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Uncovering Models and Visualizations in the Chemistry Classroom, an Assessment of Classroom Activities and Lessons

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Uncovering Models and Visualizations in the Chemistry Classroom, an Assessment of Classroom Activities and Lessons

by

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Introduction

Models have been used for centuries in order to represent an idea, a thought, or an entity. For example, it would have been impossible to create a full-scale mock-up of the Space Shuttles used in the Constellation space program without some type of smaller scale model designed to show different aspects for study. We begin to teach children from a young age using models and multi-modal approaches. By giving our youngest students toy cars, blocks and human-like figures we are getting them ready to make connections on a much larger, or much smaller, scale.

Learning science is strongly connected with building knowledge through understanding and developing students' long-term memory by interpreting multi-modal representations of science phenomena (Devetak, 1562, 2009). When we allow students to access their previously learned knowledge prior to being exposed to new information, we allow connections to be made naturally and incrementally. Prior knowledge in the science classroom is a key tenet of helping students understand a new concept or artifact. By helping a student construct knowledge in a way that is comfortable for them, we are preparing them to retain more information. We are learning that it takes substantial time for students to achieve conceptual understanding of chemistry, and that most students are able to significantly improve their thinking given the time and opportunity (Claesgens, 81, 2008).

When it comes to bringing models into the chemistry classroom, it becomes more than just having a model represent a concept such as an atom or a molecule. The visualization process comes into play because without the ability to turn a conceptual idea into a visual thought, the chemistry student will be unable to transfer learned information into quality scientific thought over time. An algorithmic problem is one that can be solved using a memorized set of procedures; a conceptual problem requires the student to work from an understanding of a concept to the solution of a problem, where no memorized procedure is likely to be known to the student. The findings across recent studies showed that a majority of students in high school and college chemistry courses rely almost exclusively on an algorithmic approach to quantitative problem solving (Cracolice, 873, 2008). If a shift can be made from a strictly quantitative problem solving approach to a more qualitative observation based model, it is expected that students will be able to craft their learning into something usable in their minds, and at a higher cognitive level.

Mental Models

According to mental model theory, mental models are a form of knowledge organization that represents objects, states of affairs, sequences of events, the way the world works, or social and psychological actions of daily life (Khan, 2007). For example, in the chemistry classroom, a student can have a mental model of molecular structure without seeing one for themselves. These mental models are fluid and ever-changing and can be partial or incomplete. Learning from models means that we can learn from building, critiquing and changing our mental models as we encounter new material.

Traditional forms of chemistry instruction that employ textbooks as a major resource often fail to bring about engaging activities or to involve students in evaluating physical or mental models or in inquiry. Students who have received this type of instruction (standard lecture and textbook) often do not have an accurate mental image of molecular structures, pay little attention to bonding in their molecular models, and harbor alternative conceptions about substances at the molecular level. The mental models that students possess may not resemble the way nature holds to be true or how nature works.

Several model-based teaching strategies documented in the literature have involved students working with interactive multimedia and computer simulations. These types of modeling practices from model based teaching have reported significant gains in student understanding (Khan, 2007). According to Khan's research, students, who were involved in classrooms with a learning environment constructed to be inquiry based, enriched their models of molecular structures and developed understanding of intermolecular forces through a simultaneous and ongoing process of generating, evaluating and modifying hypotheses. All of these processes are the fundamental building blocks of experimentation in the chemistry classroom.

While students are studying science, they can gain a multitude of information from their instructor depending on the level of constructive, meaningful models used during instruction. Through an instructor's teaching models presented to young science students, these students can now create mental models on their own in order to construct meaning for themselves. In science, mental models are used to describe a system and its component parts as well as its states, to explain its behavior when changing from one state to another and to predict future states of a system (Jansoon, 148). Mental models are used to produce simpler forms of concepts, to provide stimulation and support for the visualization, and to provide explanations for scientific phenomena. In science teaching, teachers use mental models in two distinct ways. First, they try to communicate the models of science (e.g., atomic structure) to their students. Second, they use certain types of models – particularly analogy, to explain scientific ideas to students (Jansoon, 148).

Jansoon described three types of mental models for use in the chemistry classroom, macroscopic, sub-microscopic and symbolic. At the macroscopic level, students are able to make observation concretely according to observable objects and phenomena (for example, their experiments in the laboratory). The sub-microscopic level is more abstract than the macroscopic level and is characterized by theories about very small objects such as electrons, molecules and atoms. The symbolic level of models includes the use of chemical equations, graphs and model kits as these are used to represent chemical and macroscopic phenomena. Through the use of each different type of model, a chemistry instructor can provide knowledge to different types of learners while keeping the content uniform and allowing for differentiation at the same time. Students who recognized relationships between different representations demonstrated better conceptual understanding than students who lacked this ability (Devetak, 2010).

Due to the nature of the different types of molecular models, the variety of students in a classroom and how they learn, instructors should allow for multi-modal learning in the classroom because as instruction changes so does the ability to model a concept appropriately. While using these models in the classroom, all students need to be able to not only use the models to describe a scientific process but be able to verbalize and use algorithmic problem solving involving the same concepts.

Mental models are pictures or visualizations in the mind. Mental models can be of macroscopic objects that students have seen in the past (e.g., a beaker), or they can be of abstract things that cannot be seen (e.g., atoms or molecules). According to Williamson, our level of knowledge is dependent upon our ability to construct mental models from our conceptual frameworks, which we can then use to reason.

The mental models of experts usually include both sensory, macroscopic data from the physical world and formal abstract dimensions of the phenomena, while novices usually have in-complete or inaccurate models (Williamson, 2008). The idea that experts are capable of more abstract thought, while novices are confined to thought about concrete objects is consistent with constructivist learning theory.

Visualization techniques to help students picture particles and enhance formation of their mental models can take a number of forms, including the use of physical models, role playing, fixed computer models that rotate, dynamic computer models or animations, student-generated drawings or animations, and interactive computer models (Williamson, 718, 2008).

Visualizations

Since the beginning of time, scientists have been using their five senses to make scientific discoveries. When the first farming began, people began realizing that if they threw rotting food in an area, they would create better crops, leading to the world's first use of fertilizer. In a more "recent" example, Isaac Newton was enjoying his day before being struck in the head with an apple. This observation led to Newton's laws of Motion and his theories on gravity. Over the centuries, these discoveries became more focused and formalized by people who were eventually called scientists. Visualization of scientific phenomena has been the key ability of several renowned scientists (Ganguly, 1995). Bohr's development of the atomic model and Einstein's abstract theories would not have existed in their current form if not for their ability to think visually.

Effective science teaching practice calls for the infusion of skills such as visualization and extrapolation into daily science instruction. Mental models are built from personal interpretation of information based on these visualizations. Employing visual information to model a system's structure and inherent casual relationships is vital to invoking systematic thinking in students (Ganguly, 1995).

Visual thinking is a key tenet of scientific thinking. Scientists “see” by gathering data, measuring, making assumptions and forming conclusions. In an effort to visualize something that is unseen, scientists and students have often resorted to metaphors to build up their thought processes, meaning, they have to create likenesses. In the context of chemistry, a metaphor would be a relationship to a real world connection a student can make. Metaphors are a means to anchor scientists thought processes in generating a pattern that would thematically bridge the gap between the seen and the unseen (Ganguly, 1995). Using analogy is another way to lead the student’s mind through an interpretive system. Once a student derives a clear idea of the base and target concepts, and their attributes, knowledge acquisition can proceed in a more systematic and meaningful pattern.

Results from Ganguly’s study questioned factors that would make a student more competent in making the visual connections required in an effort of analogy transfer. Students should be able to make learned visual structures to new information. Without direction and training, students were not likely to use any of the methods of visualization, such as analogies, concept maps or illustrations (Ganguly, 1995). Perhaps most importantly, without direct instruction designed to increase a student’s ability to visualize, they will be unable to use the skills of visualization, constructing analogies and designing concept maps. If a student is unable to “see” or visualize what the concept is about or how to get closer to it by making connections with prior knowledge, the curriculum, problem solving and assessment strategies will be useless. Being able to visualize something also becomes more and more difficult when the objects you are trying to see become smaller than what the strongest microscopes can pick up.

Seeing the Unseen

The concept of an aqueous solution in chemistry is difficult for many students to understand based on the sheer nature of the process. The fact that a substance can 'disappear' in water is impossible to describe without significant background knowledge. In an attempt to improve the learning of molecular structures and dynamics, animations and simulations of molecular level and macroscopic chemistry processes have been developed to supplement instruction (Kelly, 413, 2007). This visualization of the dissolution process can be very effective in showing students exactly what is happening.

When using visualizations in the classroom, it allows for students to watch a process that might not be visible to the human eye and also be able to watch the process over and over to allow for maximum absorption.

In Kelly's research (2007), the animations of salt dissolution appeared to have a positive influence on students' explanations in the two main areas of structure and function. The visualizations of the microscopic structure of the sodium chloride lattice can help students to recognize that solid salt consists of a network of alternating charges rather than isolated pairs or molecules. Some students also noticed that the chloride ion was shown as significantly larger than the sodium ion. Not only do students need to be able to draw these processes, but they also need to be able to communicate the process through written word and/or verbally. In his research of having students use these animations, Kelly (2007) wrote that most students gained ability to communicate the functional process of dissolution, in which the water attracted and surrounded the ions, and pulled the ions away from the lattice.

Through my experience in the classroom, I have found that students generally enjoy animations but then often struggle to connect them to concepts after the fact even if a discussion of the animations follow. In Kelly's 2008 study, the wide variety in what students reported is consistent with the distinctive way people construct their unique mental models when they are from diverse backgrounds and have different prior knowledge into which to fit their understanding. Students tend to struggle to transfer their understanding of salt dissolution to drawing the aqueous reactant solution of sodium chloride in the chemical reaction without guidance to consider how the solution was made. In the classroom, it is important to not only show animations of processes, but also to show the processes themselves so that students will be able to construct better knowledge in this manner, especially if the task is completed autonomously. Steps must be taken to deconstruct the process co complete and accurate visualization can occur.

Students also need to be able to recognize similar processes in order to connect what they know to what they are currently learning. For example, a discussion of a trip to the beach may be feasible to illustrate salt dissolved in water. Students can then use their experiences to describe differences in separate bodies of water. Another example could include the making of a powdered drink, such as Kool-Aid. Students would be able to not only see the substance dissolve, but they will be able to see that the more solute that is added, the darker and more intense the color becomes. This is a good experiment because students can also taste the difference between amount added and taste.

It is possible that students in this study (Kelly, 2008) did not immediately connect the aqueous sodium chloride solution with the salt dissolution activity because the clear, colorless sodium chloride solution in a test tube depicted in the video looked like many solutions the students experienced in the laboratory course. In order to help students realize that all clear solutions are not necessarily all water or just salt and water, water molecules should be included in particulate-level diagrams of solutions to help students understand the formation of aqueous solutions and how precipitates are able to form in the presence of the solvent. Often textbooks and instructor diagrams represent the solvent as a continuous fluid in which the solute molecules float. Consequently, students are unaware of the importance of interactions between solute and solvent molecules during the dissolution process.

Cartoons

As animations are visual to the human eye, so are cartoons and humorous drawings. Humor has long been a part of many societies as it tries to attempt to bring at least a measure of levity to a population. Over the years, numerous studies have examined and attempted to define the role of humor with respect to both student motivation and learning. At the university level, humor has been positively attributed to various aspects of learning including increasing the rate of learning, improving problem solving skills, increasing retention, reducing nervousness (especially in test situations), and increasing perceptions of teacher credibility. Cartoons have been used for different reasons by educators including enhancing motivation, developing good laboratory technique, improving writing and thinking skills, teaching laboratory safety, and augmenting reading skills (Roesky, 2008).

Cartoons are also not necessarily humorous, but cartoon-style drawings can present characters with differing viewpoints around a particular situation. They can be eye catching, meaningful and allow for a sense of interpretation to give voice to the differing points of view of individual students. Teaching and learning have long been an excellent springboard for humor and chemistry is no exception. Many first-rate teachers instinctively incorporate a touch of humor into their lectures without explicitly realizing the exact benefits. Cartoons have the power to both draw attention quickly and come to the point. The art, of course, is in getting your message across once you have student attention.

In visualizing through cartoons, students not only have the opportunity to express themselves through a medium other than what they are used to in a science class, but they can also construct their understanding so they can find scientific meaning. Students can use their imaginations to make analogies and interpretations about chemistry facts and concepts. The link between humor and learning can be helpful to a teacher looking to give students another way to make learning connections in the classroom.

Scientific Models

Scientific models evolve through the processes of scientific inquiry and discourse, and may be sophisticated and highly abstract (Adbo, 2009). Often, in the chemistry classroom, information is presented in a manner that shows students particles in chemistry as definite and known species in nature and as scientists, we know that these species are just models of what we think are correct. Often, the limitations or roles of these models are not presented to learners and cause some alternative conceptions about the material. Students are forming their own mental models, as all students do when learning new information in order to construct their own learning, and can create comprehension problems in their mind. The visualizations they form can be backed by solid scientific knowledge, but students may be unable to describe the situation as the model is somewhat confusing to them.

It has been found that even with opportunities for applying and consolidating learning, most students need a number of years to overcome the counterintuitive aspects of the basic (i.e. undifferentiated into atoms, molecules etc.) particle model (Adbo, 2009). If teachers were able to design a more specified curriculum that allowed for creation of essential questions based on visualizations and turning generalizations into more concrete evidence for students to use while creating mental models.

Only when this level of understanding is well established, can it be considered robust enough to act as foundations for further learning about particles models (Adbo, 2009). Only then will the introduction of molecules and ions, and subatomic particles, provide a coherent differentiation of the basic particle model, and allow meaningful learning about the Bohr model of the atom. This process can in turn provide the basis for understanding chemical change, and how this involves different types of particle interactions compared to physical changes such as changes of state (Adbo, 2009). Emphasis on the connections between the different models presented and the different contexts in which they are used, would support developing understanding over time and so contribute to preparing these students for further learning, and making sense of the more intellectually challenging models to come.

Analogies

When students construct new knowledge, it is conveyed and blends with what they already know. A key feature of constructivist ideals points to the importance of learners' prior knowledge when developing teaching activities or approaches. That is, the learner tries to relate new knowledge with what he or she already knows; this forms the basis of analogies (Calik, 2009). Calik states that that key features of teaching with analogies are to ensure the analogy is familiar to the students, map as many shared attributes as possible, and identifies where the analogy breaks down.

In classroom activities involving solubility, analogies can be an effective approach because, like other particle based chemistry concepts, it is difficult to visualize a substance dissolving. An analogy of people getting on a bus over the course of a route can portray solutions and concentration accurately because eventually, people may need to begin to stand if the bus is too full. Another analogy to be made could be connecting solution concentration to the appearance of a Kool-Aid beverage. The lighter the drink looks, the more dilute it is. Students often have prior knowledge of these types of powdered beverages and can connect these chemistry concepts to these ideas.

Conceptual Change

In school science teaching, ideas need to be presented in ways that are both authentic representations of the scientific concepts, and yet simple enough to be meaningfully understood by the learners. (Nahum, 2010). As students become more facile with using a technique, the more sophisticated the work can become. In student learning, it's the process of scaffolding or spiraling. Yet, chemical bonding is inherently an abstract and complex concept that students often struggle with. Even though conceptual understanding is a major objective in science courses, most students of all ages have difficulty in understanding scientific concepts and possess some intuitive and fragmented knowledge (Noh, 199, 1997). Another example is that a major problem occurs when teachers attempt to teach the concept of bonding. There are many different ways to explain the concept of bonding and no person explains it the exact same way. People have a wide range of views on many topics and each person's experiences and interactions shape and construct their learning. It is also one of the areas in the physical sciences where understanding is developed through diverse models – which are in turn built upon a range of physical principles – and where learners are expected to interpret a disparate range of symbolic representations of chemical bonds (Nahum, 180, 2010). Research into the relationship between students' ability to solve numerical problems and conceptual knowledge indicates that students who can produce the correct answer in an algorithmic problem may not be able to provide appropriate answers in conceptual questions dealing with the same topic (Dahsah, 228, 2007).

The difficulty in teaching bonding at the secondary level hinges between what we actually know about bonding and what our curriculum guides us to teach. Professional development in the area of modifying curriculum as well as connecting what we know to effective teaching practice through research will allow for stronger classroom experiences for our students.

Assessment and Instruction

The goal for a science teacher is to not only impart knowledge to their students, but to be able to insure measureable learning results from the educational process. If the source of assessment is only the instructor and there is not enough collaboration between the students and the instructor in assessment, then the instructor exerts a stranglehold that deters the development of collaboration with regard to all other processes (Kaya, 91, 2008). In New York State, the assessment piece is decided for all teachers who are required to give a regents exam. Within a district, a teacher is potentially bound by a curriculum as well as an assessment measure. In this process, students hold no power and do not participate in decision-making about their learning progression at all (Kaya, 2008).

Student involvement in assessment typically takes the form of self-assessment or peer-assessment. In both of these activities, students engage with assessment criteria and standards, and apply them to make judgments. In self-assessment, students judge their own work, while in peer assessment they judge the work of their peers. A concept map can bring visualizations into the assessment process by allowing students to map out their understanding through drawing and connecting various ideas and thoughts. While assessing these works, the instructor can now perceive what the student is seeing and allows for the potential changing of the curriculum and instruction.

With respect to science education during the past decade, assessment tools often used by science educators (e.g., multiple-choice and open-ended questions) have been challenged because of the lack of students' active participation in the assessment process, reflecting lower-order thinking skills (Kaya, 92, 2008). Kaya states that a shift from the prevailing lower-order cognitive skills to higher-order cognitive skills in science classrooms and laboratories requires a radical change not only in teaching and learning but also in assessment strategies compatible with the goal of student application of higher order thinking skills. Using visualizations in this manner can help assist with the radical change spoken of in literature.

The traditional lecture process is often considered to be the best way to convey a large amount of information in the smallest amount of time. One factor in the failure of students to retain the Lewis structure concept may be the lack of effectiveness of the traditional lecture format relative to a more active learning process (Bell, 450, 2009). Using visualizations and manipulatives can give students the background they need to not only learn, but retain the material related to such an abstract concept. Games and puzzles represent an enjoyable method of requiring a student to actively participate in the learning process.

The Ionic Puzzle Pieces Lab completed by students allows them to see the number of bonding opportunities an ion can have and then transfer that information to be able to visualize the number of positive ions required to bond with a specific number of negative ions. This lab also allows students to create chemical equations for compounds through these activities.

A number of researchers have reported that students hold alternate conceptions concerning the particulate nature of matter. These alternate conceptions of the particulate nature of matter conflict with the theoretical, particulate explanations that are given by chemists for most experimental chemistry data. Williamson (2008) described three components of chemistry: the macroscopic (what can be seen with the eyes); the symbolic (equations and mathematics); and the submicroscopic (particulate) levels. Conceptual understanding of chemistry often involves understanding particulate behavior but without understanding all three levels of chemistry, students will struggle with the basics of chemistry. In the process of science learning, the teacher should therefore incorporate students' "rich pool of representational competence" (Devetak, 2010) when creating lessons so that they are motivating for students and also points out that the quality of the representation ought to be evaluated according to its purpose.

Evidence suggests that viewing particulate animations increases conceptual understanding. Particulate animations come in a number of types: some are driven by mathematical equations (computational animations); some are artistic representations of phenomena (representational animations); others can allow or require student input or control (interactive animations) (Williamson, 718, 2008).

Conclusion

Research in the area of visualization must be conducted with different audiences and in different contexts, including use of a more sensitive content instrument. Research with student populations should be conducted to discover whether the same results are observed as with the chemistry instructors in this study. The implications may be that it is not so dismal for those students who have low scores in spatial abilities. With practice, these abilities may increase, as they did in the context of this study. Instructors of chemistry need to understand that students with low spatial ability should not be dismissed as unable to learn spatial relationships like molecular geometry, stereochemistry, and so forth. Rather, teachers must deliberately design lessons so that students learn visualization and modeling in an incremental, scaffolded fashion.

It is important that teachers evaluate students' understanding of these chemical concepts related to the concepts to be upgraded in the future lessons. If teachers conclude that students' understanding of specific concepts is not sufficient, they have to provide enough time to consolidate the knowledge to prepare the basis for further concepts development in students' mental model of specific science phenomena (Devetak, 2009).

Visualizations and models are a key way to connect difficult concepts in chemistry to the real world so students can better understand and correctly apply the information given to them. Throughout this project, it will be shown that using these types of learning strategies in the classroom will allow students to better construct their knowledge and gain deeper insight into the chemical world.

Analysis of Lessons

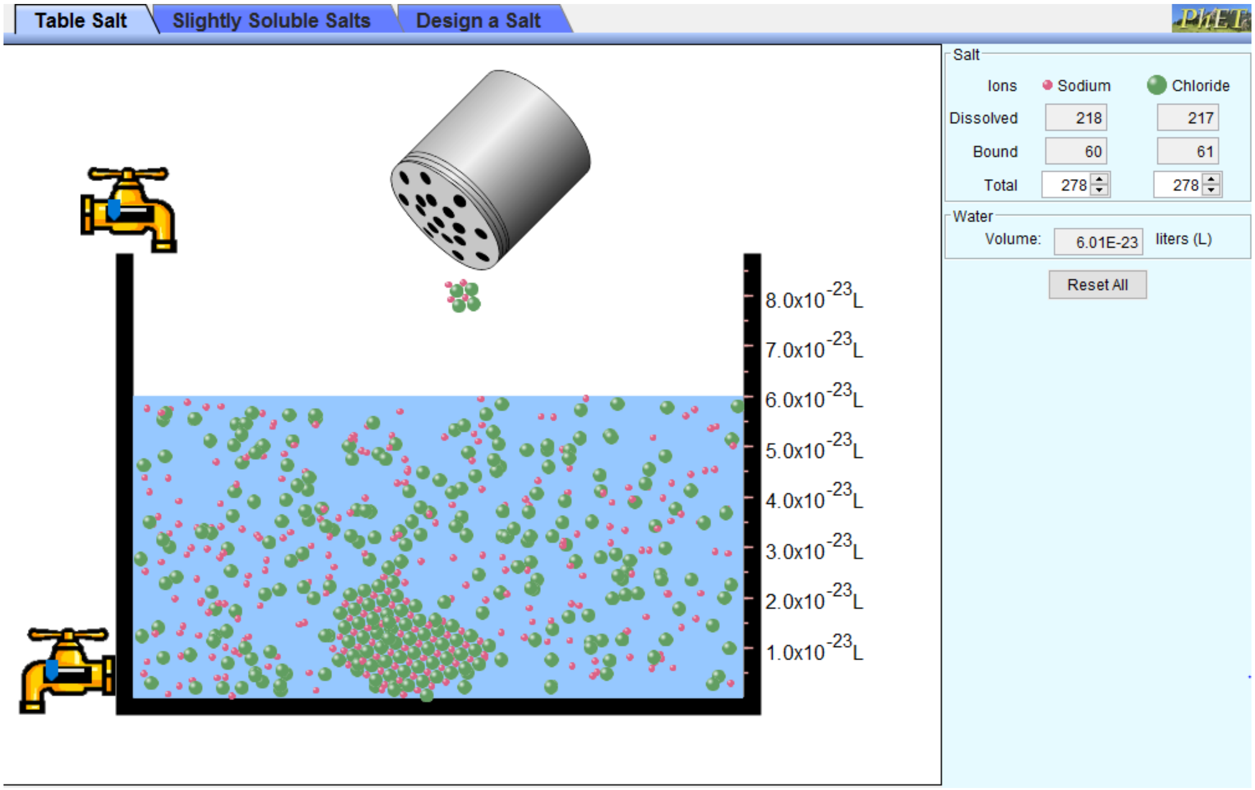
Solubility Computer Simulation

Visual observations and scientific thinking have been interconnected since the first scientific claim was made (Ganguly, 1995). From the development of the first fertilizer to the discovery of gravity due to the descent of an apple, people have been making observations and turning those observations into working models and theories. In the classroom, students use their vision first to make observations, turn those observations into assumptions and eventually a conclusion.

Prior to the use of models in the classroom for solubility, one would discuss dissociation and write out equations for students to copy down. For example: $NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$ would be discussed by saying "the sodium chloride (NaCl) is dissociated in water by breaking up into its ions." As chemistry teachers, we could even put them in a lab setting and using simple table salt and water, allow them to dissolve salt in the water. But, as experience has shown us, simply putting salt in water doesn't allow for the observer to see the dissociation, which is an important component of the NYS Chemistry curriculum. According to NYS Learning Standards, students need to be able to connect the dissolving process to electrolytes and conducting an electrical current in solution. Students still struggle with the understanding and in order to increase student learning, teachers can introduce a model.

By using a visual model, students can use their own electronic devices and interact with a model. Visual models are often used when there is something microscopic or too small to see in an actual experiment. The model shown below is giving the student multiple pieces of information.

First, the "salt shaker" releases solid NaCl to the water and as the salt hits the water, it dissociates, or breaks apart. The dissociation is something you would not be able to see or experience in the laboratory setting as personal experience tells us, once you put in the salt into the water, it is no longer visible. Another aspect not experienced by the student in the natural world would be the size of the ions in the solution. Although not shown by the salt shaker model, the sodium loses an electron and decreases in size while the chloride ion does the opposite giving the students something to consider while exploring the model.



Salt

Ions	● Sodium	● Chloride
Dissolved	218	217
Bound	60	61
Total	278	278

Water

Volume: 6.01E-23 liters (L)

Figure 1. Computer Model of Solubility

Also shown in the model that won't be seen at the bottom of your cup of salt water will be the exchange of ions. A saturated solution is created when more ions are in solution than can be supported by the solvent. When the solution is saturated, ions are exchanged at the surface of the salt at the bottom of the container and an equilibrium is formed. Being able to experience the exchange of ions through the computer model is an important step as the recrystallization/dissolution process is a difficult one to process as a student.

Once the student spends some time with the model; adding more salt, adding more water, draining the water from the bottom of the container and exploring the changes occurring during the process, it is important to have conversations with or ask for a product from the students to ensure understanding. In the case of the salt shaker model, a teacher could ask the students to take what they learned and expand upon it to describe might be happening at the bottom of a glass of Kool Aid that has too much sugar in it. The explanation could be done either informally through a conversation, or with some other type of formative assessment.

Even though the model is a good representation of the process that occurred, instruction is still necessary to discuss the process and turn it into the language associated with chemistry, the chemical equations. The concept of multi-modal instruction is important to remember as models are not the end all be all of instructional possibilities.

Subatomic Particles Chemthink Tutorial

Computer models do not always need to discuss a complicated concept. At the beginning of any chemistry course, high school or college, students learn the basics of atoms and how they are put together. Because atoms are so small, students often struggle with the connection of particles that are too small to be seen to the concepts in the classroom (Jansoon 2009).

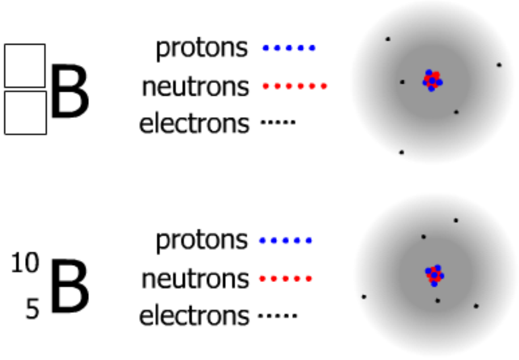


Figure 2. Example problem from Subatomic Particle simulation

As shown in Figure 2, students can use a computer model while learning about subatomic particles and the visualization often gives students the opportunity to make the connections necessary to be successful in the chemistry classroom. This animation allows students to have some input control (as evidenced by the empty boxes in the picture above). Students will look at the model and decide what the symbol would look like using the given information. By using an animation in this way, students will increase their conceptual understanding because using a representational animation that requires input by the students (Williamson, 2008).

Balancing Chemical Equations

Another visual model could be used to represent the concept of balancing chemical equations. There are many ways for students to practice balancing equations. One can begin by giving students a simple equation and using a method that starts by balancing metals, moving on to nonmetals and saving hydrogen and oxygen for last. The instructor can write out the numbers of each element as the process continues and students can practice by emulating the teacher. Direct instruction and the number method can work for some students, but others need a more interactive method to understand the balancing of equations.

If students are able to “see” and gather data, balancing equations becomes more interactive and the understanding of the why the equation needs to be balanced comes to the forefront. By using a computer model students are able to see the imbalance and connect that imbalance to the coefficients in the equation. As shown in Figures 3 and 4, the PhET model uses a seesaw to show when a student has an equation that is not balanced.

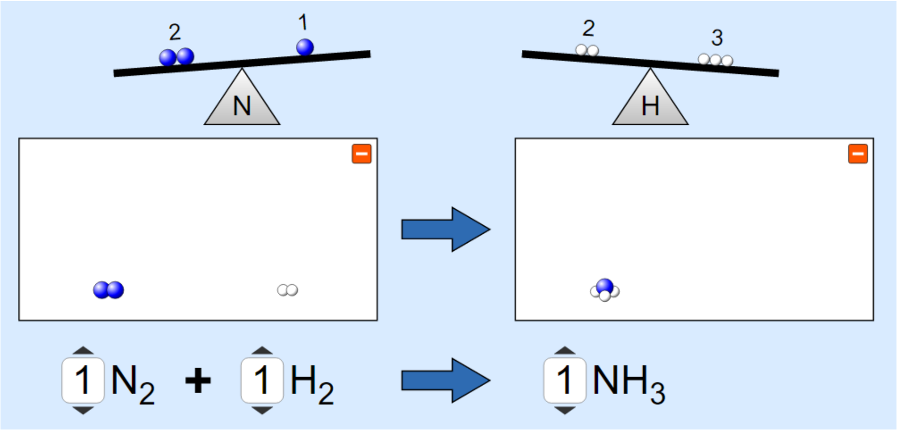


Figure 3. Unbalanced Equation

If a student notices part of the equation is not balanced, they can use the arrows to change the coefficients and balance that atom in the equation.

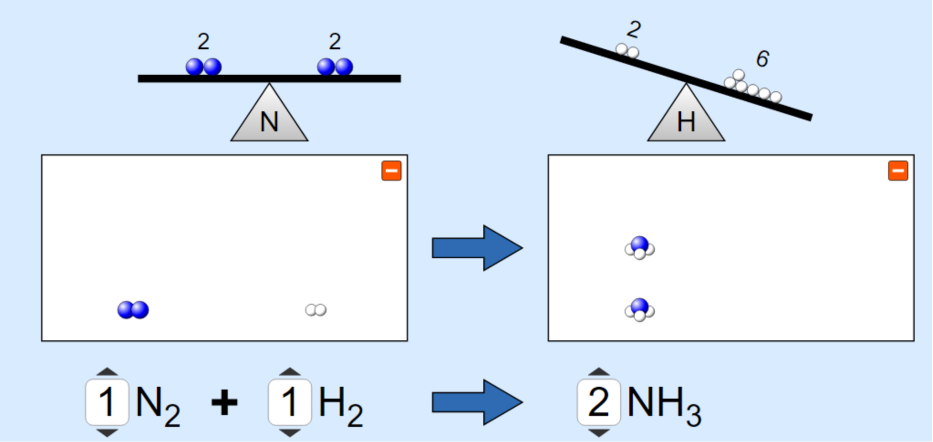


Figure 4. Unbalanced Equation

By increasing the number of ammonia (NH_3) molecules, the student balances the number of nitrogens (the triangle with the N) so that there are two on each side of the equation. The student should also recognize that there are too few nitrogens on the left side of the equation and they should increase the coefficient on the hydrogen to balance the equation.

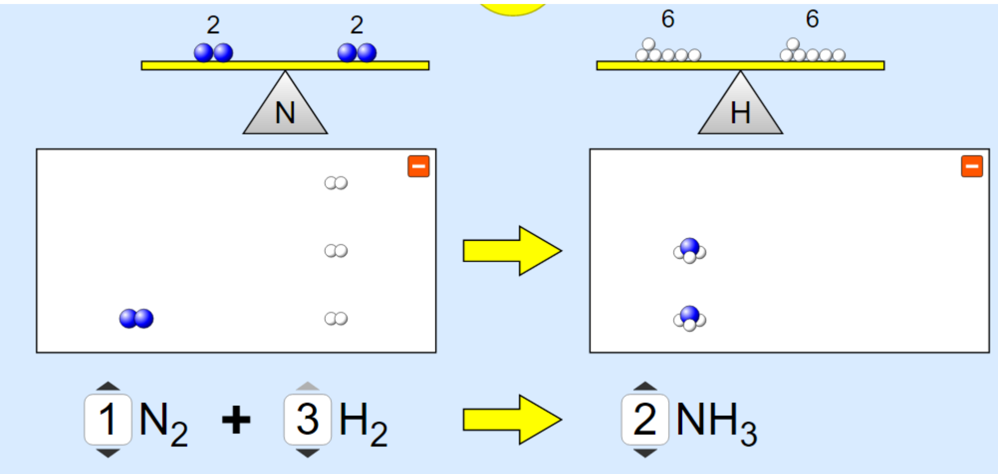
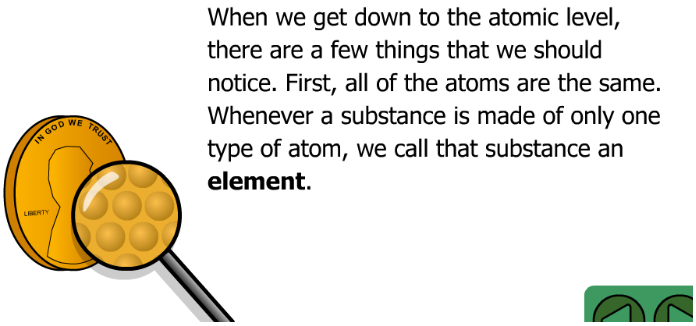


Figure 5. Successfully Balanced Equation

As students practice using this model, the instructor should have a similar example ready for each time they complete one using the model. By having students practice with the model and then complete a similar example, the instructor is building confidence in the students as well as their skills. As the teacher circles the room and checks in with students, the teacher is able to spot check student work and ensure students are understanding the model and balancing equations correctly prior to ending the activity.

<u>Particle Behavior of Matter Chemthink</u>

In another activity used to demonstrate the different types of matter, students get to explore and experience solids, liquids, and gases at the atomic level, something one would only be able to do with multi-million-dollar equipment. Seen below in Figure 6, it is shown that if you could get down to the atomic level you would be able to see the types of atoms within the sample.



When we get down to the atomic level, there are a few things that we should notice. First, all of the atoms are the same. Whenever a substance is made of only one type of atom, we call that substance an **element**.

Figure 6. Example of particles at the atomic level

Students can be asked "What do you observe in terms of the behavior of the particles?" Whether the sample is a solid, a liquid or a gas, students would give observations and begin to construct their understanding of something they cannot see. At the conclusion of the computer model, students could answer these questions in groups:

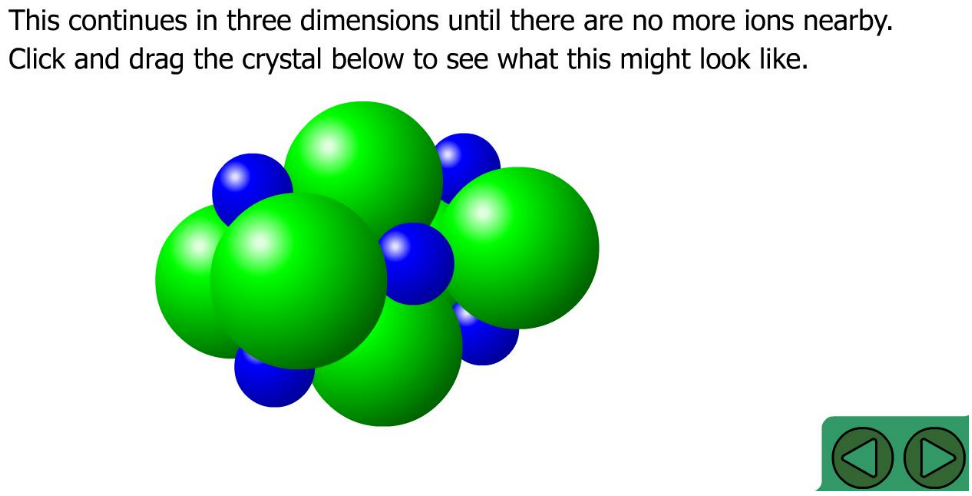
- In the depiction of a gas, the animation shows a lot of empty space between the molecules. What do you think is in this space?
- Why do you think the particles of a gas move so much more rapidly than the particles of a solid?

By asking these open ended questions, not only can the instructor hear what the student mentally constructed in their completion of the activity, but also hear how the student is extending their knowledge beyond the scope of the activity, The teacher could then connect this lesson to others in the future as prior knowledge.

Dynamic representations of chemical processes that have been developed for the chemistry classroom help increase the visualization for students (Kelly, 2007) and by bringing visualizations into the picture, students can increase their understanding (Kelly, 2008).

<u>Ionic Bonding Chemthink</u>

Computer simulations exist to allow students to work with interactive media and introducing this computer based modeling instruction allows significant gains in student understanding (Khan, 2007). Another example of computer based learning that allows students to visualize something that is considered too small to see is one that models ionic bonding. Shown below in Figure 7 is a snapshot from the model that shows how the lattice structure comes together. This difficult to visualize concept being brought to a visual simulation allows students to understand something they would not have been able to see without the model.



This continues in three dimensions until there are no more ions nearby.
Click and drag the crystal below to see what this might look like.

Figure 7. Example of an Ionic Crystal

This interactive model allows students to rotate this structure and experience the bonding that exists between the two atoms. The students begin to understand the concept of the ionic formula here as a ratio of 1:1 rather than 6 atoms combined with 6 atoms. The students complete an online question set after the online model is finished that has them apply this knowledge to other situations. By looking at different structures and formulas, students are able to demonstrate their understanding by applying their knowledge about ionic formulas and the ratios that exist. Students that are able to recognize the relationship between structure and formula demonstrate better conceptual understanding than students who did not make these connections (Devetak, 2010).

Covalent Bonding Chemthink

In another computer model, covalent bonding is introduced to the students. At the point in the course where teachers would bring this to the students' attention, students would have a general understanding of the atom, its nucleus, and the electron(s) that circle the nucleus. By using this model, students are able to interact with the nuclei and explore the covalent bond in terms of the potential energy and the interaction of the valence electrons.

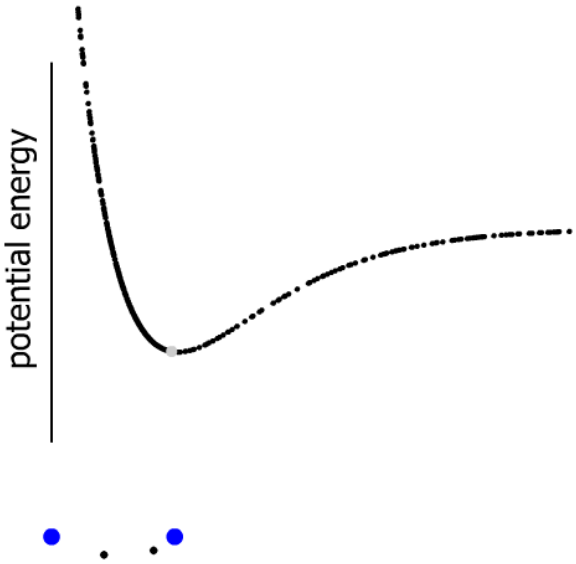


Figure 8. Graphical Representation of Covalent Bond Energy

In the picture above, students have the opportunity to move the nuclei closer to and further away from each other and observe the changes that occur. Students will recognize two phenomena while manipulating the slide shown. First, they will see the graph being drawn as they move the nuclei. Second, they will realize that instead of the electrons orbiting the nuclei, they are "stuck" in between the nuclei as the bond is formed. A question that could be asked to ensure the students are on the right track is: "What do you notice about the electrons as the graph hits the minimum point? Why do you think this happens?" By asking these questions, the teacher is not only checking for understanding, but guiding students that may have not picked up on the main idea of this part of the computer model. Claesgens said in 2008 that by giving the students the time to understand a model, the instructor gives the students the opportunity to improve their thinking and possibly achieve a conceptual understanding in chemistry.

Bare Essentials of Polarity

Cartoons are valuable aids that instigate and foster genuine student engagement in the classroom (Gafoor, 2013). By using a cartoon in the classroom, the cartoon can grab attention and generate participation. If a teacher is able to use humor in the classroom, it often gives students an opportunity to connect to the material and provoke the reader to a better understanding of a difficult concept (Gafoor, 2013).

Polarity of bonds is a difficult concept for students to understand in the chemistry classroom as it involves electrons that are the smallest part of an atom as well as introducing a value that is arbitrary and new to the student, electronegativity. When discussing polarity of bonds in the classroom, talking about using an electronegativity difference number line to differentiate between non-polar, polar and ionic bonds used to be the accepted way to teach these concepts.

Students had difficulty understanding the difference between the bonds and how each was different.

Using the cartoon “Bare Essentials of Polarity,” students are able to use a tool that is not only eye-catching, but humorous in order to increase their learning. The cartoon uses penguins and polar bears and their ice cream to represent atoms and their electrons and how they interact. The first thing students usually ask has something to do with the fact that polar bears live at the north pole and penguins at the south pole. After their initial shock at a polar bear and penguin coexisting, they are able to start using their imagination and can visualize the difference between the interactions among different atoms in the molecules. In the cartoon, the penguin and polar bear interact in different combinations to show different elements and how they bond (or do not bond). By reading and answering guided questions about the polarity cartoon, students are able to visualize and see the physical world expressed in a novel way that they may not be used to and construct their learning in a way that is conducive to long term retention.

In part one (Figure 9) of the "Bare Essentials Cartoon," there is a clear introduction to the concept of polarity which demonstrates the difference in electronegativity which can result in an uneven sharing of electrons (ice cream). Page one also connects the size of the animals in the cartoon to the value of the electronegativity (the bigger the animal, the bigger the electronegativity.) Connecting the size of the animals to the relative electronegativity allows the student to better understand the cartoon and in turn, hopefully understand the concept.

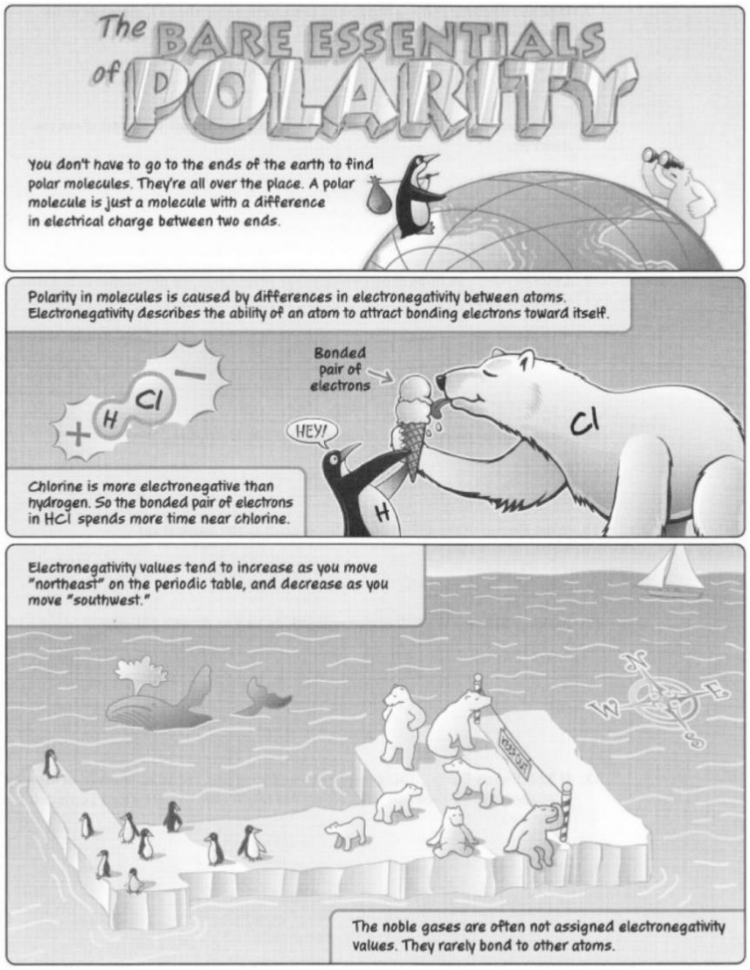


Figure 9. Bare Essentials of Polarity part 1

Part two (figure 10) discusses the charges involved and how sharing can be equal or unequal. The symbolic representation of the stalemate in the arm wrestling match between the animals represents an equal "struggle" for electrons and the opposite in the crushing defeat of the penguin. Using cartoons and symbolism in the classroom allows students to not only describe a scientific process, but verbalize the concepts related within that topic. Through page two of the cartoon, the notion of polarity has been introduced, but the true meaning behind the concept and the actual name of the bonds have not been established. Building the concept behind the cartoon allows students to construct their understanding during the initial stages of the cartoon and gives an opportunity for the student to construct their idea of polarity before the main focus comes into the picture.

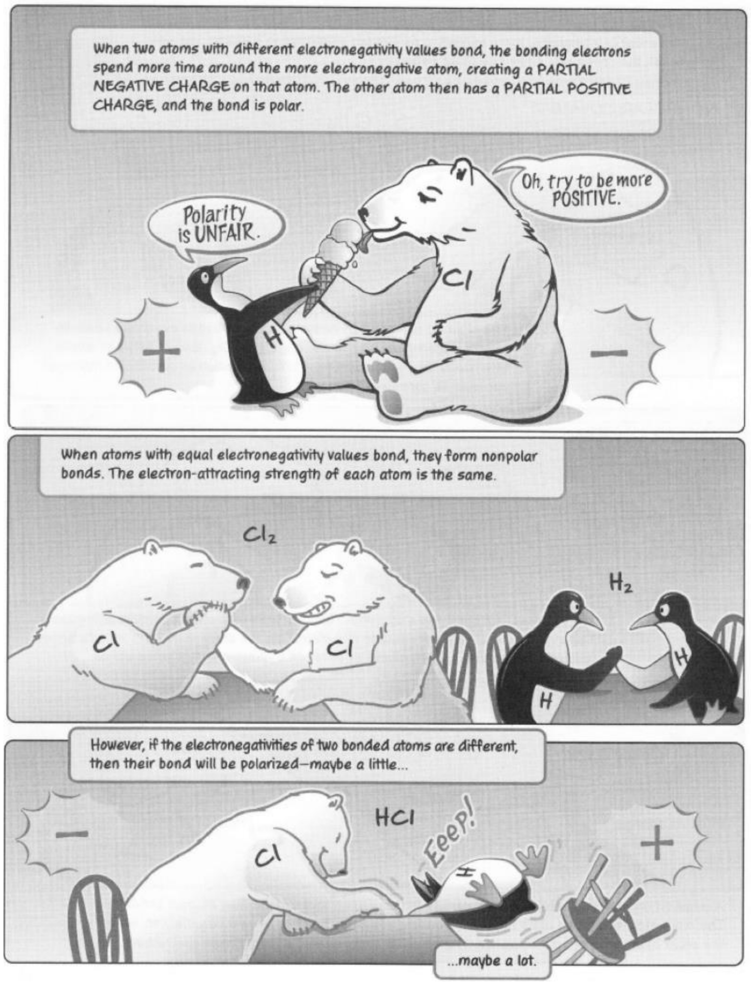
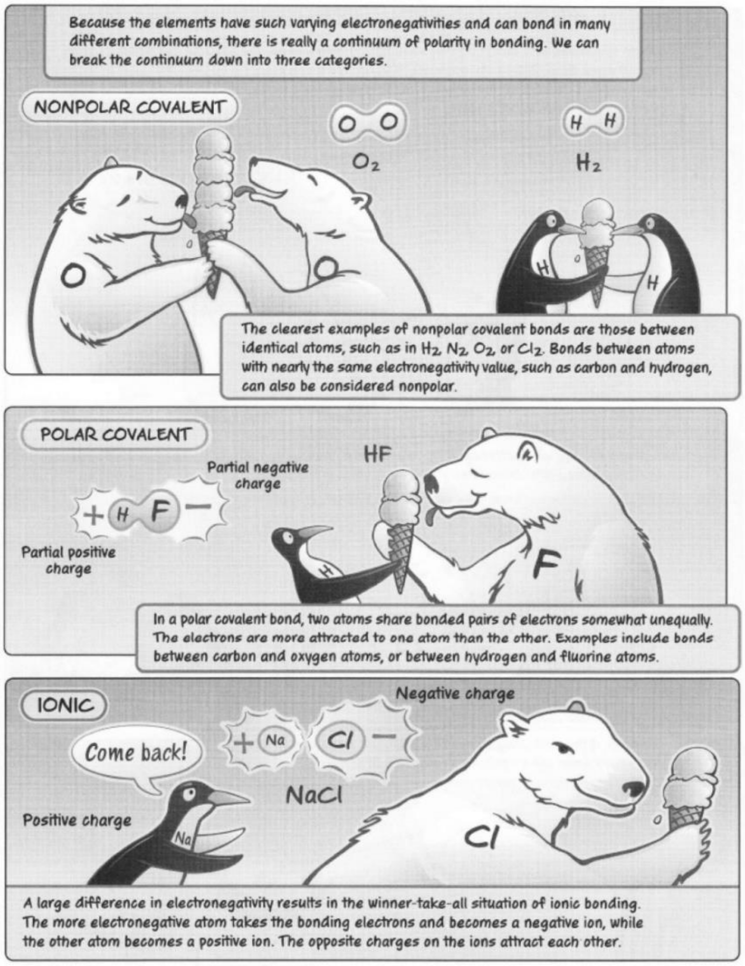


Figure 10. Bare Essentials of Polarity part 2

Part 3 (Figure 11) illustrates the types of bonds between the atoms and resurfaces the ideas from previous frames. The reader has had an opportunity to absorb the content and interpret the information and now they are able to make connections to the idea while beginning to understand the three types of bonding associated with polarity. The visual and textual information given within the model gives the student the opportunity to build those relationships and turn the relationship into a systematic understanding of the content.



Because the elements have such varying electronegativities and can bond in many different combinations, there is really a continuum of polarity in bonding. We can break the continuum down into three categories.

The clearest examples of nonpolar covalent bonds are those between identical atoms, such as in H_2, N_2, O_2, or Cl_2. Bonds between atoms with nearly the same electronegativity value, such as carbon and hydrogen, can also be considered nonpolar.

In a polar covalent bond, two atoms share bonded pairs of electrons somewhat unequally. The electrons are more attracted to one atom than the other. Examples include bonds between carbon and oxygen atoms, or between hydrogen and fluorine atoms.

A large difference in electronegativity results in the winner-take-all situation of ionic bonding. The more electronegative atom takes the bonding electrons and becomes a negative ion, while the other atom becomes a positive ion. The opposite charges on the ions attract each other.

Figure 11. Bare Essentials of Polarity part 3

Throughout the polarity activity, students could be working together, discussing their ideas and forming their knowledge by listening, contributing and connecting to the groups' discussion. At the culmination of the activity, a teacher would want to know what the students gained and if they are understanding the concept. By asking the students a series of questions, it is possible for the teacher to assess student comprehension and correct any potential misunderstandings. Here is a series of questions that could be used:

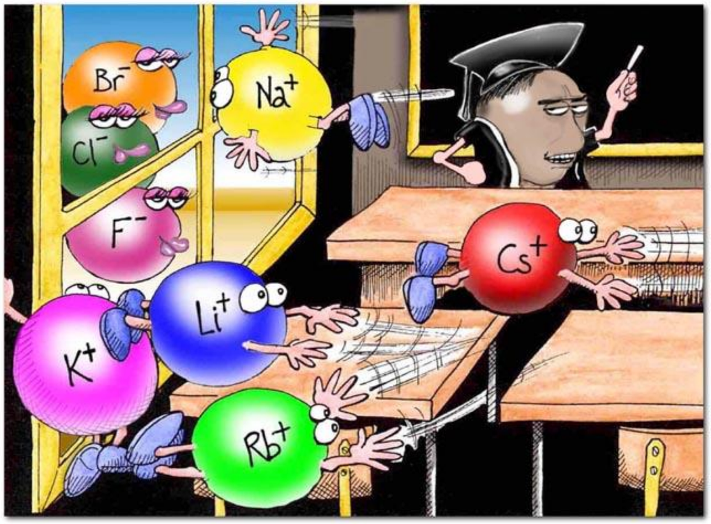
1. How does the comic strip define a polar molecule?

2. Define electronegativity as you understand it, after reading the first two pages of the comic strip.
3. What is the artist trying to represent by two polar bears arm wrestling or two penguins arm wrestling?
4. What three types of bonds are represented on the third page of the comic strip? What happens to the bonding electrons in each type of bond?
5. Why there are four scoops of ice cream in the illustration of O_2 on the third page?

By having students discuss these questions, either in a group or with the instructor, one would be able to assess the student understanding and see if the students are putting information together correctly.

Electrostatic Attractions

The concept of electrostatic attractions can be as simple as opposite charges attract, like charges repel. The simplistic statement about attractions can be learned as early as one understands the concept of positive and negative charges and how they may interact. In chemistry, the concept of positive and negative charges is often applied to the ions formed when electrons are lost and gained. Being able to use the elements on the periodic table and recognize which elements will form positive ions and which will form negative ions allows students to take this simple concept of electrostatic attractions further.



"Perhaps one of you gentlemen would mind telling me just what it is outside the window that you all find so attractive..?"

Figure 12. Electrostatic Attraction Cartoon

Cartoons are eye catching, meaningful and allow for a sense of interpretation to encourage the voice of the student to come to fruition (Roesky, 2008). The cartoon shown above in Figure 12 gives students an opportunity to explore a simple concept with a basic picture of positive ions being attracted to the negative ions outside the window. During the activity, students are asked questions about their observations of the cartoon. Expected responses include, the opposite charges are attracting as well as comments on the types of ions being shown in the cartoon. The follow-up question that should be proposed to the group of students is: what do the positive particles have in common? and what do the negative particles have in common? Students should be able to identify the metals versus the nonmetals. It is the intention of the activity to connect student thinking to the types of elements shown with the charges of the ions they produce. With the information gathered by the students during the activity, they should be able to pick two elements from the periodic table and describe whether or not they would attract one another as ions. Using cartoons for a simple task can help create interest for the student as well as make the students think about a concept in a different way and helps in their discussion with other students.

Ionic Puzzle Pieces

Using a scientific model in the classroom gives students an opportunity to connect an abstract scientific idea to something tangible. As this knowledge evolves, students begin to be able to explain and expand upon the target concepts in the activity and show their understanding to others (Adbo, 2009). After students use visualization and create their own mental models, they are able to use the information gleaned to show their understanding is backed by actual scientific knowledge.

When students begin to look at ionic and covalent compounds as formulas, they start by drawing Lewis diagrams that show connections of electrons to form bonds. Lewis diagrams can be difficult to comprehend as it is almost like a puzzle in order to fit these elements together. Shown below is an example of a Lewis electron dot diagram for calcium chloride. Students will often forget the second chlorine atom because one was already “satisfied” with its eighth valence electron. If students are able to connect the oxidation numbers of these elements to the structures, the picture can be completed much easier.

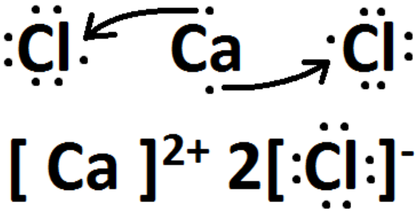


Figure 13. Lewis Structures of Ionic Compounds

The formulas of ionic compounds can be determined by making sure their oxidation states (charges) add up to zero (neutral) and can be more easily visualized with puzzle pieces (Figures 14 and 15).

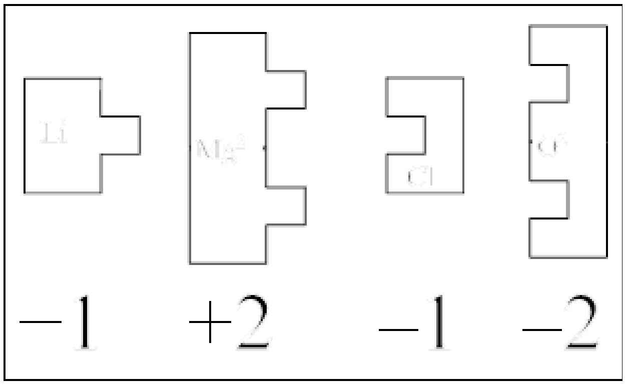


Figure 14. Ionic Puzzle Pieces Illustration 1

An element with an oxidation state of +1 is represented by a puzzle piece with one tab jutting out (representing the electron it wants to lose). An element with an oxidation state of +2 is represented by a puzzle piece with two tabs jutting out, and so forth. On the other hand, elements with negative oxidation states have indentations representing the electron(s) they want to gain. An element with an oxidation state of -1 has one indentation, -2 has 2 indentations, and so on.

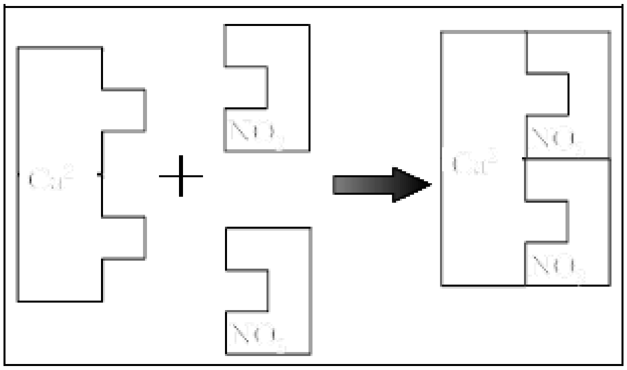


Figure 15. Ionic Puzzle Pieces Illustration 2

In order to get the correct formula for a compound, the puzzle pieces for the ions need to be fit together so there are no tabs or indentations left over (see diagram above). Putting the pieces together appropriately (Figure 15) makes the positive charge equal and opposite to the negative charge, giving the compound a total charge of zero. Students can be given any combination of metals within the scope of the activity in order to test their understanding. During the activity, students will be given pairs of metals that have corresponding puzzles pieces. Their job would be to assemble the puzzle pieces so there are no empty indentations or leftover tabs in order to figure out the formula to the compound. They would then draw their model that was created, write out the ionic compound's formula correctly and the draw a suitable Lewis structure for the compound. As shown in the calcium chloride example above, students would draw the individual elements with their valence electrons, draw arrows to represent electrons that are involved in the bond (the tabs and indentations) and figure out the charges for each ion. The students would know the correct formula by looking at the number of puzzle pieces used from each element and writing the ratio of those elements.

Constructing Molecular Models

On the covalent compound side of things, students should now have a basic understanding of the role electrons play in chemical bonds, but in the case of covalent bonds, instead of charges being formed because the electrons move, there is a sharing of electrons that takes place. In order to recognize the differences and build this understanding, a different model must be used. By using molecular model kits, students will build compounds and use those built models to create a chemical compound. Students will be given a selection of covalent compounds and be expected to build those compounds with the models. Because of the different nature of covalent compounds, they must be given the formula, but by using the model as a guide, they can easily create the Lewis structure. To begin constructing a model, students will select the spheres needed to represent each of the atoms shown by the formula. The sticks which will hold the spheres together represent bonds (shared pairs of electrons). The holes in the spheres represent bonding sites (unpaired electrons that are looking for another electron to bond with). In order to complete the model, students will attach the spheres together in such a way that all holes are filled. If all the holes are not filled when all the spheres are in place, they use the longer sticks to make double or triple bonds. Once the model is created, students can then take the information given by the model and weave that information into a Lewis structure. The element balls become the element symbols and the sticks become pairs of electrons shared by the atoms.

When checking for understanding, one can use the same assessment technique for the ionic compounds as the covalent compounds. By giving the students a list of unfamiliar, yet common compounds, they should be able to draw out the Lewis structures for either an ionic or a covalent compound. While in their groups, students can check with one another to see what other students' drawings look like and discuss their similarities and differences to check their work. In order to be successful, students should be able to draw a Lewis structure correctly from the elements given.

Organic Chemistry Models

Another adaptation of the molecular model kits relates to organic chemistry. Once the use of the molecular models has been mastered, and students begin to understand the bonds between atoms and the subsequent compounds that are created, the extension to organic chemistry is not that far off. In the beginning of organic chemistry, students can start learning about the compounds themselves and use their background knowledge to connect to the chemistry. Introducing mixtures like crude oil or compounds like octane allows students to make a connection to the material prior to diving into the minutia of the content. The introductory material in organic chemistry often yield conversations about structure and naming. Models can be helpful with the visualization of these molecules, but the real help can come when discussing the concept of isomers and that these organic compounds can have the same molecular formula but a completely different structure and chemical name. Without using molecular model kits, students are forced to try and draw different chains of molecules on their papers in different orientations that will most times end in students frustrated and confused because they believe they have drawn something different, when in reality they have just kinked, bent or reoriented the same molecule they started with.

As students begin using the molecular model kits, they start taking the model apart to try and rearrange the atoms within the compound. Once they rearrange the models, they can begin to draw their new compounds from their models. The ability to physically take apart the atoms and reconnect them in different places gives students the vision needed to create all of the isomers for that molecular formula. The idea is to start small with an organic molecule with the minimum number of isomers, butane for example with just 4 carbons and two isomers. Once the students are able to draw and name both isomers, they can move on to the 5-carbon isomers of which there are three. Sometimes, students are just as frustrated because impatience sets in and finding the isomers is difficult. It is important for the instructor to give the students attention during the lesson as some students have difficulty thinking in three dimensions and creating the different isomers is hard for them.

Using models for the isomer activity is not imperative for the task to be completed as some students can very easily use a different part of their brain and write out the different isomers without help. In the activity, the models allow certain students the ability to have a hands-on visual approach that a single mode of teaching would not have provided.

Bag O'Atoms

Another physical model that can be used in the classroom represents the parts of an atom. When students are attempting to recognize and understand the parts of an atom, they can look at pictures and study from a textbook; however, these students often do not have an accurate mental image of the atom and its parts. Using a model can be a way to assist students in building their knowledge and understanding of the atom.

The activity Bag O' Atoms is a three-part activity wherein students are given a sample of four "atoms" and then are asked guiding questions in order to understand the atom and its components. The four bags they receive have different numbers of red and white stones in the bag (representing protons and neutrons) as well as a collection of black dots on the outside of the bag (representing the number of electrons. In part one, students are at first only exploring the components and they do not know what the dots on the bag and beads in the bag mean.

1. How are all of your "atom" bags the same?
2. What do you think the two colored stones inside the bag represent?
3. What does the inside of the bag represent?
4. What do you notice on the outside of the bag?
    a. What do you think they represent?
    b. Why are they on the outside of the bag?
5. How are your "atom" bags different from each other?

6. What quantitative data about each bag could you record and use to tell the bags apart?

These questions represent the introduction to the understanding that atoms can be identified by the number of particles in and around the atom. The guiding questions would continue by asking the students to compare the number of stones in each bag and eventually, the students would be told what the stones and dots mean so they can finish constructing their underlying thought process. After completing part one of the activity, students would then work together to use their periodic table and identify the number of particles in select elements. As the students are working together, the instructor circles the classroom and asks students different questions to gauge their understanding such as: “What would the bag for Carbon have looked like if we had used that model in the activity?” or “How would you have changed bag number three in order for it to be the element Boron?” By answering these questions, students are be using the information learned in the activity as well as connecting that learning to what they already know about the periodic table. Questions can be differentiated to recognize different levels of student understanding.

In part two of the Bag O’ Atoms activity, the students use the same bags as before but explore them in a different way. Instead of just identifying parts of the atom, students focus on the electrons. On the bags, the electrons are drawn in the same configuration as shown on the students’ periodic tables. Students use this information to draw Lewis structures and Bohr diagrams of each of the four bags to make the connection between the electron configuration and the structure of the atom. The teacher can check student work to ensure understanding as well as ask questions such as: “How do you know the structure will look as you’ve drawn it?” The student should be able to explain why and how his or her drawing represents the element selected as well as the connection to the model.

The third and final installment of the Bag O' Atoms activity involves a new set of bags with different colored stones (blue for protons and clear for neutrons). The bags still represent atoms with the inside of the bag (and the stones) representing the nucleus and the electrons being represented by dots on the outside of the bag, but there is one major change. The number of electrons no longer equal the number of protons, which means the atom is no longer neutral, and is an ion.

First, the students are asked to identify the elements based on the number of protons in the bag and using their periodic table only, write down the information identifying the element: symbol, electron configuration and group number. Asking students to complete this task first is important because the desired result will be the students comparing the information on the periodic table to the information given on the bag. Their exploration of the differences will turn into the students constructing their understanding of ions and their structures.

Once the students have found the information on the periodic table, they record the information given about the electron configurations according to the model. The next piece is the comparison to the periodic table. They discuss with their group whether the information about the electron configuration given by the model has more or less electrons than the periodic table. They are then asked: "Why are the electron configurations on your bags different from the electron configurations from the periodic table? What do you think happened?" By giving the students a thinking question, they are trying to connect the what happened with the "why." Students can then be led through a series of questions designed to connect the element’s position on the periodic table with the fact that electrons were either lost or gained. In order to discern whether or not students are understanding, the instructor can give each group of students a list of elements and have them predict what type of ion they would make, positive or negative. The students would need to both identify the type of ion as well as the reason for the charge in order to successfully complete this activity. After the connection between the position of the elements and the gain or loss of electrons is made, students are then ready to continue exploring the concept of ions as well as begin extending their thinking deeper into bonding.

Rate of Decay – A Simulation of Half-life

When an instructor begins to construct a lesson that deals with half-life, they must consider the microscopic processes that occur during radioactivity that students will not be able to grasp. In order to improve instruction, one must consider creating macroscopic processes to simulate a concept that cannot be seen with the naked eye (Kelly, 2007.) Kelly stated in 2007 that if students were able to experience these processes, they would be able to communicate the functional process better.

In “A Simulation of Half-Life,” students use candies with lettering on one side and nothing on the other (M&Ms) in order to simulate the process of half-life. At the start, they count their nuclei and write their data in their notebooks in the table they have created. As they work through the activity, they discover that if the ‘M’ side is down after they shake and pour their ‘nuclei’ the nuclei are still considered radioactive and they have not decayed yet. They continue to take data and consider only their radioactive nuclei for inclusion to their data table. When the last radioactive nucleus has decayed, they use their data table to create a graph (an example is shown below) and they spend time analyzing the graph.

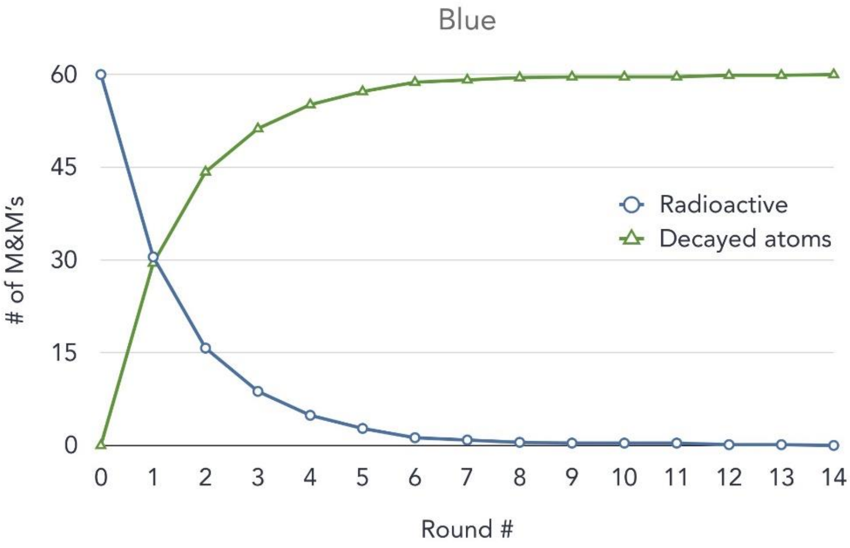


Figure 16. Graphical Representation of Half Life Activity

The instructor can also have each student group enter data into a shared document that would display the classes' data for all groups to examine. This pooled data would give students an opportunity to compare results with other groups. The student groups would then answer a series of questions deigned to test understanding an expand thinking.

1. What does each toss represent?
2. Why didn't each group get the same results?
3. How accurate is our assumption that half of our parent atoms decay in each half-life?
4. If you started with a sample of 600 radioactive atoms, how many would remain undecayed after three half-lives? (Show the math)
5. If 175 undecayed atoms remained from a sample of 2800 atoms, how many half-lives have passed? (Show the math)
6. Why did we pool the class data?

7. Is there a way to predict when a specific piece of candy will land marked side up or “decayed?” How do you know?
8. If you could follow the fate of an individual atom in a sample of radioactive material, could you predict when it would decay? Why do you think that?
9. Strontium-90 has a half-life of 28.8 years. If you start with a 10-gram sample of strontium-90, how much will be left after 115.2 years? (Show the math).
10. What is meant by half-life?
11. What kinds of materials do we use with the term half-life?

"What's the Matter?"

In the beginnings of understanding and classifying different types of matter, students can be told and given examples of elements, compounds and mixtures through background knowledge and prior experience. As teachers, we can show them pictures of different common items and ask them, "Does this picture represent a mixture?" We can sit back and listen to them guess about why a package of ground beef, a jar of peanut butter or a glass of milk is a mixture or not. In the same lesson, students could explore other items, water, salt, copper and try and decipher whether or not they are elements or compounds.

All of these activities, with accompanied explanations and teacher driven lectures would probably do the trick for most learners, and the others would eventually "figure it out." Many students would still be in the mindset of "Why are these the way they are?" By using a model (Figure 17) giving the students the opportunity to see these elements, compounds, and mixtures at a submicroscopic level, they can begin to understand why with a scientific explanation through the formulas and "chemical code" that accompanies the samples.

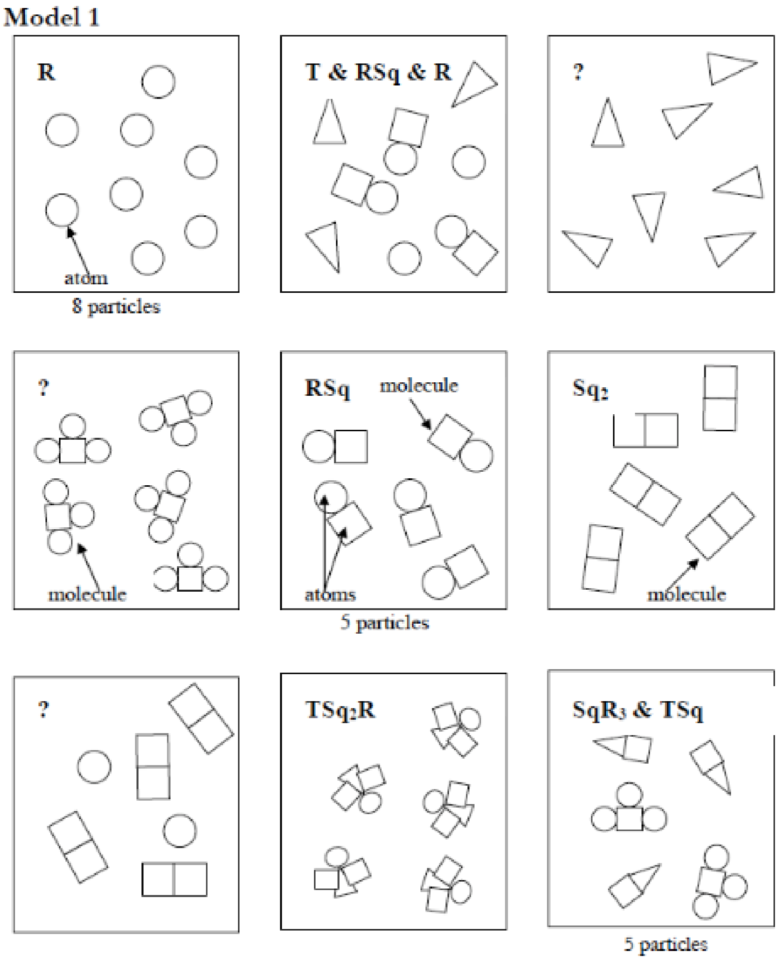


Figure 17. Models of Elements, Compounds and Mixtures

The model of different shapes with their chemical code is something the students explore with a series of questions that end with students looking at actual chemical symbols to connect their learning in the activity to the chemistry behind it.

1. Circle a molecule of RSq in Model 1. How many atoms are in a molecule of RSq?

2. Circle a molecule of TSq_2R in Model 1.

a) How many different types of atoms are found in a molecule of TSq_2R?

b) How many Sq atoms are in a molecule of TSq_2R?

3. a. How many different types of atoms are found in a sample of SqR_3 & TSq?

   b. How many different types of molecules are found in a sample of SqR_3 & TSq?

4. When two atoms are touching in the drawings of Model 1, what is holding the atoms together?

5. a. Can a *particle* be a single atom?

   b. Can a *particle* be a molecule?

   c. How many particles are in the drawing representing T, RSq, & R in Model 1?

   d. As a group, agree on a definition of the word "particle" as it is used in chemistry.

6. Compare the codes listed at the top of each drawing in Model 1 with the shapes in that box.

   a. What do the letters R, Sq, and T in the codes represent?

   b. What do the small numbers (subscripts) in the codes represent?

   c. When atoms are touching, how is that communicated in the code?

   d. When atoms or molecules are not touching, how is that communicated in the code?

   e. In Model 1 there are three drawings that are labeled "**?**". Write codes to properly label these drawings.

7. Matter is classified as a pure substance when all of the particles are identical. Matter is classified as a mixture if there are different particles present. Identify which set of

drawings from #7 are pure substances and which set are mixtures. List the codes for each set here.

Pure Substances Mixtures

____________ ____________ ____________

____________ ____________ ____________

____________ ____________ ____________

8. How are the codes (chemical formulas) for pure substances different from those of mixtures?

9. As a team, take the set of pure substance drawings from #8 and sort them into those containing only one type of atom and those containing more than one type of atom.

10. Elements are defined as pure substances made from only one type of atom. Compounds are defined as pure substances made from two or more types of atoms. Identify which set of drawings from #10 are elements and which set are compounds. List the codes for each set here.

Elements Compounds

_____________ ___________

_____________ ___________

_____________ ___________

11. How are the codes (chemical formulas) for elements different from those for compounds?

12. Use what you have just learned about chemical formulas to identify the following as element, compound or mixture.

a. Br_2 b. $NaHCO_3$ c. $C_6H_{12}O_6$ & H_2O d. Cu & Zn e. CO_2 f. Al

The series of questions gives the students an opportunity to build their understanding slowly with scaffolded questions designed for them to first identify different particles, then deciphering the difference between particles, atoms and molecules, analyze the different chemical codes and what they may mean and finally start breaking them into groups. Once they reach the last step, they become able to begin their look at different actual chemical symbols and identify real elements, compounds and mixtures. As shown in question number 12, students can use their ability gained from the model in the activity to identify a selection of chemical symbols. Students should check for understanding with their instructor to assure successful completion of the task.

The Black Box

When discussing the beginnings of the atom, students often glaze over with disbelief and have little to no connection with the difficulties early scientists had. The earliest philosophers gave little to no detail of the structure of the atom, they just theorized that something was there, and it was really small (Adbo, 2009). Science instruction, before considering using models to help students understand the difficulties of scientist, would often be teacher directed and students would still have no concept of the scientific methods used by scientists to discover early models of the atom. Without being able to see these sub-microscopic atoms, Thomson used a cathode-ray tube to discover the electron and Rutherford used the Gold Foil experiment to discover the nucleus. Giving the information to students in a lecture setting doesn’t allow them the opportunity to experience struggle on the scientific level that these scientists did.

An activity designed to force students from their comfort zone of being able to see the whole picture while experimenting was created and students must make observations without using their most useful sense, sight (Jansoon, 2009). Prior to the lesson, the instructor would wrap an innocuous item or items in a small box and seal it, so there would be no way a student could see or get inside. These items could range from a rock or a small block to some rice or spare change. The idea being that they have a chance to identify it. Students are given the box with one instruction: Figure out what is inside, without opening it. Some structure is provided as they are told to complete at least five "tests" on the box to decipher what is inside and write down what they observed following those tests. After the students complete their five tests and write their observations, one final instruction is given to draw a picture of what they believe is inside the box based on their observations. After students make their guesses based on observations, the most often asked question is: "When do we find out what was inside the box?" Of course, the answer is never. Questions can be posed to the students to inspire thinking as to why they cannot learn what is inside the box. For example, they can be asked: "When did the scientists learn what was really inside the atom?" To further probe their understanding a series of questions could be asked to see if they figured out the point of the activity:

1. Atoms are too small to see. How is the Black Box activity similar to what early chemists had to do when they were trying to learn about atoms?
2. What other tests might you be able to perform (without opening the box) to gather more information about the contents of your box?
3. How confident are you that your conclusion is right? If you were a scientist, would you be confident enough to share your results with other scientists? What if your career depended on your results?
4. If you had to defend your conclusions to the rest of the scientific community, like famous scientists did, what would you say to convince others that your conclusions are right? Write the words you would use to defend yourself and your conclusions here:

What is an orbital?

Although there are many types of visual models, it is often true in chemistry that a model is created for students and they attempt to use it appropriately to the best of their ability. As one begins to work more with children, it becomes evident that when a student takes part in the creation of anything, models included, they are able to connect with the learning more and will frequently retain the information better.

The model of the atom has evolved over a long period of time. There have been many scientists that have contributed to the current model of the atom. For instance, the Bohr model was based on a solar system idea of electrons in fixed orbits. After many experiments, we now know that the “electron cloud model” is the most accurate representation of the atom.

The electron cloud is a difficult concept for students to grasp as the speed of the electron is unparalleled and the concept of probability is often lost on students. Traditional chemistry instruction on orbitals would involve a discussion about Schrödinger and his famous equation on the path of an electron. One could even show different pictures of what the "cloud" could look like and allow students to explore what the different pictures could mean. Even though showing these pictures is considered by many to be sound instruction, students often leave the lesson with confusion about how the model was created and have not experienced what is necessary to fully understand the basics behind the electron cloud model and the probability of locating the electron. A student-created model becomes a valuable tool in the chemistry classroom when a student does not fully understand the basics of a chemistry concept.

Students can create the model of the electron cloud using nothing more than a piece of paper and a writing utensil. As the students complete the activity, they drop a pen or pencil over a target 100 times and then count how many "electrons" were in each section of the target.

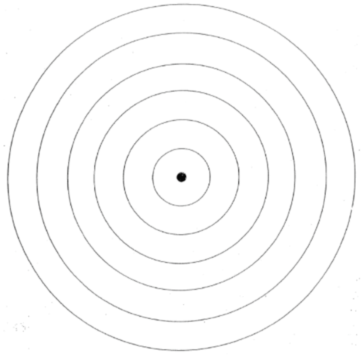


Figure 18. Example of Target from “What is an Orbital?”

Students and teacher are then able to have a conversation about the meaning of their model.

> If we were able to take a snapshot of an electron in motion the resulting picture might resemble a dot suspended in midair. As the electron moves about randomly we could then take another snapshot of the electron that would end up in another location around the nucleus. Now, let’s say you took hundreds of snapshots of the electron. You would end up with hundreds of pictures of the electron in all different locations around the nucleus. If you were to overlay all these snapshots into one picture, you would end up with a picture of the nucleus with hundreds of dots around it.

As the learning continues, students can be asked questions so that they are able to connect the model of the electron cloud to other models of the atom as well as create meaning for their model in order to understand the concept of the "electron snapshot."

1. How is the Electron Cloud Model *similar* to the Bohr model of the atom, AND how is it *different*?
2. How many electrons are modeled in the exercise? Describe how you know.
3. How does the lab demonstrate the mathematical probability of finding an electron?

By answering these questions about the lab in a small group discussion setting it allows students who are still constructing knowledge and are still working on the complexity of the model to sit, listen and absorb, hopefully feeling confident enough to jump in to the setting, knowing that it is a small group. The small group setting also allows students to take risks and give an answer that may not be right knowing that the entire class will not be focused on their response. Through the creation of their own model, students are able to not only make meaning of their own work, but connect that work to something meaningful within the classroom.

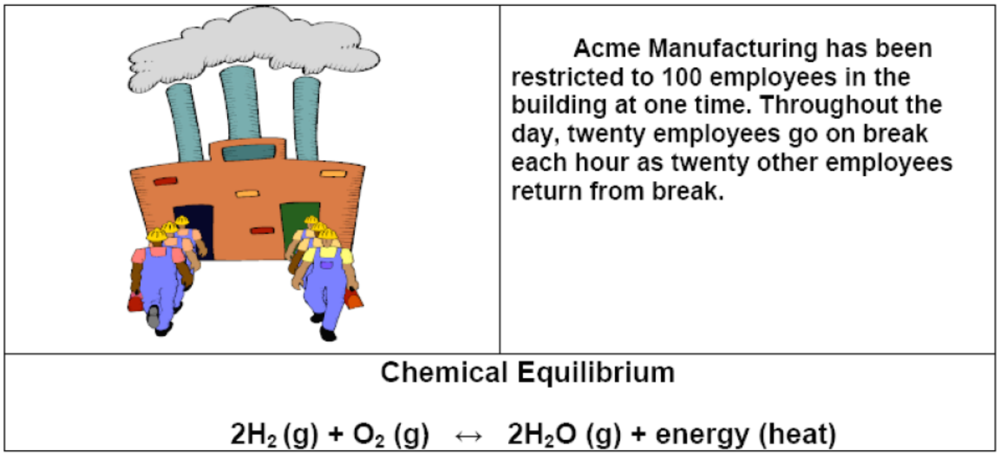
Empirical and Molecular Formulas

When using a scientific model to represent a mathematical concept, the idea needs to be presented in such a way that it is both an authentic representation of the concept and yet simple enough to be understood by the learner (Nahum, 2010). Calculating for empirical and molecular formula is a process that involves both mathematics and science and can be difficult to understand for students when they jump right into the science piece.

In this activity, students are given a sample of a “compound” which consists of a bag of beads of different sizes and shapes. For the first part of the activity, they are lead through some simple measurements and calculations involving their sample. Students measure the masses of their elements (beads) and figure out the ratio of each element in the compound. Connecting this ratio of elements within their sample compound to the ratio of elements within an actual compound is what helps to transfer their knowledge from the activity to the concept in the classroom. The teacher is moving between groups at this point checking ratios and asking questions such as: “What would this ratio mean if it were an actual compound?” The students would then be given one last piece of information the “grams per mouse” value (a play on the grams/mole that is common in chemistry). Using this value, students will be able to take their ratios and turn it into an actual formula for their compound. At this point, students will have simulated the entire process of finding an empirical and molecular formula. The post lab activity would involve using skills they practiced with their model of a compound and translating them into working with an actual compound. According to Dahsah (2007), students who achieve the conceptual understanding prior to understanding the algorithmic process often produce the correct responses faster than those who attempt to learn the algorithmic process first.

Dynamic Equilibrium

Students are always trying to relate new knowledge to what they already know (Calik, 2009.) By using prior knowledge for student understanding, the instructor can often tap into a resource that will help construct new knowledge. In an activity designed for students to begin understanding equilibrium, the students don’t even discuss the chemistry. By exploring a model of a “check-in/check-out” process at a manufacturing facility, they will be able to begin to connect the process of entering and leaving a building to equilibrium. They will be shown a picture (Figure 19) with instructions for the building’s break process and then asked questions about the process.



Acme Manufacturing has been restricted to 100 employees in the building at one time. Throughout the day, twenty employees go on break each hour as twenty other employees return from break.

Chemical Equilibrium

$2H_2\,(g) + O_2\,(g) \leftrightarrow 2H_2O\,(g) + \text{energy (heat)}$

Figure 19. Picture from Dynamic Equilibrium Lesson

1. How many employees move in and out of the factory building during each hour?

2. Are the employees who move in and out of the building each hour the same people? How do you know?

3. Does the number of employees in the building change from hour to hour? What evidence do you have to prove your answer?

4. Over the course of a day, the employees in the Acme Manufacturing Plant are said to be in a "dynamic equilibrium", Based on your understanding of how the staff move in and out of the plant, what is meant by the term "dynamic equilibrium"?

5. A new, faster and simpler check-in/check-out process has been proposed for workers at the Acme Manufacturing Plant. Some workers have said that this new process acts like a catalyst. (A catalyst is a substance that speeds up a chemical reaction without changing the outcome of the reaction and without being used up in the process.) Would this new check-in/check-out process change the number of people in the building at any given time? Why or why not?

6. What would be the effect of the new check-in/check-out process on the workers at the factory? Support or refute the idea that the new check-in/check-out process is like a catalyst.

After the students answer these questions and discuss their ideas, the teacher would introduce them to a chemical model and have them try and connect the factory model to the chemical reaction. The following instructions and questions would be given to students and eventually their results are reported out to the entire class.

Instructions: Like the Acme Manufacturing Plant, chemical reactions can also reach equilibrium. Answer the following questions about the chemical equation in the factory model by applying the insight you gained from the Acme Manufacturing Plant questions. Connect each answer back to the factory model.

When the reaction between hydrogen and oxygen **reaches equilibrium**:

a. Does the number of molecules in the reaction vessel change?

b. Is the reaction still proceeding in the forward direction?

c. Is the reaction still proceeding in the reverse direction?

d. Are the concentrations of the products and reactants changing?

e. Are the rates of the forward and reverse reactions the same?

By having students connect each answer back to the model, they are using their prior knowledge of how people enter and leave a building each day and using their newly constructed understanding to begin to understand how equilibrium works.

Discussion

When reflection occurs after completing this project, questions come to mind about how the content of the project impact instruction, learning for all students, and crossing the curriculum lines. The written question prompts look at extending this project beyond what it is (a collection of lessons and classroom interactions), and try to predict what it could be.

What do the contents of this project mean for me in the classroom? By applying new methods in the classroom, I can use continuous improvement to attempt to increase student achievement and understanding. Through the use and evaluation of these models, I can begin to reflect upon previous lessons in an attempt to improve upon these lessons and in turn, improve upon instruction as a whole.

What can this project mean for other chemistry teachers? It is my intention to share pieces of solid, tested and proven chemistry instruction to all teachers that may be looking for a change to their curriculum as a whole, or looking for a specific lesson to help with one difficult concept. Sharing of information is so important in our field and if just one teacher is able to use pieces of this project, I consider it a success.

What impact can this project have on students? Chemistry is a difficult subject where learning often takes place in the brain. Small, submicroscopic pieces being discussed and trying to apply those thoughts to the physical world often turn into confusion and frustration. By using models, teachers can give students the opportunity to experience these concepts in a larger scale and allow the interaction piece that is often missing in the chemistry classroom. Sure, the exciting laboratory experiments give students a chance to see a chemical change or experience combustion, but the meticulous inner-workings of chemistry are often not shown in these experiments. By showcasing these individual concepts through the use of a model or models, students can gain a conceptual awareness of an idea they otherwise may not have understood.

How could the use of models be applied to other content areas? Although this project focused on the use of models as a representation of something very small and made it able to be seen, not all models need to be used in such a way. A model can be something you are trying to represent in the real world. For example, you can use a mathematical model to figure out the volume inside of a cardboard box (Length x Width x Height). Like the models in the chemistry classroom, this model would also be limited.as the space inside the box does not account for the thickness of the box and would need to be accounted for. Using models in other areas in math and science is a way for teachers to represent something that potentially cannot be physically held in the real world and can give an opportunity for students to share an experience they may not have had before.

How can teachers develop lessons if they do not have an existing model to launch from? As an experienced teacher, one spends many hours, days, and years honing their craft. By always looking for ways to improve, teachers can continue to improve instruction for all students. Deciding one needs a model often comes from the reflection upon a lesson you have taught several times. A teacher would often recognize students having difficulty connecting to the material and being able to explain its function. After identifying the need for a model, the most difficult part is to create the model that the students could use. Teachers should begin by focusing on common items that may be comparable to the concept. The difficult part is if the concept doesn’t lend itself to being compared to an item. Continued improvement and professional development will help teachers create ideas for model and advance their lessons.

How did the completion of this project improve my instruction? Although using models in the chemistry classroom seems like a no-brainer, the evaluation of the models is what affected me the most. By thinking about *how* students are understanding and interacting with the material and the models, I was able to assess the effectiveness of both the instruction and the model. Also, by forcing myself to look at many different models, I was able to improve upon many models currently taught in my classroom as well as add to my repertoire so my students can benefit from the use of the models.

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