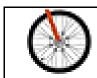
1.0 Overview

Driving Question: What is pressure?

In this unit, students explore computer models in seven activities that focus on the topic of gas pressure. These activities enable them to investigate what causes pressure in a gas, how it is measured, and how it is affected by the properties of the particles that make it up and the characteristics of the container they are in. Students are encouraged to understand how the principles and effects of pressure are generated from specific interactions between many particles and those with their environment. To do this, students gain a familiarity with a microscopic view of the system and the local particle behaviors by running a computer model of gas particles, and through making many adjustments to the parameters of the model as they go through the activities. Students make predictions, gather data to test their predictions, develop mathematical models, design experiments, and compare their assumptions with real-world values, as well as Kinetic Molecular Theory.   The students explore ideas related to modeling in science, systems thinking, and change and equilibrium. Students are asked to explain and predict the behavior of gases in many different situations that they experience every day as well as apply and expand their scientific inquiry, data analysis, mathematical modeling, and critical thinking skills.

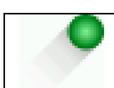


Activity One: **(1) Modeling A Tire**

This activity enables students to investigate the rules that underlie individual gas particle behaviors in the context of exploring what happens inside a bike tire when it is pumped up. Students first focus on the objects and parts of the system. Then they look at a simple model of the bike tire, observing the particles that make up the gas inside the bike tire. They then learn the rules that govern their behaviors and interactions by adding the rules into the model one-by-one. While observing the consequences of "running" these rules and the resulting motion of the particles, students gain a familiarity with a microscopic view of the system and the NetLogo model interface they will use again in later activities. Finally, students compare the assumptions of the computer-based model with those of Kinetic Molecular Theory.

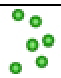
Activity Two: **(2) Changing Pressure**

This activity enables students to investigate what pressure is and how it is measured in the computer model. Students observe the effects of pumping up a tire with air by adding particles through a valve in the tire. They notice how this particle addition effects pressure, paying particular attention to the dynamics of the system, including changes, stability, and equilibrium in the system and how these are related to the particles' behaviors. Students learn to interpret time series data from graphs and make estimates of average values from these in NetLogo. These data analysis skills are necessary in later activities.



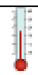
Activity Three: **(3) Experimenting with Particles**

This enables students to design their own experiments related to the study of gas particle behavior in a container. Students are first introduced to an array of new tools that enable the control and visualization of very specific particle properties.   Collisions of individual particles are investigated further, zooming in to introduce the concept of conservation of kinetic energy in the particles' collisions and the importance of a particle's speed and direction in determining the outcome of a collision. Students are then guided through an investigation of whether the particles' individual and average speed affects the pressure. Lastly, students design their own to investigation, allowing them to change properties of the particles such as their mass or direction of travel and explore what if any of these changes affect the pressure and propose an explanation of particle actions and interactions that would explain this.



Activity Four: **(4) Number and Pressure**

This activity enables students to investigate the quantitative relationship between the number of particles in a given container and the pressure inside. Students collect data from the model and develop a mathematical model of the relationship, noting that the relationship between this number and pressure is a linear one. Students are introduced to the idea of the average number of wall hits per particle and they find out that this value is independent of the number of particles. This finding is connected back to the linear equation the student discovered and shown that such a finding is predicted by the previous equation. The connection between the average number of wall hits per particle and the slope of the linear equation is explained and students are shown how such constants can be calculated in a linear relationship. Students use the equation to predict and test their prediction for new pressure values. Students reflect on many of the assumptions that they are now more familiar with in the computer model vs. the real system at this point.



Activity Five: **(5) Temperature and Pressure**

This activity enables students to investigate the quantitative relationship between temperature and pressure. Students explore the connection between the temperature of the gas and the average particles' speed, the connection to the concept of thermal equilibrium, and are introduced to the Kelvin temperature scale. Students collect data and develop a mathematical model of the relationship between temperature and pressure, noting that the relationship is a linear one. Students note the similarities between this relationship and the one for the number of particles and the pressure of the gas. They explore how both the number of particles and their temperature simultaneously affect the pressure of the gas and see how a more complex equation relating temperature, number, and pressure might be reasoned out. Students use the equations they develop to make predictions about what the pressure will be for different number and temperature combinations. Lastly students calculate pressure for a real world problem without the model.

Activity Six: **(6) Volume and Pressure**

This activity enables students to investigate the quantitative relationship between volume and pressure. Students are introduced to how the volume of a container is represented in the model. Density, the number of gas particles and the volume of the containter are related. Students also explore the temperature gradient that emerges from adiabatic expansion, again connecting these phenomena back to fundamental properties and interactions between the particles. Students collect data and develop a mathematical model of the volume and pressure relationship, noting that the relationship is an inverse one (Boyle's Law). Students extend this mathematical model, by collecting data from a computer model of a container with a variable volume to develop both an algebraic equation that relates volume and pressure and then also one that relates number of particles and volume to pressure. Students use the equations they develop to make predictions about what the pressure will be for different number and pressure combinations. Lastly students calculate pressure for a real world problem without the model.

Activity Seven: **(7) The Ideal Gas Law**

This activity poses some exciting challenges for students to apply their growing literacy of exploring models and the content domain. They are first asked to design an experiment to maximize the pressure in a container, where they can change the number of particles, the temperature of the gas, and the volume of the container. Students plan how they will change these variables and what data they will record. They then conduct their experiment and analyze their results. After reviewing the qualitative findings, students are asked to gather data for three different states, each of which gives the same pressure with different temperature, number, and volume combinations. From this students are asked to use the previous equations they developed and this data to try to derive the Ideal Gas Law through reasoning about particle behavior, studying their recent data, looking at previously developed equations, and reflecting on their recent findings from the first experiment in this activity which gave a qualitative sense of how the variables are related. Students compare their derivation with the actual equation and they then use the Ideal Gas Law to predict pressure values for different variable combinations. In the last part of the activity, students are asked to evaluate the implications of changing some of the Kinetic Molecular Theory assumptions. Changing one of these assumptions, by including an external force on the particles, prompts students to investigate a new model that introduces gravitational forces. Students are asked to explore this model and to develop a particle based explanation of why there is denser air down low near the ground vs. up high up in the mountains. Students develop an outline of the objects, properties, and interactions that would need to be included to create a model that would helpful in predicting short term local weather changes. Students reflect on the larger scientific enterprise in society and extend their thinking on the nature of modeling through by analyzing computer model predictions in the context of the short term weather predictions and long term climate change predictions.

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2.0 Learning Objectives and Standards

Alignment to National Math and Science and Mathematics Standards (NSES, and AAAS – Project 2061 Benchmarks for Science Literacy, NCTM)

Learning Objective	Standards
Students will construct a definition of pressure through manipulation of the variables within the model. **Students will predict an outcome and test their prediction.**	• Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations. • Implement solutions using computer software. • The investigation may also require student clarification of the question, method, controls, and variables.
Students extrapolate data from plots, monitors and the graphics window.	• Understand line graphs use them to display data; build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems.
Students will explore relationships between the objects and properties in the model to understand changes, stability, and other emergent behaviors and interrelationships in particle based systems.	• Physical and [biological] systems tend to change until they become stable and then remain that way unless their surroundings change. • A system may stay the same because nothing is happening or because things are

	happening but exactly counterbalance one another. • A system can include processes as well as things; A system usually has some properties that are different from those of its parts, but appear because of the interaction of those parts. • A system in equilibrium may return to the same state of equilibrium if the disturbances it experiences are small. But large disturbances may cause it to escape that equilibrium and eventually settle into some other state of equilibrium. • Things can change in detail but remain the same in general (the players change, but the team remains; cells are replaced, but the organism remains). Sometimes counterbalancing changes are necessary for a thing to retain its essential constancy in the presence of changing conditions. • Graphs and equations are useful (and often equivalent) ways for depicting and analyzing patterns of change. • Most systems above the molecular level involve so many parts and forces and are so sensitive to tiny differences in conditions that their precise behavior is unpredictable, even if all the rules for change are known.
Students use ratios between two variables to reason about the how another variable or constant would change and test the values predicted by their calculations in a model.	• Use ratios and proportions, including constant rates, in appropriate problems. • Find answers to problems by substituting numerical values in simple algebraic formulas and judge whether the answer is reasonable by reviewing the process and checking against typical values. • Consider the possible effects of measurement errors on calculations
Students will explain the rules of the computer model. **Students will compare and contrast the computer models rules and limitations with those of a real life situation.**	• Demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes. • Use representations to model and interpret physical, social, and mathematical phenomena. • Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. • Weigh the evidence and examine the logic so as to decide which explanations and models are best. • Models are often used to think about processes that happen too slowly, too

	quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous. • Mathematical models can be displayed on a computer and then modified to see what happens. • Different models can be used to represent the same thing. What kind of a model to use and how complex it should be depends on its purpose. The usefulness of a model may be limited if it is too simple or if it is needlessly complicated. • The basic idea of mathematical modeling is to find a mathematical relationship that behaves in the same ways as the objects or processes under investigation. • Computers have greatly improved the power and use of mathematical models by performing computations that are very long, very complicated, or repetitive. Therefore computers can show the consequences of applying complex rules or of changing the rules. The graphic capabilities of computers make them useful in the design and testing of devices and structures and in the simulation of complicated processes. • The usefulness of a model can be tested by comparing its predictions to actual observations in the real world. But a close match does not necessarily mean that the model is the only "true" model or the only one that would work.
Students will develop, manipulate, and solve for unknown values in symbolic representations between the number of particles, temperature of a gas, the volume of a gas container, and the pressure of the gas.	• Symbolic equations can be used to summarize how the quantity of something changes over time or in response to other changes. • Symbolic statements can be manipulated by rules of mathematical logic to produce other statements of the same relationship, which may show some interesting aspect more clearly. Symbolic statements can be combined to look for values of variables that will satisfy all of them at the same time. • Any mathematical model, graphic or algebraic, is limited in how well it can represent how the world works. The usefulness of a mathematical model for predicting may be limited by uncertainties in measurements, by neglect of some important influences, or by requiring too much computation. • When a relationship is represented in symbols, numbers can be substituted for all but one of the symbols and the possible value of the remaining symbol computed.

	Sometimes the relationship may be satisfied by one value, sometimes more than one, and sometimes maybe not at all. • Judge the meaning, utility, and reasonableness of the results of symbol manipulations, including those carried out by technology. • Recognize and apply mathematics in contexts outside of mathematics.

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3.0 Suggested Timeline

This seven to eight activity sequence is designed to allow 45-50 minutes for each activity. Many students finish the step in less time. The following represents a possible timeline.

- One class period – *(1) Modeling a Tire*
- One class period – *(2) Changing Pressure*
- One class period – *(3) Experimenting with Particles*
- One class period – *(4) Number and Pressure*
- One class period – *(5) Temperature and Pressure*
- One class period – *(6) Volume and Pressure*
- One class period – *(7) Ideal Gas Law*
- One-half to full class period - Analysis and "Wrapping Up" discussion

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4.0 Alternate Sequencing and Extension Activities.

Conducting laboratory investigations of at least some of the relationships that the students discover in the activities, may help enhance the ability to transfer understanding gained from the model to real world phenomena. For example, students might be given plastic syringes and weights with sealed ends and asked to design an experiment to validate the relationship discovered in the model (for Volume and Press) and to calculate a real world value that relate Volume and Pressure for their experiment. Also many types of activities and discussions might be interwoven in-between these activities to help students discuss and refine their understanding and application of ideas they develop in the activities. More specifically, when the students “take off” on their own investigations (e.g. in the activity “Experimenting with particles”), a discussion which integrates the different explorations, would benefit the students’ deeper understanding. Discussion of models related to diffusion, heat vs. temperature, heat transfer, and modeling of other states of matter might naturally arise in class discussions. Extensions to discuss and explore such connections are encouraged.

We do not include detailed descriptions of alternate or extension activities off of the computer for this unit of study, but encourage teachers to interweave activities or extend the unit with other class room learning experiences on these topics.

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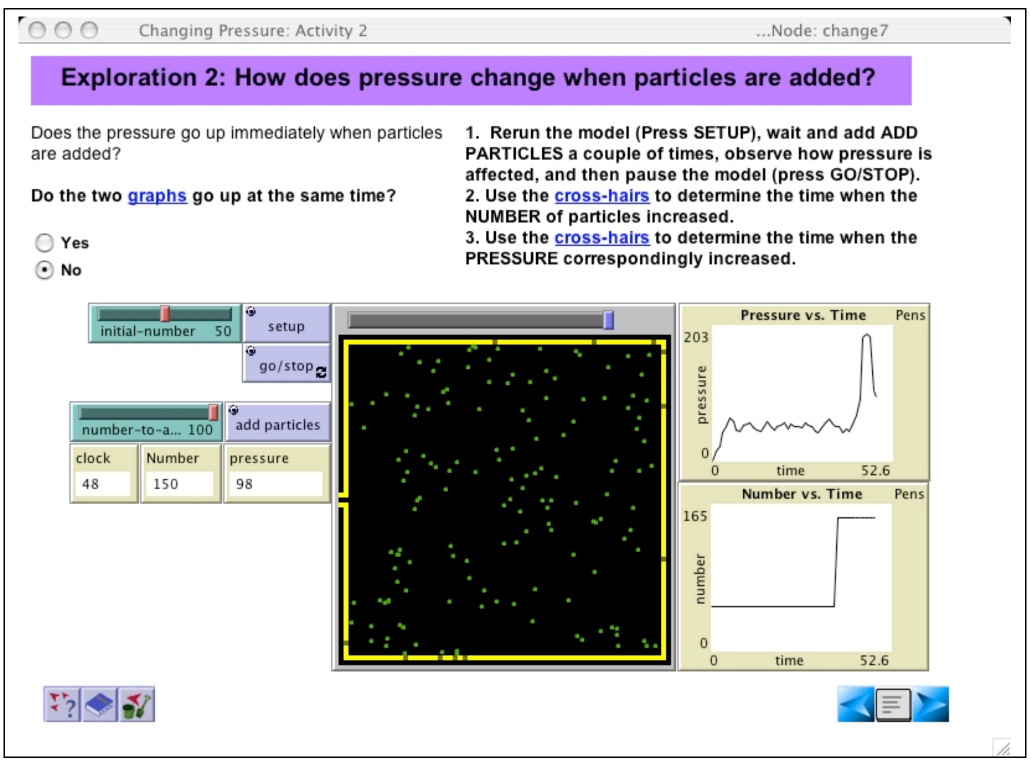
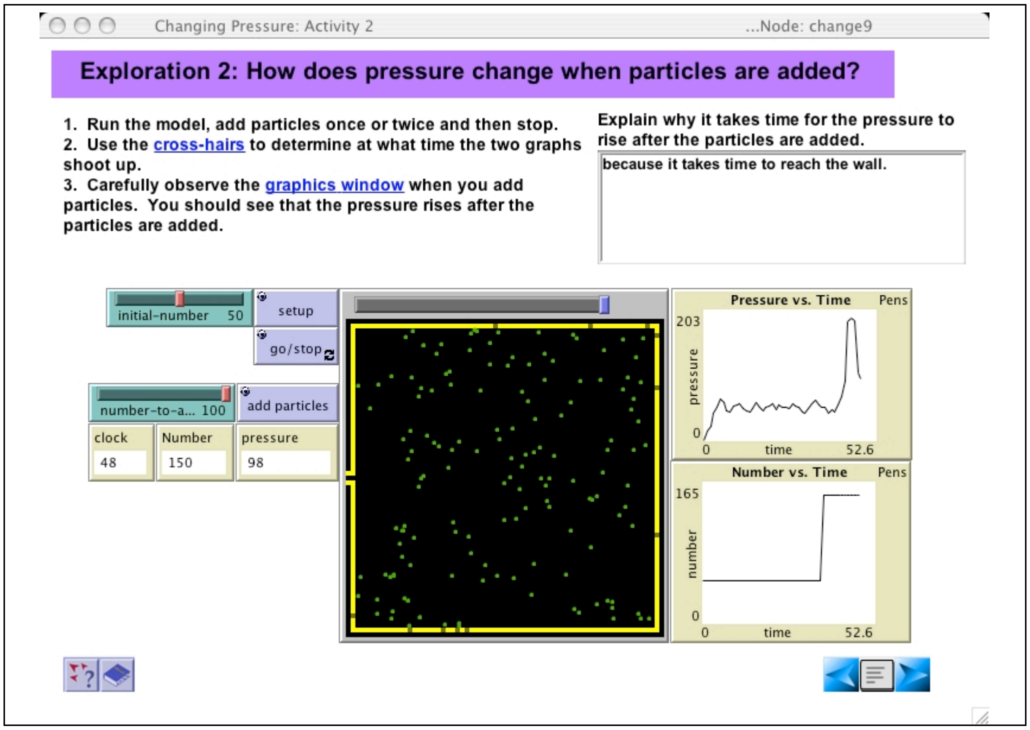
5.0 Activity Examples

To briefly illustrate the type of activities and questions in this Unit, we show an example of two of the screens that are part of the second activity "Changing pressure".

Prior to this section, the students have been introduced to the idea of pressure and that, in the model, it is measured when particles hit the wall. They have explored the qualitative relationship between the number of particles in the box and pressure. In these screens, they are asked whether the pressure goes up immediately after particles are added. Noticing the time lag between pumping particles into the container and the rise of pressure is the target phenomenon. Thus, the focus is on the dynamics of the process of change between states, in which a change to the system is gradually propagated throughout. They are offered graph analysis tools (the "cross-hairs") to quantify the values on the two graphs describing these variables over time. In the second screen, an explanation of the phenomenon is described in open form. We have found that after focusing the students on the time lag in the first screen, their explanations of the phenomenon in the second screen are typified as causal and detailed.





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6.0 Running Out of Time for Completing an Activity

If a student runs out of time during a class period you may wish that the student will try to complete the remainder of the activity during the next time he or she is using the computer or you may wish for the student to move on to the next activity. It is recommended that students progress through each activity and each exploration in order. A student who does complete an activity on a previous day, should note the page number of the activity they left off on, since the software will not show this information to the user when they restart an activity. No progress information from previous sessions is available to the user within the activity itself. If the student wishes to quickly get back to the page they were last on, the teacher may wish to help the student do this by using the Warp Mode Button (see next section).

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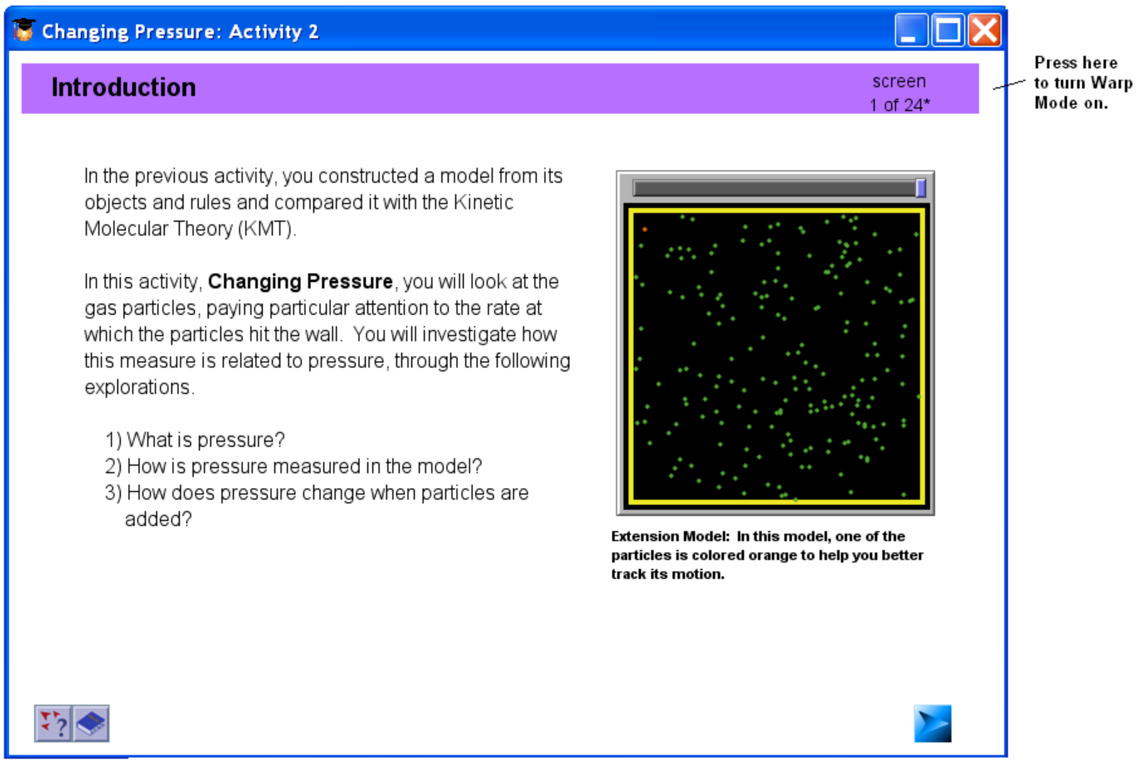
7.0 Warp Mode Button

By default, the activities will require students to complete questions or perform specific model actions before progressing to the next page on the screen. While this is a useful form of scaffolding in the activities, it may at times become cumbersome in a particular situation. For example, a student may need to resume an activity at a place where they previously left off (and want to get to that point in the activity quickly). Also, a teacher might decide that requiring student to complete every question or correctly fill out every table is not optimal in every situation.

Recognizing that many instances might arise where the teacher needs or wants to disable these checks, we have made a hidden Warp Mode Control Button available on the first page of every activity that the teacher can activate on a case by case basis. Pressing this button will remove the requirements to complete each question or data entry task on each page.

This button is located the top of each script next to a purple banner that indicates the name or title of the activity on the first page. On the right edge of this banner will be a page number indicator that will show something like “screen 1 of 21”. To the immediate right of the banner is what appears like a white space between the banner and the edge of the activity window. If you use the mouse to click on the white space you will have pressed a hidden button that will activate the Warp Mode for the activity. You will know the activity is in warp mode, because the page number indicator will now have an asterisk appended to it so that it reads something like “screen 1 of 21*”. You can now progress through the pages of the activity without any restrictions on question or table completion.



If you wish to switch back to regular activity mode, simply click on the white space again and the asterisk will disappear.

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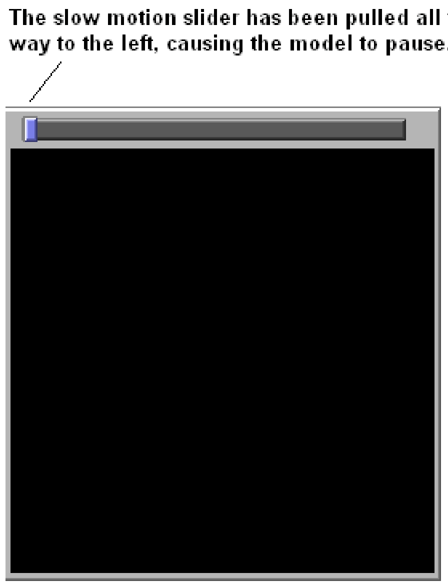
8.0 Stuck models or stuck pages

Stuck models

If at any point a model appears to be stuck and no longer running or no longer running correctly, advise the student to press the model reload button at the bottom of the page:

A stuck model is an unlikely occurrence and it is more likely the student may have simply adjusted the slow motion slider all the way to the left (which pauses the model), or not pressed SETUP before running the model. Another possibility is that the student has pressed the GO/STOP button in the model and while the model is running, they press the SETUP button. This will cause the model to sometime lock up. Students should always pause the model by pressing GO/STOP so that it is no longer depressed, before pressing SETUP.



Either way, the Model Reload Button shown above is a useful way to start the model over on the same page you are on and is provided as a failsafe for any problems you might encounter.

Stuck pages

If at any point a page appears to be stuck and the forward button does not move you to a new page, first ask the students to read the directions carefully, which may require the students to complete an action or process before moving to the next page. If this still is not helpful, suggest pressing the Table of Contents Button:

This will at least allow the student to move to a new section of the activity, even though they may not be able to complete the remaining pages in the section of the activity they were in.

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9.0 Prerequisite Knowledge

This activity assumes that students understand Force and Motion, the Particulate Nature of Matter or States of Matter and Conservation of Energy at a middle school level. If your students have not covered either of these three topics, we suggest supplementing where needed.

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10.0 Student Prior Mental Models

Prior to using the models, most students know that pressure is involved in inflating a bicycle tire or a basketball. When encouraged to think of gas particles in this context, some of the students view inflating the tire as 'packing' the ball with particles or as increasing their speed.

Regarding the notion of packing, this is quickly resolved through the activities when they observe the particles moving randomly about the container. Thus, the particulate nature of a gas is brought forth, as well as the fact that a particle has a mass, speed and direction. Using the models and visualizing the particles and the empty space around them supports the students transition toward a more intimate understanding of the gas phase.

Some students view the action of pumping particles into a container as increasing their speed, which results from their collisions, which become more frequent with a greater gas density. They tie this increase in speed to an increase in pressure. Some students employ an interesting idea -- that when the density of particles in the container increases, there is less room for each particle to move about -- but reason incorrectly that the many collisions with other particles slows the particles down.

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11.0 Research Base

A body of science education literature points to student's misunderstandings of the gaseous phase of matter (Lin & Cheng, 2000; Maz & Perez, 1987). Some of these misunderstandings can be related to what Wilensky and Resnick call "levels confusion" (1999), where the properties of the macro-level are incorrectly ascribed to the micro-level (in the particular case of chemistry). The macroscopic properties of gases are easier to experience and perceive, such as when a kettle boils or a coke bottle produces a hiss when it's opened. However, the microscopic particles that are moving, colliding and bouncing off the walls are invisible. The literature reports a variety of alternative notions about gases such as ordered packing and weightlessness. Lin and Cheng (2000) describe high-school students' failures in understanding Kinetic Molecular Theory as it applies to gases: molecules are pushed down by atmospheric pressure, molecules stay away from heat and molecules expand when they are heated. All three can be related to our macroscopic daily experiences: our gravitation towards the earth, boiling water rising out of a pot and macroscopic expansion upon heating. Mas and Perez (1987) have found that high-school students regard gases as weight-less, reasoning from the macroscopic behavior that gases rise, and therefore cannot have weight. Similar problems have been reported in a variety of scientific domains, such as genetics (Marbach-Ad & Stavy, 2000) and basic electricity concepts (Frederiksen, White & Gutwill, 1999).

The learning research community has recognized the discontinuities between conceptual and algorithmic understandings of Chemistry (e.g., Kozma et al, 1990; Niaz & Robinson, 1992; Stieff & Wilensky, 2003). For example, Berg and Treagust (1993) point to the minimal use of qualitative relationships regarding teaching the gas laws both in a variety of textbooks they analyzed and in teaching approaches in schools. Students may be capable of solving problems that involve the procedures commonly taught in science classes. However, they do not necessarily do as well when approaching a similar problem that requires more qualitative, or conceptual reasoning.

A fruitful way of approaching the problem of bridging the conceptual and symbolic forms of representing chemical phenomena is the use of computer models that employ multiple representations and that have affordances that enable connecting the representations (see 4M:Chem, Kozma et al, 1996). Frederiksen, White & Gutwill (1999) have used a variety of models in computer simulations, to help students connect the different levels that can be used to describe basic electricity: a particle model, a circuit model and an algebraic model. Wilensky et al (Wilensky, 1999b; Wilensky, Hazzard & Froemke, 1999) have shown that NetLogo models can be powerful avenues for learning about gases and, more generally, about statistical mechanics. In their studies, students used the GasLab (Wilensky, 1999x) package. Students were involved at three levels: exploring existing GasLab models, modifying those models, and constructing new such models.

The unit reported here builds upon this previous work, but differs in that all students are involved only at the exploratory level and that their explorations are not entirely free but are guided and constrained by a script. The script is designed to guide but also to enable freedom and exploratory flexibility. The primary affordance for the students is the ability to connect the observed phenomena with the mechanism or rules underlying the model. This enables students to view the model as truly computational, and not a prepared "movie" selected by the designers and programmers.

Chemistry is a natural domain for an agent-based approach, as all chemical phenomena emerge from local interactions among a multitude of interacting individual molecules. The models used in the current project are a modified version of those originally created for the GasLab curriculum (Wilensky, 1999b; Wilensky, Hazzard & Froemke, 1999). A free-form version of Connected Chemistry was created by Stieff and Wilensky (2003). In the current project, the models are embedded within a script (Pedagogica, Horwitz, 2002) that structures the interaction of the students with the models. We have found that through exploring the Connected Chemistry activities, the students gain a deeper understanding of the microscopic viewpoint and connect it with the macroscopic viewpoint (Levy, Kim & Wilensky, 2003). We have also observed their fine-tuning and adaptation of model exploration strategies as they become more fluent with the tools and domain (Levy & Wilensky, 2004).

This first set of activities in the Connected Chemistry curriculum is on the topic of gases: Gas laws, and Kinetic Molecular Theory (KMT). Kinetic Molecular Theory describes the behavior of individual particles (e.g., particles move in straight lines, they elastically collide with each other and with the walls). Gas laws describe the relationships among properties of the system of particles as a whole, when it is in equilibrium (e.g., Boyle's Law: the relationship between the volume of a box and the pressure inside, when temperature and the number of particles are constant). In addition to the traditional chemistry content, our curriculum also targets several important chemistry-related ideas: (a) Modeling: how a model is constructed, its assumptions, affordances and limitations, its relation with the target real-world phenomenon; (b) Thinking "from the molecule up" by focusing on micro-to-macro descriptions, transitions and connections; (c) Focus on processes of change in the system, such as perturbation and equilibration; (d) Mathematical modeling, deriving equations from data obtained through the students' NetLogo model explorations.

More generally, the chemistry topics are set within a wider perspective of complex systems. The domain of "complex systems" has evolved rapidly in the past 15 years, developing novel ideas and tools, and new ways of comprehending old phenomena, such as weather systems. Complex systems are made up of many elements (often named "agents", in our case, molecules), which interact among themselves and with their environment. The interactions of numerous elements result in a higher-order or collective behavior. Although such systems are not regulated through central control, they self-organize in coherent global patterns (Holland, 1995; Kauffman, 1995; Resnick & Wilensky, 1993). These patterns are often counter-intuitive and surprising.

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12.0 Student Reports

Your students' work with the Connected Chemistry activity is logged and viewable on the MAC Project Web Portal at http://mac.concord.org. For each student, you can view a report containing questions and answers. Students can also view their own reports for questions and answers by using their username and login on this portal.

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13.0 Credits

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- Michael Novak, Northwestern University
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