very dark grey.

CM: About the "Developer->Show bars/scales in Game" menu item...

Please provide feedback on the use of the bar charts and balance scales in the Game. Some of the questions that we wanted to answer:

- Do they contribute in a positive way to understanding how to balance equations?
- Do they help solve the Game problems?
- Do they make the problems too easy to solve?
- Do they make the problems more difficult to solve by obscuring other things that are more important?
- Is there enough room on the screen to show these representations?
- Will students realize that they can be dragged out of the way?

KL: Thank you for adding the developer controls! I will add your list of questions about the game to the interview protocol.

Equations:

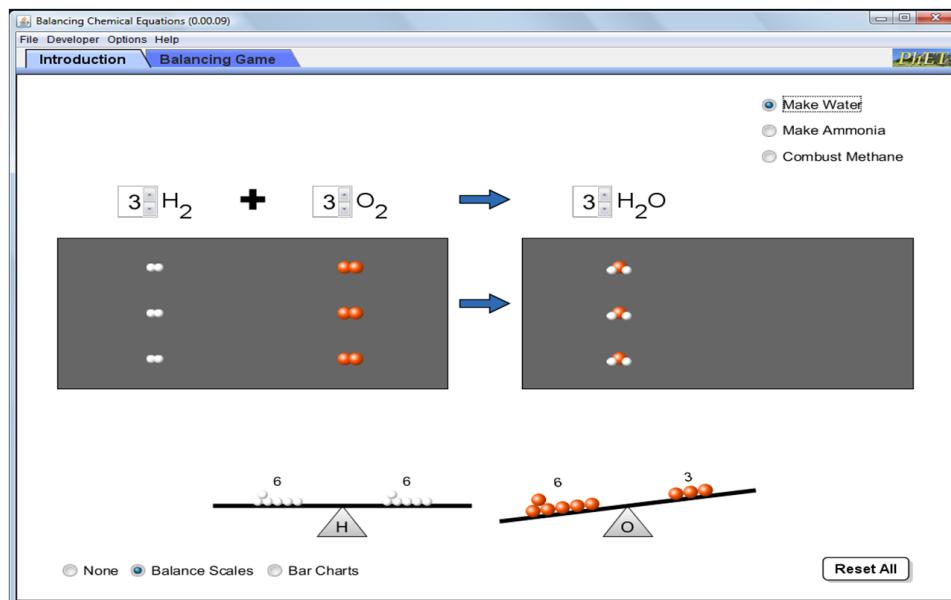
Can we try a horizontal layout for the radio buttons? Not as a permanent change, just to see how it looks. Also, I had suggested that we change "Make Water" to "Separate Water." Did

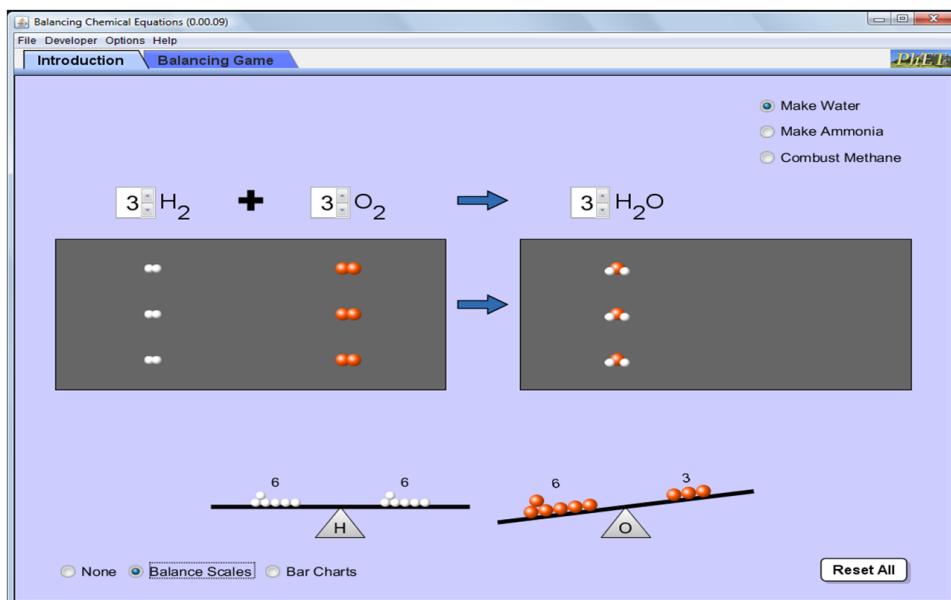
anyone have an opinion on this? I do think if we ask the advisory board for feedback, we should heed their advice.

Colors:

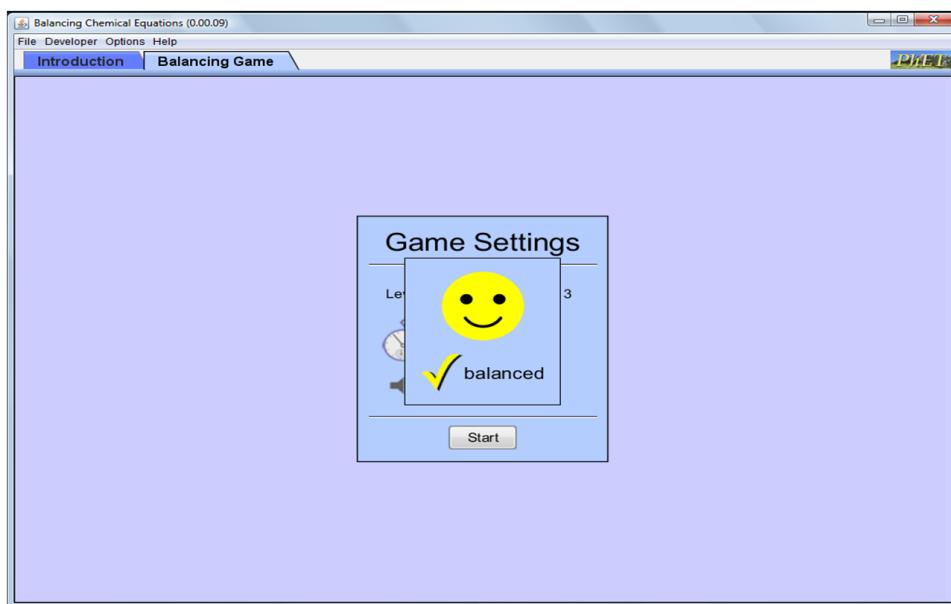
I am not sure if we ever tested the RPAL sim for colorblind issues. As I recall, the dark blue was the default fill color in Powerpoint, which I used to make the mockup. I do not recall spending any time discussing the color. This is the reason I did not include color in the mockup for the BCE sim.

Below are images of the two color options suggested by Emily. The problem with a white background is that H atoms are also white, so it is hard to see them on the scale. I do think we need to be in the same room with our computers when we discuss color, since each display is different.





Also, I saw this bug after I played a game and hit "New Game" in the Game Over dialog. It did not seem to happen when I got the last equation in the game wrong.



CM: Thanks, I noticed that too, it will be fixed in 0.00.10.

TL: Although I like showing the bar and balance after an incorrect answer because I believe it will help the students think about the problems in multiple ways, the idea that you bring up about the molecules being hidden is important. I also wondered how many students will realize that the box can be moved to view the molecules. I don't know how we would learn the answers to these questions without interviews. I believe one of the things that came out of the post-mortums was that interviewing during the game development was important because we do not

really know how students use games.

KP: I like the feedback as it is now.

- Do they contribute in a positive way to understanding how to balance equations?

I think yes.

- Do they help solve the Game problems?

A little bit, but not too much. They help you digest which has too many, but when you have to redo it, you still have to think.

- Do they make the problems too easy to solve?

I don't think so.

- Do they make the problems more difficult to solve by obscuring other things that are more important?

I don't think so

- Is there enough room on the screen to show these representations?

It worked for the combinations I got when I played.

- Will students realize that they can be dragged out of the way?

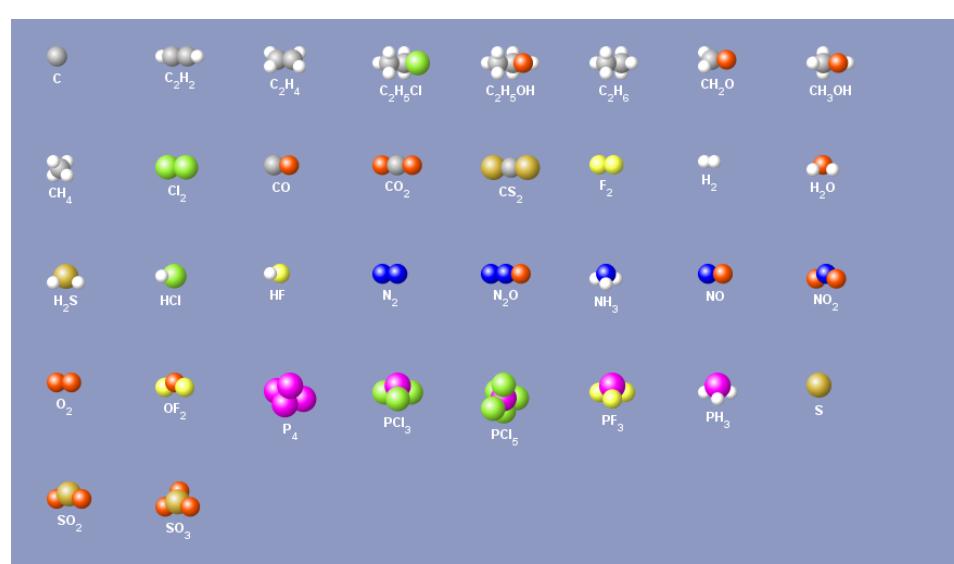
No, I don't think so, but I didn't feel the need to drag them out of the way either.

KP: It does seem useful to have the sims look somewhat different.

I did a bit of playing. What do folks think of this background color, with the black boxes for the place where you put the molecules? There are other options, I'm sure, this is just 1 suggestion that seemed reasonable given all of the colors used for the molecules.

R=142, G=153, B=193.

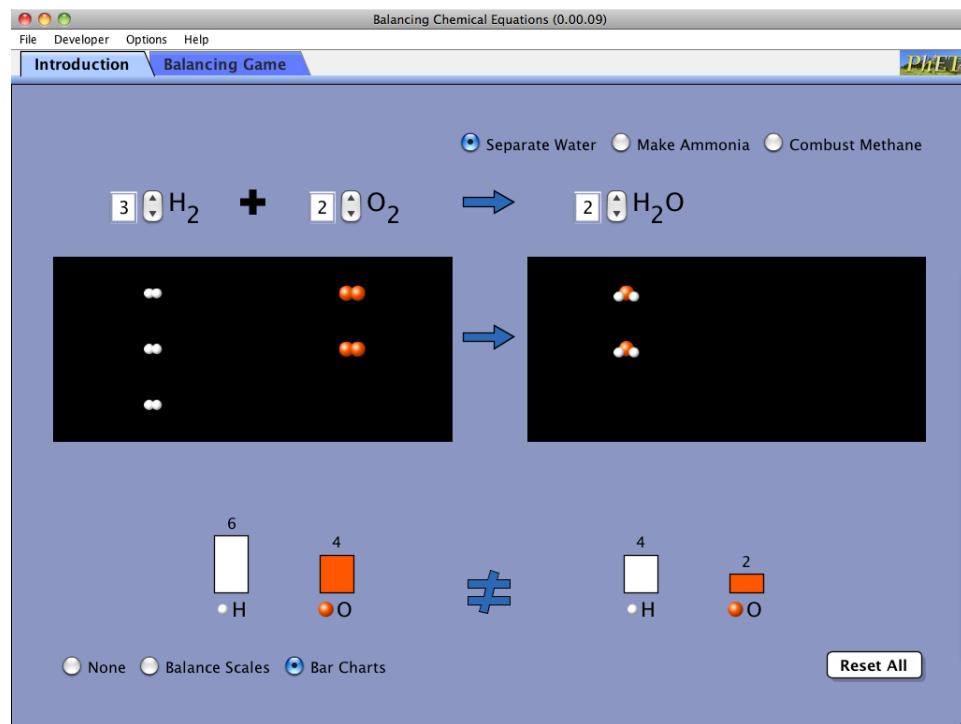
This works on VisCheck.



CM: Thanks. I'm keeping track of color suggestions in the sim's TODO file, will add this one.

Let me know if I should create dev versions for Emily and Kathy's specific color suggestions.

As for this shade of blue... It looks good in the test-app screenshot, but seems a tad dark to me in the sim (see attached screenshot). The black text and blue arrows might be hard to see on a projector (I'll try to remember to check at Thursday's status meeting). Changing the text color is doable but costly, and providing a developer control isn't an option.



TL: Two students and I thought this looked nice projected on my Smartboard.

CM: Please clarify: Were you looking at the screenshot that Kathy provided, or did you change the sim to use the color that she suggested?

TL: I just looked at the screen shot, I didn't know there was a difference. I can check something out on my Smartboard tomorrow again if need be.

KP: I'm fine with Separate Water (basically flipping it, right). Seems like good to have a dissociation in there.

Horizontal layout of radio buttons is fine with me. I like how that works in RPAL. It could cause some problems in translation because of overlapping text, but seems like there will be enough room though.

CM: Layout of radio buttons in RPAL is horizontal only for the Sandwich tab, it's vertical for Real Reactions tab. You can see vertical layout in BCE 0.00.09, horizontal layout in BCE 0.00.10 (I don't have a preference.) My left-to-right brain still doesn't like the buttons at top right, but not enough to try to influence a change.

**03/01/11 - Version 10**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.10/>

CM: Changes in this version:

- Completing the game with a perfect score displays a reward. The reward is identical to what we did in RPAL: falling images. The images vary by game level: 1=atoms, 2=molecules, 3=smiley faces. If you want to experiment with reward parameters, run the test-game-reward app. If you find something you like better, send me the parameter values (or a screenshot). Each game level can have its own set of parameters, so it's easy to vary the animation speed, number of images, types of images, etc.
- Equation radio buttons are horizontally arranged.
- Radio button "Make Water" is now "Separate Water". (Will we need to change this in RPAL, too?)
- fix: "Balanced" popup goes away when game is completed.

This sim now contains all requested features.

KL: When I suggested that we change "Make Water" to "Separate Water," I meant that we should reverse the reaction. Thus,  $2 \text{ H}_2 + 1 \text{ O}_2 \rightarrow 2 \text{ H}_2\text{O}$  would become  $2 \text{ H}_2\text{O} \rightarrow 2 \text{ H}_2 + 1 \text{ O}_2$ . This is because Loretta asked us to change some of the synthesis ("make") reactions to decomposition ("separate") reactions. I realize this would leave a big space on the left side of the equation, so if we decide to do this, we may want the default reaction in the first tab to be "Make Ammonia."

CM: I investigated reversing reactions, and there's going to be a little programming (1-2 hours?) involved to support layout of equations that have only 1 term on the lefthand side. Do you want me to go ahead and do that, reverse the water reaction in the first tab, and make ammonia the left-most radio button?

KL: Yes, since we also need to include reactions with only one reactant in the first level of the game.

CM: Will all of the reversible reactions have 1 reactant and 2 products? I'm having to change some fairly fundamental things in the model and view, all of which was built on the assumption that equations have 2 reactants and 1 or 2 products.

KP: Looks good - with exception of change to water equation, but you are on that already.

**03/01/11 - Version 11**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.11/>

CM: Changes:

- Added support for decomposition reactions.
- Replaced "make water" equation with "separate water" equation on first tab.
- Added "separate water" equation to the set of level-1 Game equations.
- "Make Ammonia" is now the default selection on the first tab, and appears first in the group of radio buttons (where "first" is leftmost for horizontal layouts, and topmost for vertical layouts).

Let me know when the additional decomposition reactions have been added to the design doc and I'll add them to the sim.

KL: I highlighted the reactions that should be reversed in the design doc. They are all in level 1, so they will all have 1 reactant and 2 products. The reversed reaction should replace the original reaction, to keep the same number of reactions (21) in level 1.

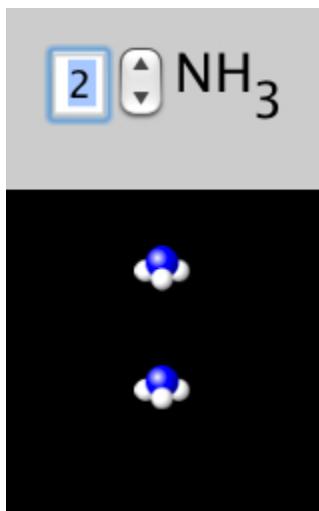
We may also want to \*add\* some reversed reactions to level 3, since there are only 7 equations. This may keep students from memorizing the coefficients.

CM:  $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$  is partially highlighted in the doc, not sure if that's significant.  
Do you want me to replace it with the decomposition reaction? (in which case there will be no "make water" equation in the sim)  
I currently have both  $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2$  and  $2\text{H}_2 \rightarrow 2\text{H}_2 + \text{O}_2$  in the set of level 1 equations, making 22 equations.

KL: The partial highlight is from a comment you wrote. I wanted to keep the "make water" equation in the game, since "separate water" is already in the first tab. I do not think we need the "separate water" equation in the game too.

### **03/01/11 - Version 12**

CM: Something odd/subtle that I'd like you to watch for in interviews. When pressing the up/down spinner arrows for coefficients, I sometimes get confused and press the wrong arrow. For example, if I have 2 NH<sub>3</sub> like this:



...then I'll try to get to 1 NH<sub>3</sub> by pressing the up arrow. I think this is because I tend to look at the molecules in the box, not the coefficient numbers, and the stacks of molecules move in the opposite direction as the arrow that's being pressed. And after pressing arrow for awhile, I start to think in terms of the motion I see in the boxes, not the value of the coefficient.

I'd be curious to know if any students (or other team members) have this problem.

KL: Yes, I see what you mean. I do not recall seeing this in the first round of interviews, because most students only paid attention to the effect of the coefficients on the scales, not the molecules in the box. But I (and Emily) can watch for this in the next round of interviews.

CM: Just for kicks, here's a version that creates stacks of molecules from the bottom up:  
<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.12/>

Pros:

- The piles grow/shrink in the same direction as the spinner arrows.
- The piles grow/shrink in the same direction as the bar charts.

Cons:

- In the Game, there's a lot of space between the spinner and where first molecules appear, because the boxes are so tall.

**03/02/11 - Version 13**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.13/>

CM: Changes:

- Level 1 reactions have been changed as indicated in the design document. Each reaction highlighted in yellow in the doc has been replaced with the reverse (decomposition) reaction.

- Since the Game selects equations at random, and since adding decomposition reactions required so many changes, I thought it was important to provide an easy way to test all equations. For this purpose, I've added a "Developer->Game: play all equations" menu item. If this is checked, then the Game will step through all equations for the selected level, in the order that they appear in the design document. I have tested all of the equations, but it might be good to have another set of eyes run through them.

KL: Thank you for the "play all equations" menu item - I tested the equations in level 1, and I did not see any issues.

I really like the decomposition reactions in the game - they actually threw me off at first!

I will ask Kathy D to recruit some middle school students for interviews next week, since spring break is a ways off. It seems like we'll definitely want to try the game with and without feedback. Are there other configurations you'd like us to try?

Also, can you bring your copy of Edward Tufte's "Envisioning Information" to the PhET meeting tomorrow?

KL: Here is the protocol and post-lab I plan to use in interviews next week. Emily: feel free to alter or add to this.

I had a thought while working on this: Can we enable students to close the pop-up window in the game? The only way to get rid of it now is to press "Try again" or move it out of the way. It seems like all pop-up windows should be close-able.

CM: Close buttons on all Game popups:

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.14/>

EM: Looks good! Having the popups be closeable might help students recognize they can move the box, also.

**03/07/11 - Version 15**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.15/>

CM: Changes:

- Added a bar at the top of the Game popups that makes them look like dialogs.  
(It would be interesting to see if this encourages dragging in interviews.)
- source code documentation
- internal cleanup/refactoring to reduce future maintenance costs

TL: I certainly like the new bar on the top. As you say it will be interesting to see if it makes students move it to look at the molecules.

KL: I also like the bar at the top of the popup.

I interviewed a middle school student yesterday on v14. He did move the popup to look at the molecules, but only after he had played 3 games at level 1, and 1 game each at levels 2 and 3. Before then he just closed the popup.

I will use v15 in my next interview with a college student tomorrow.

CM: Did he close the popup every time it was visible?

Or did he sometimes leave the popup alone and press the yellow button?

And when he moved the popup, did he grab it by the bar at the top, or somewhere else?

KL: Yes, he \*always\* closed the popup before he pressed the yellow button. There was no bar at the top in the version of the sim we used yesterday.

CM: If this turns out to be common behavior, then it would be interesting to see how students behave with a version that has no close button.

KL: Yes - would it be more interesting in the case where there is feedback, or when there is none?

CM: By "feedback" do you mean "showing balance scales or bar chart"? If so...

I think it would be interesting in any case, feedback or not. If users feel required to dismiss popups before continuing, then that's adding an unnecessary step to game play. And if you don't see anyone closing the popup because it's affecting their ability to reason about the correct answer, then the close button is not serving its intended purpose, and it might be better to get rid of it. In that case, we'd like to know: if there's no close button, do users press the yellow button (eg "Try Again"), or do they look for a way to close the popup?

KL: Yes, that is what I meant by "feedback."

So I've done one MS interview with feedback and a close button.

How about this for the next 4 interviews:

1. Feedback, close button, bar at top (college)
2. No feedback, close button (MS)
3. Feedback, no close button (MS, Emily)
4. No feedback, no close button (college)

CM: Sounds good.

EM: Sounds good to me, also.

KL: I just heard from two more college students, so here is the revised plan:

1. Feedback, close button (M, ms)
2. No feedback, close button (M, college, Emily)
3. Feedback, close button, top bar (F, college)
4. No feedback, close button, top bar (F, ms)
5. Feedback, no close button, top bar (F, ms, Emily)
6. Feedback, no close button (M, college)
7. No feedback, no close button (F, college)

Chris: I assume you will add developer controls for the close button and top bar? The next interview is at 10am tomorrow.

CM: I wasn't planning on it, and it's nontrivial. Is there any reason why you can't use older dev versions? If not, it would be easier to simply build you some dev versions with these features hidden.

### ***03/08/11 - Version 16***

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.16/>

CM: Requested changes:

- Added 2 menu items to the Developer menu, for hiding the close button and top bar in Game popups (to be used in interviews)
- Added 7 equations to Game level 3. They are the reverse versions of the original level-3 equations.

Let me know if you need anything else.

KL: Thanks, it will be interesting to see all the permutations in interviews!

KL: One thing I noticed: in the RPAL and BAA games, we show how many points the students earn (+1 or +2) along with the smiley face. But we do not show this in the BCE game. I feel like we need to show the points - what do you think?

CM: What do I think?... Hmm... I think that this feature is in version 0.00.17.

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.17/>

### ***03/10/11 - Popup window***

Notes from PhET meeting:

**KL** – Emily and I have been doing college and middle school interviews. It seems like there is not a whole lot of differences between the two. One thing that we are trying in interviews... is what do students do if there is a close button on help box. Do students know that they can move it? What would they do if we made a bar at the top to make it look more like a window.

**CM** – by putting the close button there it is adding another hurdle to them progressing through the game.

**NP** – maybe could extend blue box down so that ‘Try again’ Button is in?

**CM** – I think we should just remove the “X” on box. So then they will just intuitively hit the ‘next’ button.

**KL** – in interviews they are sometimes not even using the dialog box... they just think “I got it wrong...” and close and retry.

**CM** – the only reason the dialog is movable is that we can have a way to show what is behind it.

**NP** – Kelly what are you seeing students doing?

**KL** – so far we have done 3 interviews. They have feedback with dialog box when they get it wrong. 1 student never moved it. And 1 student figured out he could move it... after he used it he thought it was helpful. So is there a way to let them do that without having them close it every time?

**NP** – is there a way to fit what the user entered into the dialog box.

**EM** – particularly with level 2 and 3. The user stopped using representations of molecules because they just got too small.

**CM** – I think if we backtracked all the way...to where we get back to – here’s the feedback on what you did... and now we are trying to jam all this information in it.

**KL** – so far the dialog box doesn’t seem like it is particularly useful.

**EM** – It seemed like when he used the scale in the first part it seemed like he never actually used them to help with the molecules... he just used them to help with themselves.

**RP** – so the student isn’t connecting the representations.

**KL** – The student I interviewed went back and forth and tried to connect how big the bar charts were with the molecule amounts.

**NP** – how do you weigh the benefits of the dialog box versus the problems associated with having it?

**KL** – I don’t think it is hurting and it may be helping a little.

**CM** – it was decided to make the dialog a random help.

**NP** – it sounds to me like you want some feedback on why the equations aren’t balanced. And that is what I mean... you don’t really need an extra representation showing that equation is balanced/not balanced. And if it is not helping or hurting... then it is just adding a piece of complexity.

**NP** – adding it as additional feedback seems like it is just shoving additional representations in student’s faces. How do we get them to understand how to work this? It also seems like because the representation they get is a random help dialog, it may confuse them into thinking that there is a reason they are being shown bar chart versus a balanced scale.

**EM** – I interviewed on this version [dialog box no help representation... but with close button] and user closed box every time.

**NP** – it seems like it is not worth it to have dialog help representation. Students should really be trying to understand the representation in the game. And the other representation adds a necessity for them to understand that and how it is connected to actual game representation. One of the things that came up at a conference I was just at... is that it is always a good idea to get 70% of the utility at 40% of the cost.

**CM** – I have run into this too where we will encounter an issue that takes 20% of sim but takes 90% of time.

### **03/15/11 - BCE Interview**

**KL:** Thanks! I put your notes in the G-doc. I thought the coefficient of 1.5 was very interesting - both because she used it, and also because she felt like it was wrong. Did you want to talk about any possible changes to the sim as a result of the interviews?

**EM:** I don't really see any issues with the sim. Students seemed fine without the feedback, and with or without the close button on the popup box, students seem to catch on pretty quick (so I don't really have a strong opinion about whether it's there or not). Students didn't use the 'reset' button on the first tab, but that didn't seem to be a problem. I think it's great that the sim doesn't open with balance scales, because sometimes that is distracting...but I think it's through use of the balance scales that students really develop comfort with using the 'balance the equations'.

You might want to put in the teacher tips a comment regarding simplifying (that students will get a prompt that they haven't simplified). It didn't throw off the student I interviewed who found it, but she never quite figured out what it meant. She could fix the coefficients, so that the answer was accepted as simplified, but this didn't seem to be a robust understanding for her.

**KL:** Yes, there is a note in the G-doc to tell teachers that "we expect least coefficients, but do not specify in the sim", so I will expand on that in the tips. Thanks for your help with the interviews!

### **03/17/11 - Popup window, Part 2**

#### Notes from PhET meeting:

**KL:** There was little difference between Middle School and College. The talk that we had last week was about feedback in game. We tried all sorts of different feedback options. When there is a close button... students close it before they hit next – so close button needs to go. Only 1 student actually moved dialog box. They didn't seem to be using it to see why it is wrong.

**KP:** they didn't actually look at the direction it is wrong.

**KL:** Most of them were using the picture to match the green balls etc.

**TL:** the middle school students haven't had experience with balancing? Because I got a lot of questions at booth about having scales.

**KL:** I think when students started out they would accidentally get a smiley face then use the scales.

**CM:** to summarize from last week is that the reason they are not useful is that you can't

compare what is in the boxes at the same time.

**KL:** Could be an optional feature that could be turned on.

**KP:** I know they didn't use it actively. I still feel like it is a useful way for them to think. I guess I am wondering if they close it right away is it getting in the way?

**CM:** I don't think anyone thinks this isn't useful... but because you can't see both views it is hard to use.

**KP:** what if in the balanced dialog box there is a check box that says "show scales".

**SR:** what do you think about making the scales viewable in play area. Without obscuring what user created.

**CM:** we investigated early on... for most of game you would have blank game area. We don't want to shrink molecule size down (want to make consistent). And it is easier to compare and count if you have things in line.

**TL:** also in the game.. there are a lot more molecules.

**MD:** so when they show answer vs not show dialog. It could condense play area to show both play and scales.

**SR:** or distort them?

**CM:** we could put a check box in here but there is still no way to compare it to what they did.

**KP:** but then they could check it and see then hide it and look at the molecules.

**KP:** I think Kelly would not like feedback there... but I like the option of having it.

**KL:** would it be good to have a check box "show why..." One guy was curious why he received scales or bars? One student liked bars because she could see both sides.

**CM:** if we still want random it would be generic.

**KP:** I like show why

**KL:** I like it because it gives them a choice

**CM:** "show why" button then

**KP:** then it will stay random

**KL:** but no close button

**KP:** and make it so they can show... then hide if they want to see whats behind it.

**TL:** I like the fact that they can see the molecules and make sense of it if they want.

**CM:** one more thing on this... the drag bar on the top?

**KP:** last thing we need to talk about is colors... will wait for Emily and try to set up a time next week to meet.

**CM:** did anyone else have same problem where I'm playing the game fast where arrows go in opposite direction as molecules increase. [Upside down bar graph]

**KP:** didn't see a lot of trouble with that? [no]

**KL:** the only other thing is the equations in level 3 are very similar. After a while, students would figure out a trick ... balance hydrogen's first. Because we artificially grew the amount of questions we just flipped the previous questions.

**CM:** I would have to actually look at the equations

**KL:** Other way would be to simplify the equations. These are considerably longer than others.

**CM:** will pick one equation for existing list then pick another from another list... so that there are not too many similarities

**KL:** In the meeting today, we decided to give students the option of feedback when they are

wrong: Chris is adding a checkbox for "Show why" under the "Not balanced" popup.

It seems like we should interview at least one more student to see how this works. Can you use one of your middle school interviews next week for BCE, or do you have other plans already?

EM: Doing another MS interview on BCE next week will be fine.

### ***03/17/11 - BCE Level 3 equations***

KL: I changed the equations for level 3 in the G-doc (or at least how we determine which equation is used). I also copied them below. Let me know if this makes sense.

CM: Ugh... I just finished implementing what we discussed at this morning's meeting, which (I thought) was having one separate category with all the reactions that include 6 H<sub>2</sub>O and 4 NH<sub>3</sub>, and picking one from that category. I didn't anticipate this in the new design, so I'm going to have to start over. That's OK if this is really what you really want. Also be forewarned that this design will require the number of equations per game to be 5, because you have 5 "pick one" categories. That number is currently flexible. Shall I proceed?

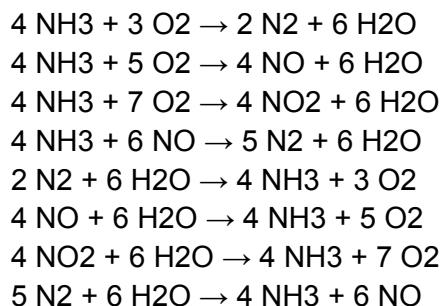
KL: Maybe I did not understand what we decided at the meeting.

CM: Here's what I understood at the meeting:

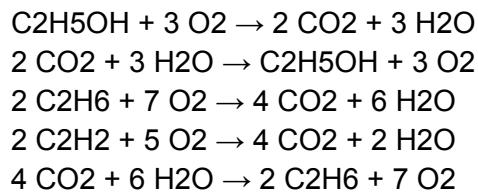
Problem: Students are getting too many level 3 equations that contain both 4NH<sub>3</sub> and 6H<sub>2</sub>O.  
Solution: Limit level 3 games to include only 1 equation that contains both 4NH<sub>3</sub> and 6H<sub>2</sub>O.

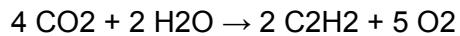
So now I have 2 collections of equations for level 3:

Pick 1:



Pick 4:





It looks like you've refined this with "don't include the forward and reverse of the same reaction" -- unless the reaction involves  $4\text{NH}_3$  and  $6\text{H}_2\text{O}$ , then it's for some reason OK to include both the forward and reverse reactions (which can happen when "picking 1" from your last 2 categories).

Proceed or wait until I talk to you? (Tomorrow morning)

KL: Your problem statement is correct, but I think we can include 2 equations that contain  $4\text{NH}_3$  and  $6\text{H}_2\text{O}$ , as long as one of the equations is reversed. I am not sure that students notice when they get the same equation twice in one game. (And if you look closer at my categories, I actually say it's OK to include both the forward and reverse of the same reaction, except for the one with  $\text{C}_2\text{H}_5\text{OH}$ .) That would mean we only need to pick 3 from the remaining 6 equations, instead of 4. There is already not a lot of replay value in the game, so this could help some...

**03/17/11 - Version 18**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.18/>

CM: Changes:

- close button and top bar are hidden for Game popups (but still accessible via Developer menu)
- added the "Show Why" feature to the "Unbalanced" popup (can be disabled via Developer menu)
- rewrote the strategy for level-3 games (but apparently didn't understand what Kelly wanted, so will be revising again in the next version)

Some more notes about the "Show Why" feature... Deciding where to place the popup as it is expanded/collapsed was an interesting problem. Most of the time the right thing to do is to keep the top center location of the popup constant, so that the "Show Why" and "Hide Why" buttons remain in the same place, making it easy to toggle back and forth. The exception to this is when expanding the popup covers the "Try Again" (or "Next") button. Covering that button could put the user in a blocked state, especially if they haven't discovered that the popup can be moved. So if the popup would cover the button, I am moving the popup up to ensure that the button is not covered. Personal opinion: I'll be surprised if anyone uses this feature more than once, and I seriously doubt that anyone will toggle Show/Hide to compare with the molecules in the boxes. And I hope I'm wrong because this was an expensive change, a total rewrite of the "Unbalanced" popup.

KL: I actually like the "Show Why" button, but I think "Hide Why" is weird. Maybe because of the wording? When we let students "Show Answer", we do not give them the option to hide it again, so do we need a "Hide Why" button?

KP: I like the "Show Why" also.

A few suggestions:

- moving the response box up so it starts near the top between the black would mean that that essentially you would more rarely have to have the box "jump" to a new height. I think it looks fine there, but see what you think (screenshot below). Could be even higher ... I find with it higher it seems to draw my eyes up to the equation some, myself.
- If students don't hit the Show Why at all (e.g. don't see it), we might need to investigate other colors for it. It doesn't have the button behavior of changing shade when you mouse over because it is white.
- After playing with it, I don't have a strong feeling either way about the "Hide Why" button. I'm fine with removing it, or leaving it.

KL: Emily is going to do another MS interview on Monday, so we will find out soon how (or if) students use the "Show Why" button.

CM: Popup position: In its current position (centered), I've only seen the box jump up if the user has moved it down. Have you seen otherwise? If so, with which equation(s) and which representation (bar charts or scales)? Easy to change the default position, I just want to make sure the change is to solve an actual problem.

Button color: I chose white for the "Show Why" button because we have consistently used white in this sim for the ancillary buttons (eg, "Reset All", "New Game", "Start Game") while reserving the bright color (yellow) for the primary button. If you don't think that consistency is necessary, then I'd suggest a slightly paler shade of yellow than the "Try Again" button, which should make it obvious that it's another button, but make it slightly less "eye catching" than the "Try Again" button. I'll add this to the "decide on colors" list.

Hide Why button: I'll be happy to remove it. But in yesterday's meeting we said that it was necessary to enable comparisons between the balance scales (or bar chart) and the molecules in the boxes. If we remove the "Hide Why" button, then we're back to the problem of being unable to compare representations, due to the size of the popup. And we've demonstrated that moving the popup is not a solution to this problem. So I recommend that we leave it in for interviews, to see how students use it in the context of this "Show Why" feature.

### **03/18/11 - Version 19**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.19/>

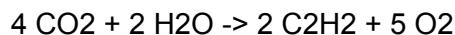
CM: Changes:

- equations for level-3 games are chosen as per the new specification in the design document. (Kelly: I amended the spec per our phone call today, noting that reverse of 4NH<sub>3</sub> reactions are excluded.)

KL: I like how this works for the 4NH<sub>3</sub> reactions. I noticed that you can still get the same

equation (albeit reversed) for the other reactions.

For example, I got these 2 equations back-to-back in one game:



How hard would it be to extend your code to all of the reactions in level 3? I am not sure that many students will notice when they get the same equation, but if it's not too difficult...

CM: The design spec indicates that reverse reactions are to be excluded only for equations involving C<sub>2</sub>H<sub>5</sub>OH or 4NH<sub>3</sub> (groups 1, 4 and 5 in the doc). It says nothing about excluding all reverse reactions, so that's why you're seeing what you described.

When I wrote version #3 of the game code, I made it as general as possible. For each equation, you can specify a list of equations to exclude. So it's easy to exclude the reverse of every reaction. Is that what you want?

KL: Yes!

CM: OK, will do.

EM: I observed a middle school student getting the same equations (once forward and then once reverse). She didn't notice at all...she was focused on counting atoms.

This also made me think that having the Build a Molecule sim prior to BCE would be good, students might start recognizing molecules, as well as counting the atoms. For the one middle school student I interviewed, she would only call water by name. Perhaps we should try to include the molecules in BCE into Build a Molecule to help with this.

KL: Yes, the college students did not seem to notice either, but it could be an issue in a classroom setting.

Maybe we can add a note in the teaching tips that the BAM sim is a good precursor to the BCE sim?

KP: I like this connection.

Let's be sure to list them as "related-sims" on the website. That feature is now live, and will be visible if a sim has something listed as related.

I like idea of looking at molecules in BCEs and see which are easy to include in BAM.

CM: Are BCE and BAM using consistent representations for molecules and atoms (colors, 3D look, etc)?

Or maybe that's not important...

KL: Yes, I am pretty sure they are planning to use Piccolo for the molecules in BAM.

CM: Adding JB to this thread...

John, it sounds like there's a need for consistent representation of molecules/atoms in BCE and BAM.

So let's coordinate to make that happen.

BCE uses Piccolo rendering via ShadedSphereNode.

Ticket #[2773](#) deals with generalizing the BCE implementation and moving it to common (piccolo-phet package).

KP: cc'ing Jonathan because he will be lead on BAM ... with John B partnering.

### **03/18/11 - Version 20**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.20/>

CM: Changes:

- exclude the reverse of all selected equations in level-3 games

I updated the "Level 3" section in the design document to better describe the strategy used in level 3, and to indicate the set of exclusions for each equation. Kelly, please review to make sure this describes what you want. Also please search for "Kelly, please explain" and describe the one heuristic that I don't understand.

KL: The strategy in the G-doc looks correct. I played a game at L3 and it also looked correct.

The reason for not allowing both forward (or reverse) C<sub>2</sub>H<sub>x</sub> reactions in the same game is similar to why we only allow one forward (or reverse) 4NH<sub>3</sub> equation - students can use a similar strategy to balance both equations.

CM: OK, thanks. Here are the revised rules from the design doc:

- > (1) don't include the forward and reverse versions of the same equation
- > (2) include at most 1 equation that has 4 NH<sub>3</sub> as a reactant and 6 H<sub>2</sub>O as a product
- > (3) include at most 1 equation that has 4 NH<sub>3</sub> as a product and 6 H<sub>2</sub>O as a reactant
- > (4) include at most 1 equation that has C<sub>x</sub>H<sub>x</sub> as a reactant
- > (5) include at most 1 equation that has C<sub>x</sub>H<sub>x</sub> as a product

### **03/28/11 - Game changes**

KL: Emily did an interview with a middle school student last week. Her notes are below.

It seems like we could make a couple of changes to the sim as a result:

1. Use scales only for feedback in level 1, a mixture of scales and bars in level 2, and bars only in level 3.
2. Restrict level 1 equations so that ones with big molecules (e.g. C<sub>2</sub>H<sub>6</sub>) cannot be first.

Let me know how this sounds or if you have any questions.

CM: Change request #1 is relative easy, 1-2 hours.

Change request #2 is difficult. I'll call you to discuss.

KL: Do you recall how (or if) the student used the "Hide Why" button? Based on your interview, do you think we should keep the "Hide Why" button in the sim?

EM: Yup, the student used the hide why frequently.

KL: So do you think it should stay?

CM: If it goes away, then how does the student compare representations?

Moving the popup only works for some equations, and it's not an effective way to compare.

EM: I didn't see any reason that it was bothering the students. For the student I observed it was pretty intuitive how to use it, so that's good.

KL: Ok, sounds like it should stay.

### **03/28/11 - Version 21**

<http://www.colorado.edu/physics/phet/dev/balancing-chemical-equations/0.00.21/>

CM: Requested changes:

- for the "Show Why" feature, vary the representation by level: 1=scales, 2=random, 3=bars
- restrict level-1 equations so that equations with big molecules (>5 atoms) cannot be first

KL: This looks great, thanks for the quick changes!

The only item left on the to-do list is to pick the final colors. I propose that we use the last 5 minutes of the PhET status meeting (on Friday) to do this.

CM: I did not change the play area to Emily's preferred color (RGB=204,204,255). I discovered that that color (and other shades of blue) detract from the light blue used for the Game Settings, Game Over and Scoreboard panels. I think your preferred color (RGB=204,204,204) works best, and I'll advocate for that when we have the colors meeting.

KL: Yes, I noticed that too. I suppose we could also change the game panel color... (or at least be ready for someone to suggest that).

## Interview and Other Feedback

### Chemistry Helproom

(Students only saw static images)

#### 2F chem 1 students

11/19/09

##### Symbolic, with bar graph; balanced

Saw that you could change the number in front of the symbols

Asked if the sim would balance equation for you

Asked if the images below the symbols were updated when you changed the numbers; if so, then would be helpful

Did not like the bar graphs, thought they were redundant

Would prefer just the total number on both sides, thought that would be most useful

##### Symbolic, with scale; unbalanced

Noticed that the equation was now unbalanced

Liked the idea of the scales

Thought it would be confusing because it was not lined up with the equation

Said it might be hard to use for more complicated reactions; hard to count the number of atoms

##### Microscopic, with bar graph; unbalanced

Did not like this representation; said you would never see this on a problem

Now that equation unbalanced, thought the bar graph would be helpful

Liked the big unequal sign

##### Microscopic, with scale; balanced

Did not like this at all

Said the scales were even more confusing

##### Control panel

Saw that you could check your answer

Said that the timer would "stress them out"; would not use it if given a choice

Said they would be distracted by the clock

#### 1M chem 1 student

12/03/09

##### Symbolic, with bar graph; balanced

Asked if the sim would give the equations, or if you could enter own equations  
Liked the bar graphs

Symbolic, with scale; unbalanced

Liked the idea of the balances, maybe more than bar graphs  
But thought they would both be better as checks, after one submits answer  
Too easy if there when balancing  
Did not mention molecules until asked

Microscopic, with bar graph; unbalanced

Liked the other representation better  
Said molecules would help more when under symbols

Microscopic, with scale; balanced

Did not like the scales

Other

Liked spinners better than click-and-drag  
Liked the idea of time pressure

**1M chem 2 student**

12/03/09

Symbolic, with bar graph; balanced

Knew that spinners would change # of molecules under symbols  
Did not like bar graphs at first, because different; liked later

Symbolic, with scale; unbalanced

Liked the balances better than bar graphs  
Said it was nice to have scales for each element

Microscopic, with bar graph; unbalanced

Knew what it was trying to show  
Liked the other representation better  
Said molecules would help more when under symbols  
Because shows difference between coefficients & subscripts

Microscopic, with scale; balanced

Thought it was interesting, but see above

Other

Liked spinners better than click-and-drag  
Thought spinners were more traditional  
But thought click-and-drag would show what coefficients mean

Said would need to try both to know for sure  
Must use mouse more for click-and-drag  
Liked the idea of an *optional* time constraint

### **1M chem grad student, helproom tutor**

12/03/09

#### Symbolic, with bar graph; balanced

Understood interface  
Ambivalent on bar graphs

#### Symbolic, with scale; unbalanced

Loved the balances, said it was intuitive

#### Microscopic, with bar graph; unbalanced

Liked other representation better, since more traditional  
Better to have symbolic on top, then visualization below

#### Microscopic, with scale; balanced

Liked scales w/ balls better than w/ symbols

#### Other

Did not see benefit to click-and-drag; liked spinners better  
Liked the timer

### **Middle School Classroom**

(Observed 3 6th grade classes)

02/08/11 v 1.00.04

#### 1st class - 19 students

- teacher: going to give you less information, more responsibility
- boy pairs played w/ monitor
- up at the board to start (review)
- then worksheet (given a molecule, what are the atoms)
- did not have icon on desktop (had to set up)
- students excited to get yellow arrow
- students: what do you do once you get it?
- used balances more than bar charts
- teacher: what was point of sim?
- asked: did you memorize it?
- student: how do you know when it's right?
- then new worksheet, up at board (goes through steps)

### 2nd class - 28 students

- distracted by sim (set up at start of class)
- introduced me, students asked me for help
- one student had suggestion: more rxns, (spinners) higher than 3

### 3rd class - 15 students + 2 late

- teacher to me: how to deal w/ absent students?
- less distracted by sim (minimized after set up)
- teacher on sim: figure out how to balance eqns
- after sim play, guides students to use bar graphs, none
- students can do from memory

Notes:

- in computer lab, not regular classroom
- students liked to draw boxes on desktop
- distracted by sim (faced the computer, not front of class)
- worked in pairs, all pairs were same gender
- students excited to get the yellow arrow - "got it!"
- used balances more than bar charts, did not use images
- many students asked: what do you do once you get it?
- after sim play, teacher guided students to use reset, bar graphs, none
- students could do from memory
- in sim, start w/ 0; in class, start w/ 1...

## Middle School Interviews I

(Students only saw first tab)

### **M1F**

02/08/11 v [1.00.04](#)

Warm-up:

11 years old, in 6th grade at Monarch  
Likes language arts, doing acid-base in class  
Previous interview on PhET sim

Sim:

Uses spinners, balances water  
Selects ammonia, then balance, bar chart, back to none  
Selects methane, balances  
Clicks reset, but closes  
Back to ammonia  
Says she is trying to make arrows yellow

Says it means eqn is balanced  
Tries different #s (randomly)  
Goes back to other rxns to see what yellow means  
Uses balance, gets it to turn yellow  
Says she got it to equal out - same # of dots on both sides  
Says the bar chart shows the same thing  
If move this up (the spinner), not equal  
Says dots come from the eqn and the box  
Had to balance eqns on sheet in class  
Says it shows what you need to do to balance  
Likes balances better than bar chart

Follow-up:

Spent about 20 mins on sim  
Had a hard time on assessment - said "not good at balancing eqns"  
Drew coefficients as circles, then drew molecules on the circle  
Let her re-open sim - saw 1 H<sub>2</sub> in the sim, re-drew 1 H<sub>2</sub> correctly

Notes:

- Tried to make the arrow yellow by changing the numbers
- Got stuck on ammonia, used balances to get it to equal out
- Said the sim shows what you need to do to balance the eqn
- Drew coefficients as circles, then drew molecules on the circle

## M2M

02/09/11 v [1.00.05](#)

Warm-up:

11 years old, in 6th grade at Centennial  
Likes math and science, doing chemical rxns in class  
Previous interview on PhET sim

Sim:

Uses spinners, radio buttons, back to spinners  
Clicks on scales, bar chart, back to scales  
Uses scales to balance all 3 reactions  
Clicks on bar chart, back to scales  
Resets, balances water again  
Says "I get this", but cannot explain  
Calls the atoms electrons  
Balances ammonia, methane again, clicks on bar chart  
Clicks on game tab, resets  
Says he is trying to balance molecules  
Says 2 molecules of water = 2 oxygens, 4 hydrogens

Balances w/ none open, resets  
Says you add these 2 (reactants) to make this (product)  
Says you go until you see yellow arrow, happy face  
Says he has memorized  
Scales more helpful - shows you which side weighs more  
Images? One silver here, one over there, etc.  
Tries to balance fast

Follow-up:  
Spent about 15 mins on sim  
Did well on the assessment!  
Had a hard time balancing the 1st rxn until he drew out the atoms  
Used the same strategy to balance the 2nd rxn  
Almost got the 3rd rxn

Notes:  
- Used the scales to balance at first, then none  
- Said the scales were more helpful, show you which side weighs more  
- Did not use the bar chart or images much  
- Tried to balance fast, but had memorized  
- Did well on the assessment!

## M3M

02/10/11 v 1.00.05

Warm-up:  
11 years old, in 6th grade at Centennial  
Likes social studies and science, doing chemical rxns in class  
Previous interview on PhET sim

Sim:  
Starts on bottom radio buttons  
Uses spinners w/ scales  
Clicks game tab  
Uses spinners w/ bars, back to scales  
Did not balance water  
On ammonia: balances w/ scales  
Back to water: balances w/ scales  
Says when scales are even, they create the formula  
On methane: balances w/ scales  
Says he is trying to get it even  
Clicks bars, back to scales  
Clears methane, tries to "get it back" w/ scales  
Says the images are good: CH<sub>4</sub> = 1 C and 4 H

Says I see, if I add 1 H<sub>2</sub>O it adds 1 O and 2 H  
Says hard to do w/out scales - try to get them even  
Says bar charts don't show when its even  
Asks is this (NH<sub>3</sub>) ammonia?  
So is methane CH<sub>2</sub>O<sub>3</sub>? (tries to put products together)  
Wants more rxns  
Knows water is H<sub>2</sub>O, so could be H<sub>2</sub>O<sub>2</sub>  
Clicks reset, closes  
Learn? Have to be even to make it  
If get right, wants the formula  
Likes the choice of bars and scales  
Says hard to get right w/ none

Follow-up:

Spent about 20 mins on sim  
Did well at drawing molecules, but not sure how to balance eqns

Notes:

- Used scales to balance all eqns - tried to get the scales "even"
- Saw that CH<sub>4</sub> is 1 C and 4 H
- Did not understand what a balanced eqn means - tried to put products together to make new formula
- Did well at drawing molecules, but not sure how to balance eqns

## Middle School Interviews II

(Students also saw the game)

### M4M

03/07/11 v [1.00.14](#)

Feedback, close button

Warm-up:

11 years old, in 6th grade at Centennial  
Likes reading, doing energy conversions in science class  
Previous interview on PhET build-an-atom sim

Sim:

#### Intro

Turns on scales, enters 1 all  
Clicks on charts, back to scales, did not balance  
Same for water and methane  
Looks at scales, then chart, then scales  
Clears, enters 1 all

Tries to move the images  
Asks: can I do the game?  
On ammonia, enters 1 all  
Back to water, balances! (on accident?)  
On methane, uses scales  
Uses water to explain: You have to balance it out  
Back to ammonia, balances!

Moves mouse over the images

### Game

Turns off timer and sound

L1: Uses images, closes box before clicks on "Next"

Gets balanced, not simplified; then correct

Gets 9/10

Back to L1 (clicks "New Game") to explain: It's what amount makes this; you match the icons; you add this to get that

Did not use chart popup

Gets 8/10

L2: Lot of time trying to match icons on first eqn

Looks at scales briefly

Puts 1 all for every eqn to start

Explains: It's kind of like a scale; has to be same number of red on both sides; has to balance out

Gets 8/10

L3: Puts 1 all again

Explains: to see what they are

Says harder because the [molecules] are more complex; on left, white is in 3's; on right, white is in 2's

Starts to balance H atoms first! (Puts in 4 NH<sub>3</sub>, the 6 H<sub>2</sub>O)

Looks at scale when wrong; when correct, counts before he closes the box

Gets 7/10

Back to intro; uses images now

Back to game; turns on timer!

L1: Always closes the popup

Gets 8/10 in 1:41

L2: Finally moves the popup! (when wrong twice)

Wants to interact with chart popup

Stop and ask him questions:

Levels get harder? Yes, harder when two [molecules] on each side

Wants someone to tell you that each side needs to be the same

Likes the scales; tell you when you're right, annoying to count

Wants to be able to use spinners w/ popup

Follow-up:

Spent about 10 mins on intro, 30 mins on game

Drew the coefficients as circles (similar to S1F)

Used a letter to balance an equation!

At the end, said the number in front tells you the number of groups, but then drew symbols instead of circles for the atoms

Notes:

- Figured out (by accident?) that you have to balance it out
- Turned off timer at first, then turned on after he had played all 3 levels
- Always closed the popup before he pressed the yellow button
- Used images in the game, did not use the popup until he moved it
- Always put in one of each molecule before trying to balance
- Did well in the game, but poor on the post-test

## M5F

03/10/11 v 1.00.17

No feedback, no close button

(Emily interview)

Age: 12

Grade: 7th

School: Centennial Middle School

Interviewed once before, otherwise never used PhET sims

- Not sure what to do to start, increases amount of products and reactants in first tab
- Gets a smiley face, says she thinks she needs to 'get the correct number of H's and O's' to get the smiley face
- Finds balance scale, says she gets it, that she needs to 'balance the two elements' (hydrogen and oxygen)
- Finds bar chart
- Finds game tab
- Tries level 1, balances an equation accurately with a strategy in about 1 minute(!) on game tab
- Doesn't understand what is meant by 'not simplified'
- Says it must have something to do with 'math', 'simplify equation', 'algebra'
- Goes through level one and part of level two
- Game levels got harder for with increasing level...even said 'Goodness!' when she saw the first equation of the second level.
- Switches back to first tab
- Balances all three equations here, leaving them all with smiley faces
- Used scales and bar graphs a little, but not extensively. Used scales to help her figure out what 'balance' meant, didn't focus only on balancing scales.
- Never uses 'reset' on first tab
- After balancing all on first tab, tells me she thinks she did everything. I asked to her to play the game some more, so she goes back and completes level 2 and level 3.

- Got mixed up with the scroll buttons towards the end of the interview
- Typed in coefficient multiple times, even tried using decimal numbers (3.5) (this was an appropriate value to try)
- At one point says the subscript of a molecule as a superscript (as a power) then makes a comment that she doesn't know what that is, though she uses it accurately in balancing, and later draws molecules correctly with subscripts.
- Pop up box: Initially would click on popup box, then on yellow button. After a few times, only clicked on yellow button, not popup box.
- Never tried to move the box.

She had gotten quite while working through the game tab. She would hover the mouse over the molecules as she counted, and counted loud enough that I could hear her so I felt like I understood enough of what she was doing. When she was done with level 3, I asked her to try to describe out loud what she was doing, and then she could barely finish one equation...it was too difficult to talk as she solved.

It appeared that she was starting all coefficients at 1, then counting the amount of the element with the largest subscript on the reactant side, making the product side match that and then balancing out the others from there. When she described it out loud it seemed somewhat random her selection of element to balance after the one with the largest subscript, but considering how quickly she was able to do it without talking, I'm not sure that it was.

Post Test:

Accurately represented the molecules.

Had difficulty balancing the third part of the second to last problem. She asked me if she could use 1.5 as a coefficient. I said to do what she thought was best. She acknowledged that she thought it was wrong to have 1.5 coefficient, and pondered it for awhile. I even told her she could stop if she wanted, but she wanted to keep trying to figure out what to do with the 1.5. Ultimately she decided to leave it, but still thought it was wrong.

## **M6M**

03/22/11 v [0.00.20](#)

“Show Why” button

(Emily interview)

Age: 12

Grade: 6th

School: Centennial Middle School

PhET History: No use of sims and no prior interviews

Adds some of each molecule to start

“Blue balls form up to create one bigger ball, white balls center around the sides”

Switches to Separate Water, to Make Ammonia, Separate Water again, adds molecules

Switches to Combust Methane, adds molecules  
Hovers over Balance Scales and Bar Charts, but doesn't click on them  
Switches to Game Tab ~ 4 minutes in  
Uses spinner fine, adds one molecule of each  
Gets first attempt incorrect, tries "show why"  
Studies the bar graph feedback  
Selects "Try Again"  
"Seems like you're trying to balance them out maybe", "create like an even formula...or even atom, something like that"  
Counts atoms on both side when correct answer is shown  
Trouble interpreting bar graph representation in feedback  
May be trying to have each side be equal individually (for example,  $2C + 1O_2$  means two of carbon and two of oxygen on the right side)  
Uses new game button  
Moves popup box on 4th equation  
Balances first equation after 8 minutes in game tab  
Keeps replaying level 1  
Starts to get multiple correct in a row after 20 minutes in Gab Tab.  
Replays level 1 three times  
Switches to level 2  
Confused by "balanced, not simplified"  
Finished Level 2 and Level 3

General:

Uses "Show Why" every time it appears, moves pop up around to try to compare with molecules  
Never used bar chart or balances in first tab, so had to interpret from only the "Show Why" pop up, took him a long time to come up with a working strategy  
Uses spinner the wrong way twice, not a major problem though  
Counted atoms a lot  
Used radio buttons fine to change between reaction on first tab, but didn't use for bar graphs/scales  
Didn't use reset  
I think the bar charts were confusing for him, he thought he was trying to make each side equal individually

Since this student didn't use the bar graph/scale in tab 1, the Level 1 equations with more than one molecule on the reactant side seemed extra challenging for him  
Used feedback every time available, moved the popup box frequently, though had difficulty seeing the popup and the molecules

## Post Test

You'll have to take a look...he interprets the product side of question 3 (1NO) as symbolizing  $\text{1N}_2 + \text{1O}_2$

I think he's taking some kind of substitution approach, with the left hand side acting as a short hand for the right hand side...

We should get together and compare what the students came up with for wrong answers in the post-test...it might be interesting to see if we can come up with some alternative interpretations from the chemistry symbols used in the sim.

## College Interviews

### C7M

03/09/11 v [1.00.16](#)

No feedback, close button

(Emily interview)

The interview went well.

Here are some of the things I noticed:

- He found everything clickable quickly, but even before he figured out he was supposed to balance anything he had moved on to playing the game at level 2.
- wasn't confused by stacking direction/spinners.
- didn't use 'reset all' button on first tab, just changed between equations.
- didn't realize the radio buttons at the top changed the equation at first, but figured it out quickly.
- While playing level 2, he realized he had no idea what he was doing, only that he needed to be 'balancing' so went back to the first tab to figure out 'how to balance'.
- Liked the use of the scales, found the bar graphs, but didn't use them. I don't think he even recognized that he could use the bar graphs in the same way as the scales to determine balancing. He seemed to just intuitively 'get' the scales better.
- when using the scales, he focused only on the scales, not on the molecules.
- He accidentally balanced something after maybe a minute or so back on the first tab, then he figured what he did to make that happen and began to catch on. He didn't stay long here before going back to the game tab.
- He went back to the game tab on level 2, was able to describe what he was trying to do (have the same number of atoms on each side) but had a hard time doing this, finally dropping down to level 1. In level 1 he was able to successfully balance pretty quick.
- Initially he didn't seem to be using the molecules to help (I could be wrong, but from where he seemed to be looking and from where the mouse was he seemed focused on the written out equations initially). After about 15 minutes he started using phrases like 'oh, I need to balance out the blues now' that indicated to me he switched at some point to using the molecules also.

He didn't use the molecules exclusively though. I have the suspicion that some of the atoms were hard to see, so he used the molecules to count out diatomics and perhaps the bright white hydrogens, but I think he was also using each molecule as an indicator of the number of 'sets' of things present. For example, for 2 NH<sub>3</sub> molecules, I think he might have been using the molecule representations as a counter that there were two sets of three hydrogens he had to account for.

- Even with the molecule representation, the student had a hard time distinguishing element symbols for elements throughout...for example, called Cl<sub>2</sub> "see eye 2" so he wasn't always using the molecules to help him figure out what was present.
- Eventually made up a rule to start balancing the atom type with the largest subscript in the equation.
- Didn't have feedback enabled. Once he balanced something in the first tab, he seemed to get what he needed to do and didn't seem to need the feedback, though he might have liked it.
- The levels definitely got harder, and he was more and more pleased as he was able to answer the ones he thought looked intimidating.
- I think he answered all of the post-test correctly, except for the last one, in which he shows 2F<sub>2</sub> as four connected circles.
- He worked through the game levels 1 and most of 2 without the molecules, initially he was hesitant and didn't think he could do it, but then got more confident.
- He always, in all cases, closed the pop up box before clicking on 'next'.
- He never moved the pop up box.
- He played for the entire hour, and was quite pleased with his ability to figure out how to balance and answer all the level 1, 2 and 3 questions correctly.

I see what you're saying about watching a student get the game wrong repeatedly, it's really uncomfortable. Initially, when this student was getting the game wrong, I felt that I was able to sufficiently reassure him that it was ok that he didn't know how to get the right answer, that I was interested in what he was thinking, but that may be harder for a middle schooler.

## C8F

03/09/11 v [1.00.17](#)

Feedback, close button, top bar

Warm-up:

Anthropology, int. physiology, 1st year

Took chem in high school

Previous interview on M&L sim

Sim:

[Intro](#)

Uses spinners, did not balance

Clicks bar chart, uses spinners

Says it looks like ratios  
Says bars go up when press up  
Clicks scales, uses spinners  
Accidentally balances!  
Says smiley means correct: when # of red particles match up  
Says she is making them equal  
Says she is looking at black boxes  
Balances all 3 eqns  
Says when scales are balanced, so is eqn; also when bar charts are equal  
Says blue symbolizes wrong

### Game

L1: Closes box before she hits next  
Counts atoms in the box  
Hits next, did not close first  
Gets 9/10 in 1:53  
L2: Says it's a game w/ diff levels; you try to balance eqns w/ less help  
Puts 1 all to start  
When not simplified, gets correct  
Clicks on box before she hits next, but did not close  
Gets 6/10 in 2:22  
L3: Hits try again, did not close first  
Gets stuck, goes back to 1 all  
Sometimes closes boxes, sometimes not  
Do we need to constrain the eqns? (note to Chris)  
Gets 8/10 in 6:09  
Ask her specific questions:  
Says the game is kind of fun  
Says she had a hard time understanding this before  
Says it's easier to see visual  
Says you have to use ratios more in L3  
Popup: helps you see what you did wrong  
Says scales more helpful than bars; you can see what is uneven  
Wants more problems in the game  
Not confused by stacking: just adds more to the black box  
Ask her to **hide** the molecules:  
L2: Did not enter all coefficients at first  
Says it's harder; liked it better w/ molecules  
Hits check accidentally (note to Chris)  
Says it's nice to have the box (popup)  
Gets 6/10 in 2:37  
Said it's better to see the molecules 1st, before doing in your head

### Follow-up:

Spent about 5 mins on intro, 15 mins on game

Got all correct on the post-lab  
On #3, said "two N and two O", but wrote "N2 and O2"  
Says the eqns (in #4) get harder to balance  
Checked the last eqn by counting up atoms on each side in a table  
Says she forgot about the # in front when using the sim

#### Notes

- Did not know to balance the eqn until she accidentally did
- Sometimes closed the popup, sometimes clicked on it but did not close it, sometimes hit next or try again first
- Said it was harder to balance without the molecules
- Got all correct on the post-lab
- Said she forgot about the # in front (the coefficient) when using the sim!

#### C9M

03/11/11 v [1.00.17](#)

Feedback, no close button, top bar

Warm-up:

Music, 2nd year  
Took AP chem in high school  
Previous interview on M&L sim

Sim:

#### Intro

Uses spinners, says you can add stuff  
Did not balance NH<sub>3</sub>, went to next eqn  
Opens scales, balances H<sub>2</sub>O; says the scales show the balance  
Opens charts, balances CH<sub>4</sub>; says you've got to balance the eqns  
(Demos w/ chart) If you add another, not equal

Clicks reset (ask: is that ok? on dialog)  
Balances NH<sub>3</sub> w/ scales, then charts  
Says you can just use the scales, wait for smiley face  
Asks: how come only goes to 3?

Balances H<sub>2</sub>O w/ charts

#### Game

Starts on level 2  
L2: Says these [coefficients] go to 7  
Gets wrong; says did not take enough time, maybe should try level 1  
L1: Asks: what are you supposed to do?  
Says there's only one way to balance the eqn  
Gets not simplified; says not good at this  
Moves box before hits try again  
Says he's stuck on this one, but gets correct

Goes to level 3

L3: Gets correct

Likes the molecules; but says you can **cheat** by counting

Says it's a diff way to look at it; you don't need to look at these [symbols]

Says wish the scale was here, but prob the point

Gets stuck, starts over w/ smaller #s; says "this one is hard"

Quits, back to 1st tab, then game

L2: That's the sound & clock

Says he can't remember how to balance

Says he uses the symbols; if can't figure out, then look at picture

Gets not simp, then correct (twice)

Says not sure why he went to 2 right away

Says it helps to see if you put in 1 of everything

Gets **8/10** in 4:39

Says he's going to try level 3

L3: Says it's good to see this (images), way to check answer

Says the best way is to put 1 of everything

(Talked though) Can't get 3 H's, etc...

Says not using this (images) to balance

(Back to intro) Says it's easier to use scale & bar

Says you have to work it out in the game

Gets wrong, looks at scales, then counts atoms

Gets wrong twice, wanted to look at scales more

Says you only get 2 tries per question

Gets wrong, looks at charts for a second, then not simplified

Gets **6/10** in 10:14

Ask him more pointed questions:

Says you can just add & take away to get the scales to line up

Says it shows you how it gets equal

Says it would be too easy if add scale to game

Says the sim is pretty self-explanatory

Easier with scales (vs. charts) because you can see the problem for each atom; have to compare both sides of eqn for charts

Popup? Just read that not balanced

Does it always show scales when wrong? (Finds out) No, sometimes shows bars, good to switch it up. Says it shows you what is wrong. Sees that it's random.

Asks: how come only 2 tries?

Wanted to fix it when it was not simplified on 2nd try

Says on 2nd try, either want to get it right or be done w/ it

Says he did not see the game tab at first

Follow-up:

Spent about 5 mins on intro, 30 mins on game

Got all correct on the post-lab

On #3, said you can only change the # in front, but did not seem sure  
On last eqn in #4, said the sim helped him know to multiply by 2  
On #5, had to ask him to point out H and F

#### Notes

- Said you can just add & take away to get the scales to line up, or wait for the smiley face, but you have to work it out in the game
- Clicked on reset, but asked "is that ok?" when he saw the dialog
- Easier with scales (vs. charts) because you can see what it is for each atom; have to compare both sides of eqn with charts
- Not sure what to do in game at first
- Said you can **cheat** by counting the atoms; it's a diff way to look at it; you don't need to look at the symbols
- Used the symbols to balance; said he only looked at the picture if he could not figure it out, or to check his answer
- Said it helped to put in 1 of everything first
- Very perceptive: noticed the random feedback when wrong, the number of chances, the diff ranges of coefficients in the tabs

#### C10F

03/11/11 v [1.00.17](#)

No feedback, no close button

Warm-up:

Business, 1st year

Took chem in high school

Previous interview on M&L sim

Sim:

#### Intro

Uses radio buttons, then spinners

Maxes out spinners, clicks on game tab, resets intro

Balances H<sub>2</sub>O on accident; says "that's right"

Opens scales, then charts, uses spinners

Says she likes the bar charts; tells you when not balanced

Balances NH<sub>3</sub> w/ charts, then H<sub>2</sub>O, then CH<sub>4</sub>

Says all done & can't go higher

#### Game

Did not know this tab was diff - thinks she did level 1

L2: Did not move the popup

Says she looks at symbols: add one here, so need one over here...

Gets 8/10 in 4:45

L3: Says she uses pictures to see if equal

First 4 eqns all have 4NH<sub>3</sub>, 6H<sub>2</sub>O; learns to balance H first

Says she uses pictures more, easier to use colors to see

Gets 9/10 in 8:36

L1: Puts in 1 all

Makes one mistake

Gets 9/10 in 1:41

Ask her specific questions:

Liked the game, was fun

L1 was easier because not as many

Did not like being timed, makes her nervous

Liked 2nd try

Intro: gives you sense of what was going on in the sim, good practice for game

Prefers charts, liked separation between 2 sides

Says you could balance it more in 1st tab if (spinners) went higher

Did not want feedback: says it makes you learn what you did wrong

Follow-up:

Spent about 6 mins on intro, 16 mins on game

Got all correct on post-lab

Notes:

- Liked the bar charts (better than scales), because it separates the two sides
- Thought the intro tab was level 1 in the game (at first)
- Said she used the pictures more in the higher levels
- Said the game was fun, but did not like being timed
- Said the intro tab gives you sense of what is going on in the sim, good practice for game
- Knew that you could balance the eqns again if the spinners went higher