From Demonstrations & Clicker Questions to Guided-Inquiry Activities: Resources for Integrating PhET Simulations into Introductory Chemistry Courses

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Abstract
The PhET Interactive Simulations project at the University of Colorado Boulder (http://phet.colorado.edu) develops interactive simulations in science and mathematics, including over 30 simulations designed for introductory chemistry courses. The PhET project supports teachers in their use of the simulations by providing general and discipline-specific teacher resources. In the summer of 2013, the PhET project organized a diverse working group of five chemistry faculty from four institutions in the United States, each experienced using PhET simulations in different classroom contexts. In collaboration with the PhET project, this working group created classroom resources based on their use of PhET simulations in their introductory chemistry courses (General Chemistry, Preparatory Chemistry, and Physical Science for non-majors). Resources include: 1) Interactive Lecture Demonstration Guides, 2) Clicker Questions, 3) Annotated Presentation Slides, and 4) Guided-Inquiry Activities. Here, we introduce these resources to the community by highlighting a specific example from each category. Each resource is designed to be flexible for teachers to use and adapt to their course needs.

Introduction
The PhET Interactive Simulations project at the University of Colorado Boulder (http://phet.colorado.edu) develops interactive simulations in science and mathematics, including over 30 simulations designed for introductory chemistry courses. The PhET simulations are a popular Open Educational Resource, with over 50 million uses per year in locations worldwide. Since the start of the PhET project in 2002, supporting teacher resources have been developed with each simulation, including: a list of main conceptual topics that can be addressed using the simulation, sample learning goals, and general tips for teachers, as well as a teaching ideas collection – a place where any teacher can upload and share relevant activities and materials for use with a particular simulation.

Over the past two years, the PhET project has increased its efforts in supporting teachers' use of the simulations through the development of expanded teacher resources. The simulations are flexible tools that can be utilized across a range of age groups, disciplines, and pedagogies, and the teacher resources reflect this diversity. In addition, many of the resources are developed in collaboration with teacher partners, including K-12 teachers and college faculty. General resources can be found in the "For Teachers" section of the PhET website, while simulation specific resources can be found on each simulation's individual website page. Here, we briefly describe some of the general resources available, and then highlight some examples of the simulation-specific resources for chemistry teaching.

General Resources for Teaching with PhET Simulations
In the "For Teachers" section of the PhET website, you can find short videos and guides filled with tips for teaching with PhET simulations. These resources provide an introduction to PhET simulations and tips for using them in different ways, with examples. They include implementing simulations in K-12 and undergraduate classrooms using a range of pedagogical techniques (e.g., lecture, guided-inquiry, and with clickers), as well as links to browse the simulation-specific resources available. For example, from the "For Teachers" section of the website, you can select "Tips for Using PhET", and then "Interactive Lecture Demonstrations". There you will find the "PhET in Lecture: Interactive Lecture Demonstrations" video, which is 7-minutes long and shows examples of college faculty using the

simulations as part of lecture demonstrations, along with tips on how to implement these lecture demonstrations effectively. Next, on the same page, is the "PhET in Lecture: Prediction Experiments" video, which is 6-minutes long and includes examples and tips for using the simulations as part of in-class prediction experiments. You will also find on this same page a short (2-page) overview of using PhET in lecture settings.

Resources for Teaching with Specific PhET Chemistry Simulations

In addition to the general resources, we have also developed resources specifically designed for chemistry. Beginning in the summer of 2013, the project organized a group of five chemistry faculty from four postsecondary institutions in the United States to work together to create classroom materials based on their own use of PhET simulations in introductory college courses. The faculty working group members represented two research-intensive universities, a primarily undergraduate institution, and a community college. Across the faculty working group there were teachers of general chemistry, preparatory chemistry (which precedes the traditional general chemistry sequence), and chemistry for non-majors. They each incorporated the simulations through distinct teaching strategies – in-class guided-inquiry activities, interactive lecture demonstrations with clicker questions, recitation sessions, and in online pre-class assignments. The goals of this faculty working group were to document their use of PhET simulations in their courses, and to formalize their simulation-specific course materials for sharing through the PhET website, with support and feedback from the PhET team and their colleagues in the working group.

This resource development project aimed to support teachers by providing:
Teacher-Developed, Classroom-Tested, and Documented Materials: Sharing teacher-developed materials ensures that the resources are authentic and reflect the needs and constraints of real classroom environments. Classroom-testing materials allows for iteration over activity design, improving the quality and clarity of the materials. These materials also provide an opportunity for teachers to get a sense of what activities their peers are implementing – which can be a challenge at smaller institutions where only a few faculty teach introductory courses. The results from classroom implementation were thoroughly documented.
Exposure to New Implementation Ideas and Teaching Pedagogies: Faculty implement PhET simulations in many creative ways, using a wide-range of pedagogies. Through the sharing of authentic materials, faculty browsing the materials have the opportunity to be exposed to new ways of using simulations, and to new pedagogical techniques.
Flexible Materials: By providing teachers with access to flexible materials, we aim to support teachers in adapting the materials to their class needs. The activities are licensed under a Creative Commons Attribution license – allowing use, sharing, reuse, and adaptation (with attribution) for free.

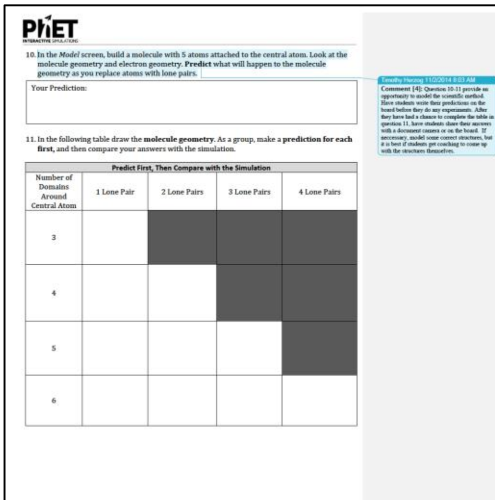
Over the course of 2013-14 academic year, the faculty working group implemented over a dozen simulations in a variety of ways. Monthly faculty working group meetings were held, to discuss challenges and insights in their use of PhET simulations. For some classroom activities, the PhET team members conducted individual and paired student interviews on different versions of an activity, to provide further insight into the student experience of course materials and to inform decisions about activity structure. All course materials were classroom tested and refined based on the classroom experience. Over the summer of 2014, course materials were put into final form, and we are pleased to announce that the first set of these materials have been finalized and published to the PhET website. These materials include:

- ***Guided-inquiry Activities*** – student handouts utilized during in-class group activities that guide students conceptually during use of a simulation. Some of these activities include annotations on teacher facilitation.
- ***Interactive Lecture Demonstrations Guides*** – guides for how to implement interactive lecture demonstrations with specific simulations to address introductory chemistry learning goals.
- ***Annotated Presentation Slides*** – the slides used by the faculty during lecture demonstrations with the simulations, with annotations on facilitation.
- ***Clicker Questions*** – slides containing clicker questions and answers, with some providing the classroom distribution of responses.

For each type of material, we now highlight one example. All examples described below, and more, are available on the PhET website. Individual URL's for specific resources are included below.

Guided-inquiry Activity: Molecule Shapes

The guided-inquiry activity, *Molecule Shapes* (available at: https://phet.colorado.edu/en/contributions/view/3947) and designed to be used with the PhET simulation of the same name (http://phet.colorado.edu/en/simulation/molecule-shapes). For this resource, we provide a teacher-annotated version of the activity (with a brief description of classroom context and learning goals plus annotations), and the student version of the activity. This activity was developed for, and classroom-tested in, a first-semester General Chemistry course with about 80 students at a primarily undergraduate institution. During the 50-minute class period, the students worked in groups of 3-4, typically sharing a single computer, with classroom discussion, and clicker questions, facilitated by their instructor. The learning goals of the activity include: Determine electron geometry and molecule geometry for molecules using VSEPR theory, explain the role that nonbonding electron pairs play in determining molecule geometry, draw molecules representing 3-dimensionality, and predict bond angles in covalent molecules as well as deviations from idealized bond angles.


PhET INTERACTIVE SIMULATIONS

10. In the *Model* screen, build a molecule with 5 atoms attached to the central atom. Look at the molecule geometry and electron geometry. **Predict** what will happen to the molecule geometry as you replace atoms with lone pairs.

Your Prediction:

11. In the following table draw the **molecule geometry**. As a group, make a **prediction for each first**, and then compare your answers with the simulation.

Predict First, Then Compare with the Simulation				
Number of Domains Around Central Atom	1 Lone Pair	2 Lone Pairs	3 Lone Pairs	4 Lone Pairs
3				
4				
5				
6				

Timothy Herzog 11/2/2014 8:03 AM
Comment [4]: Question 10-11 provide an opportunity to model the scientific method. Have students write their predictions on the board before they do any experiments. After they have had a chance to complete the table in question 11, have students share their answers with a document camera or on the board. If neccessary, model some correct structures, but it is best if students get coaching to come up with the structures themselves.

Figure 1: Sample page of the annotated activity for Molecule Shapes

The activity consists of three sections of conceptual questions, focused on guiding students through different components of the learning goals. The first section guides students in determining molecule and electron geometry, through exploration of the molecule geometry when changing the number of atoms and lone pairs on the central atom, comparing the impact on molecule geometry of bonded atoms compared to lone pairs, comparing electron geometry and molecule geometry, and developing their own definition of "molecule geometry". The second section introduces students to wedge and dash drawings, providing a key for what lines, dashes, and wedges represent, and an opportunity to develop this drawing practice while exploring the electron geometry and bond angles of different molecule geometries – first with only bonded atoms and then with lone pairs. The third section guides students through a comparison of real and model molecule bond angles, allowing students to find that real bond angles are less than in the "model" when non-symmetric lone pairs are present, and that this results in a preferential location for lone pairs and bonded atoms in certain geometries. The activity ends with Exercise and Challenge questions, that can be completed in-class (if there is time) or as homework.

The structure of the activity is modular and it is available in an editable format. The clearly distinguished sections support students in navigating the activity during class, and also support teachers to be able to clearly pick and choose particular questions, sets of questions, or sections that they would like to use, or adapt to meet the needs of their specific course, students, and context. Facilitation notes in the teacher-annotated version provide suggestions for class discussion time, and locations in the activity to have students share question responses. Notes also provide teachers with insight about particularly important places within the activity to give students feedback and ways of supporting students in coming to a shared understanding of a particular concept. Timothy Herzog (Weber State University) and Emily Moore (University of Colorado Boulder - CU) developed this activity, with feedback from Susan Hendrickson (CU) and Julia Chamberlain (Pasadena City College, formerly at CU).

Interactive Lecture Demonstration Guides: Entropy, Microstates, and Probability

This resource is a creative example of a non-traditional way of utilizing the simulation *Reversible Reactions* (http://phet.colorado.edu/en/simulation/reversible-reactions). The simulation was designed to address concepts related to chemical reactions. This interactive lecture demonstration guide – available at https://phet.colorado.edu/en/contributions/view/3948 – shows a way for teachers to use this simulation as a demonstration of a two-compartment box with a removable center partition to explore ideas of entropy, microstates, and probability. This demonstration guide was developed for, and classroom-tested in, a second-semester General Chemistry course with over 300 students. The demonstration guide contains a description of prior knowledge expected at the outset of implementation, learning objectives, a link to the simulation, and a brief description of tips on using the simulation (including some features that may not be immediately obvious). Then, the resource guides the reader through the lecture, starting with a thought experiment, then a demonstration with the PhET simulation, with screenshots of slides used in support of the interactive demonstration.

The learning goals of the interactive lecture demonstration include: Explain a spontaneous process using particle motion at the molecular level; Distinguish between spontaneous and non-spontaneous processes, and connect these to a probabilistic description of matter; Explain how a large number of microstates can produce the same macro-state; Perform calculations involving probability; Use particle motion and probability to explain heat transfer. The interactive lecture demonstration begins with a thought experiment about an evacuated chamber. Students are prompted to predict what will happen when the seal of the container is broken, and to explain their reasoning. Common student responses are described, with possible responses provided.

Next, the simulation is used to show an example of two particles in one compartment of the box. Students are asked to predict what happens when the partition is removed. The guide provides a description of the class discussion led by the instructor as the simulation shows what happens. This discussion reveals that particles move randomly, rather than being "sucked into" the second compartment. The simulation is then used to show an example in which a larger number of particles are initially in one compartment of the box, and students are asked to predict what happens when the partition is removed. The ensuing discussion concludes with the finding that particle motion explains the rush of air into an evacuated chamber when the seal is broken, and includes comparisons between the simulation scenario and the evacuated chamber discussed at the start of the lecture.

The interactive lecture demonstration goes on to investigate the idea that a macro-state can result from many different microstates. Different starting scenarios (microstates) are shown with the simulation, initiated with many particles and allowed to run, always resulting in the same macrostates (a distribution of particles across the two compartments). The probability of a particular number of particles being found in one compartment is explored, including prompts for students to cheer when a particular state is observed. The calculation of probability is then introduced, with comparisons building from simulation scenarios (with 2, 4, and more particles), up to thought discussions and calculations of scenarios involving moles of particles.

Throughout this guide, example lecture slides are shown, each utilizing screenshots from the simulation that are used to aid in setting up scenarios for student predictions, presentation of relationships between the simulation scenario and the probability calculations, and particular ideas for class discussion. Notes on typical student responses, and ideas for addressing student questions are also included. Ted Clark (The Ohio State University) developed this activity with feedback from Julia Chamberlain (Pasadena City College, formerly CU) and Emily Moore (CU).

Annotated Presentation Slides: Sugar and Salt Solutions

A series of annotated lecture slides (available at http://phet.colorado.edu/en/contributions/view/3949) is designed for use as part of two class lectures centered on the PhET simulation *Sugar and Salt Solutions* (available at http://phet.colorado.edu/en/simulation/sugar-and-salt-solutions). For this resource, we provide an annotated version of the lecture slides, along with a brief description of classroom context and learning goals. Where appropriate, we have also provided unmarked, printer-friendly versions of select slides for instructors preferring to annotate slides by hand on a document camera or tablet during the lecture. This lecture activity was developed for, and classroom-tested in, a Preparatory or pre-General

Chemistry course with 200-300 students. This series of slides was designed to span slightly less than two 50-minute lecture periods, leaving room for integration with a 5-10 minute benchtop demonstration with connections to other course material. The learning goals of this lecture activity include: Describe the atomic-scale structural features of ionic and molecular compounds before and after the addition of water, identify if solutions contain ionic or molecular compounds based on conductivity, and determine if a compound is ionic based on the location of its elements on the periodic table.

The lecture materials consist of three sections focused on scaffolding student ideas around ionic and covalent compounds. The first section of the lecture and simulation demonstration asks students to observe macroscopic differences in conductivity measurements for sugar and table salt solutions, before comparing the atomic-level structural features of both compounds as solids and in solution. The second section of the lecture focuses on comparing a variety of compounds, and asks students to extend their predictions of bonding in compounds to other ionic and molecular compounds, including those with polyatomic ions. Finally, the lecture concludes by comparing these compounds according to the placement of their component elements on the periodic table, allowing students to predict the nature of a compound based on whether the elements are metals or non-metals.

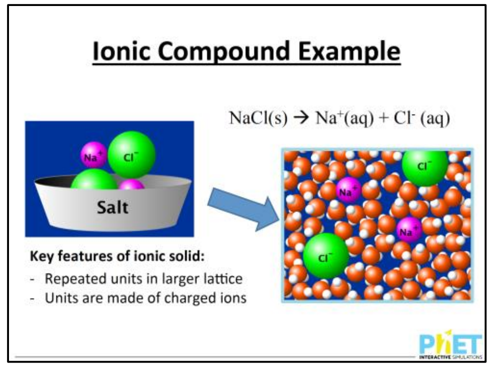


Figure 2: Sample slide for *Sugar and Salt Solutions*

The lecture slides are modular and available in an editable format, so that instructors can use those sections that meet their particular learning goals and course context, or bridge this material across multiple class days. Where appropriate, blank versions of tables are included for use by instructors who wish to integrate student observations into their notes with in-class handwritten annotations (either by printing tables for use on a document camera or for electronic annotation using a tablet). Facilitation notes offer suggestions for class discussion, as well as highlighting features that might be emphasized in order to support students in coming to a shared understanding of a particular concept. Yuen-ying Carpenter (CU), Robert Parson (CU), and Trish Loeblein (CU) developed this series of lecture materials.

Clicker Questions: Isotopes and Atomic Mass

This resource includes a collection of multiple choice concept questions (intended for use with clickers or other personal response systems) available at http://phet.colorado.edu/en/contributions/view/3950 to accompany the PhET simulation *Isotopes and Atomic Mass* (http://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass). For this resource, we provide an annotated presentation slide (in Powerpoint and PDF formats) for each concept question, as well as follow-up animations or slides indicating the correct answer to each question. This resource was developed for, and classroom-tested, in a Preparatory (or pre-General) Chemistry course with 200-300 students. Although not all questions were necessarily used in a single lecture period, all questions were designed for use during a typical large-enrollment lecture on the topic of isotopes and atomic mass, where the questions accompanied lecture material in order to engage students in periodic peer discussion. All questions were typically followed by a whole class discussion facilitated by the instructor, while questions with a substantial split in student answers were typically re-polled following peer discussion or additional demonstrations.

The learning goals of these clicker questions included: Describe how average atomic mass is related to the proportion of isotopes in a sample, relate the atomic mass on the periodic table to the natural abundance of isotopes of that element, estimate the average atomic mass based on the percent composition of a sample, determine the most abundant isotope in a sample based on the average atomic mass (or describe why it is not possible to make this determination), and calculate average atomic mass given the number of atoms of each isotope. These questions are modular and readily incorporated into the classroom individually or in series to meet the particular learning goals or level of challenge appropriate to the course and students. The questions in this collection can be roughly categorized into several topics, including reviewing the definition of isotopes, calculations of average atomic mass, estimations of sample composition or average mass, and meta-level questions that ask students to determine what information is required to solve problems in this concept area.

Annotations on each question provide specific question goals, suggested pre-question simulation demonstrations or prompts, representative student response distributions, and suggestions for follow-up class discussion. Where appropriate, the follow-up discussion indicates post-question simulation demonstrations that can facilitate class or peer discussion prior to a second polling of student viewpoints. The annotated goals support teachers in selecting questions that meet their specific learning outcomes, while the representative response distributions and discussion notes offer insight into the relative level of difficulty of particular questions to guide teachers in selecting questions at the appropriate level for course, students, and context. Yuen-ying Carpenter (CU), Robert Parson (CU), and Trish Loeblein (CU) developed these concept questions.

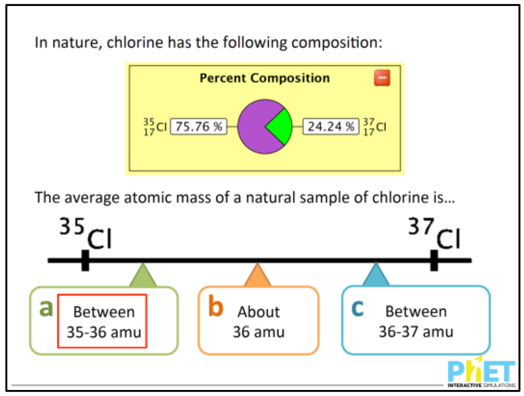


Figure 3: Sample clicker question for *Isotopes and Atomic Mass*

New and Upcoming Resources

The faculty working group will continue its work through the next year, adding new chemistry resources to the collection. These include resources for use with *Balancing Chemical Equations*, *Beer's Law Lab*, *Build an Atom*, *Concentration*, *Molecules and Light*, *States of Matter*, and *Sugar and Salt Solutions*. Each resource will be available on the simulation's webpage, in the "Teacher Resources" section of the page.

In addition to the development of these new teacher resources, the PhET project is also in the process of updating the existing suite of Java and Flash simulations into HTML5. The HTML5 simulations can be downloaded, or run directly in the browser, minimizing differences in running simulations across platforms (e.g., Mac and PCs). You can find a complete list of our HTML5 simulations at http://phet.colorado.edu/en/simulations/category/html.

Summary & Suggestions for Feedback

In this article, we described general and simulation-specific resources available for teachers of introductory chemistry courses. We highlighted one simulation-specific resource for each category of materials, to demonstrate the diversity, creativity, and flexibility of the materials resulting from efforts of a working group of chemistry faculty. We appreciate comments and constructive feedback on these, and the other materials available on the PhET website, and hope that teachers find these resources to be useful in supporting the effective implementation of PhET simulations in their own courses.

Acknowledgements

The chemistry resources highlighted were created in collaboration between the PhET Interactive Simulations project at the University of Colorado Boulder (Emily B. Moore, Yuen-ying Carpenter, Julia Chamberlain, and Katherine Perkins) and faculty at four different institutions (Robert Parson – University of Colorado Boulder, Timothy Herzog – Weber State University, Ted Clark – The Ohio State University, Susan Hendrickson – University of Colorado Boulder, and Mark Yeager – MiraCosta Community College). Some of these materials draw on earlier work by Trish Loeblein, a member of the PhET project and a high school chemistry and physics teacher at Conifer High School in Colorado. This work was supported with funding from the Hewlett Foundation, and the National Science Foundation (DUE-1226321). Any opinions, findings or conclusions expressed in this paper are those of the authors and do not necessarily represent the views of these foundations.