Technology-Aided Learning in the Classroom
ChemSense: A Computer-based Construction Tool to Display Student Thinking

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Abstract

The ChemSense project is an NSF-funded research project whose goal is to help students overcome their difficulties in understanding chemical concepts by providing students access to representational tools that can fill a gap in their ability to experience or imagine the world of molecular entities and reactions. The people on this project from SRI International; Patti Schank, Vera Michalchik, Anders Rosenquist and myself, have been working with high school chemistry teachers to develop new activities, create and refine the computer knowledge building environment with drawing and animation tools that have templates specialized to chemistry. Over a period of two years our teacher partners have developed 43 ChemSense high school classroom activities. In this paper, I will describe how teachers used the animation tool to conduct student activities, share our research and provide resources so that you may download the animation tool and curriculum materials for you and your students' use.

Introduction

Teaching chemistry is challenging. The learner must think symbolically and use mathematical and otherwise abstract reasoning skills to understand chemistry. The learner must also navigate through the multiple representations of a chemical concept. We have all heard of the studies that demonstrate that many students leave high school chemistry courses with profound misunderstanding about the nature of matter, chemical processes, and chemical systems. One of the major challenges I experienced when teaching high school chemistry was to know the details of each students' understanding of the concepts and skills within the topic we were covering. I wished that I could 'see' their thinking. Often, it was only after a test that I really knew that the students had misconceptions.

ChemSense Studio is a software tool that provides a medium with drawing and animation functionality for students to display their understanding of a chemical concept. . They may access each others animations and comment on them. Each comment made identifies the person making the comment. The teacher has access to all of the animations and comments at any time. The students know that any comment they make will be read by the teacher, which is usually enough to prevent students from making inappropriate comments. The comment section allows the teacher to correct any apparent misconceptions in a timely fashion and to give grades directly attached to the animation.

Students typically work collaboratively in pairs to animate an assigned chemical process or interaction at the atomic, molecular or ionic level. To create an animation of a chemical process, they discuss with each other the particulate level details. The teacher can 'see' their thinking, because the students must represent it with their animations. A bonus was that it became clear by the conversations between students and the creativity shown in their animations, the students enjoyed these assignments. This enthusiastic engagement in chemistry learning activities helps them to care about understanding chemistry.

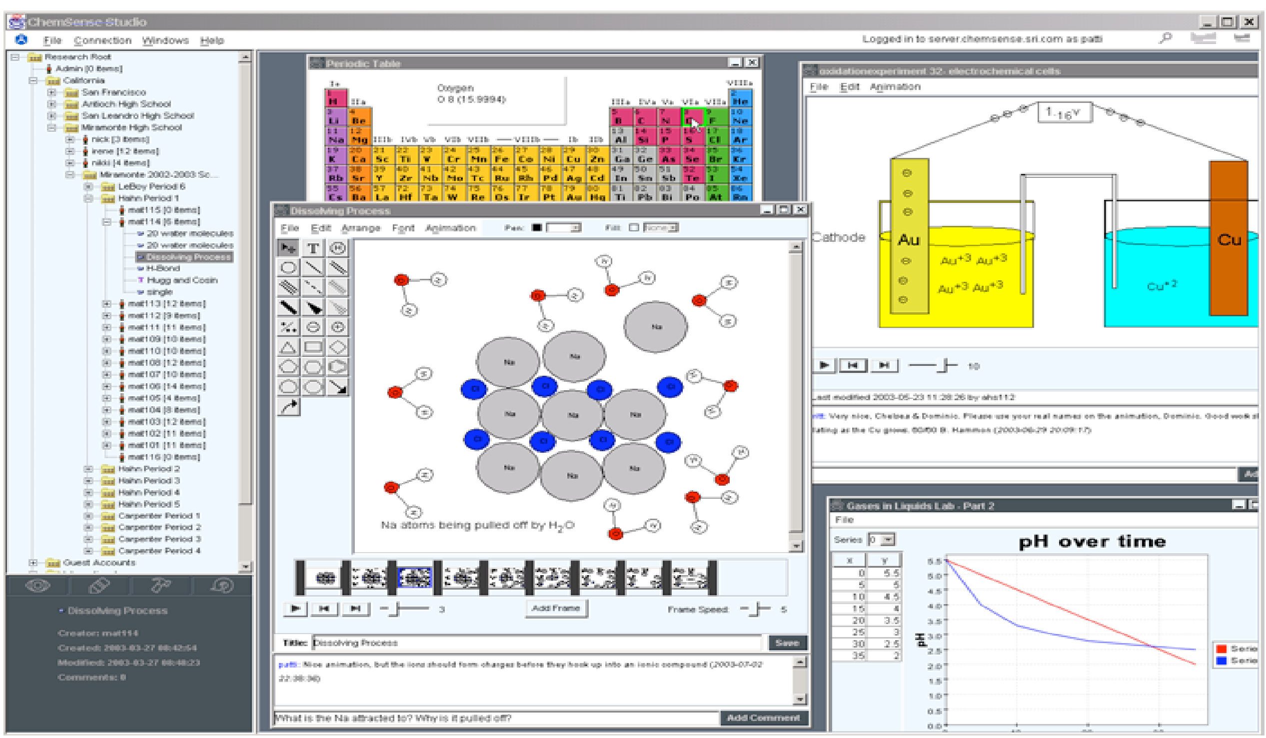
Student animations were displayed during a whole-class wrap-up the following day. Students were told to make positive and critical comments about the animations. With each subsequent animation shown, students were better able to identify the accurate and inaccurate features of the representations. The class became filled with energetic and interactive comments. Sometimes spontaneous applause erupted during the wrap-up sessions in which their animations were displayed. Students made enthusiastic requests to “Show mine!”

Section I: Introducing ChemSense Studio for Classroom Use

ChemSense Studio

The ChemSense Studio, http://www.chemsense.org/computer/index.html, software offers a way for students to create their own representations of chemical phenomena. This particular computer environment allows students to generate drawings, animations, text, and graphs. Specialized tools within the environment make it easy to create images of nanoscopic entities and processes. Students' ability to readily generate representations at the nanoscopic level helps them to move from simply depicting surface appearances of chemical phenomena to representing the underlying phenomena that align with the surface features. Though the software has a variety of tools for the students use, the animation tool has been used for about 90 percent of the activities. Figure 1 is a screen shot of a ChemSense display.

Figure 1: Screenshot of ChemSense display.



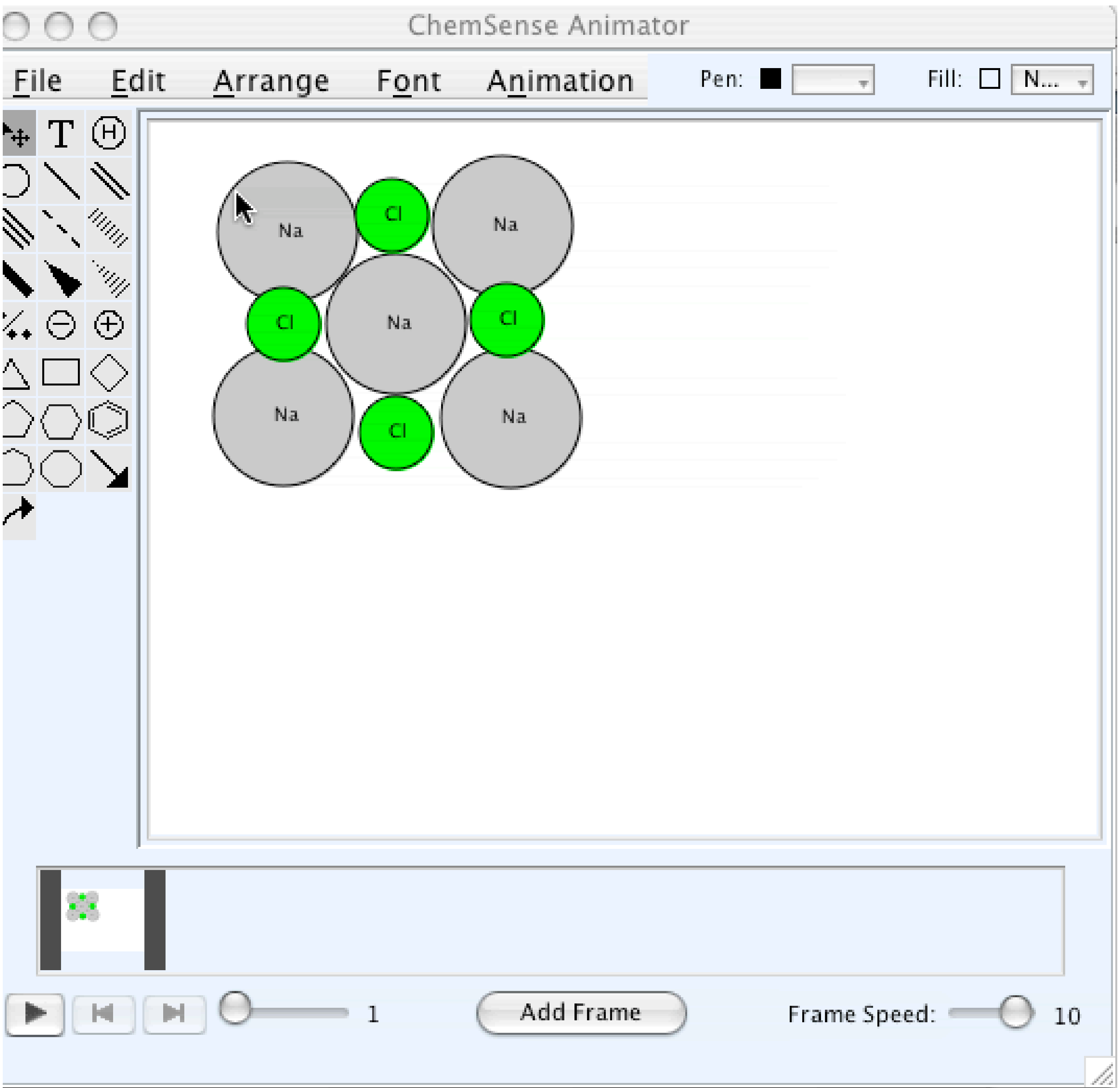
This is a screenshot showing several different displays of ChemSense simultaneously. It shows a graph constructed with data collected from probeware, the periodic table from which ‘atoms’ are selected and two screenshots of student created animations.

An animation of how to create an animation!

My colleague and Principal Investigator of the ChemSense project, Patti Schank, created a Quicktime movie demonstrating the creation of part an animation using ChemSense. This animation shows some of the features of the software being used to demonstrate salt dissolving into water. To run this animation, select the movie icon on the lower left of the picture. It should then reveal a Quicktime runbar. Select the forward arrow or select anywhere in the middle of the screen to run the animation.

Note: Ideally the author would have put (+) signs on the Na and (-) signs on the Cl ions.

Figure 2: This is screenshot of an animation being created using ChemSense software.
To view the animation: http://chemsense.org/computer/ChemSenseAnimator.qt



Many of the assignments using ChemSense are posted on our website, http://www.chemsense.org/classroom/activities.html. They are accompanied by scoring rubrics, NSES standards, prerequiste knowledge needed and topic identification. To give you a feel for how this tool works, I will show you an assignment, samples of student work and a sample of an animation a teacher created for instructional purposes. To show you the animation samples, I will show a screenshot, then provide a link which will direct you to a quicktime animation. You will need to select the link to be able to view the animation. What you see next is a partial copy of the student handout for this assignment:

Construct an Animation of the State of Matter Phases of Water Molecules

Water Wiggles

The purpose of this ChemSense activity is to allow you to learn in a deeper, more visual way what is taking place at the molecular level during phase changes. If, in addition to that, you can also apply the knowledge that you have learned about the energy changes that take place while a substance is raising temperature and while it is changing phases, that would be great! Please try to think about these two areas while creating your animation.

Task

1. You are to make an animation of at least 12 water molecules as they change temperature and change phases from ice at -25 ^{o} C to gas water molecules at 100 ^{o} C.
Each phase, as they increase in temperature, should be ***a minimum of six animation frames*** to show the dynamic motion between the molecules. Phase changes should be animated to correlate with the phase change diagram of water provided.

2. Draw a small graph of the temperature vs. time, like the one provided on the back. Indicate on the graph you've drawn what temperature and time with which your animation correlates. The graph and the animation will both appear in each frame together.

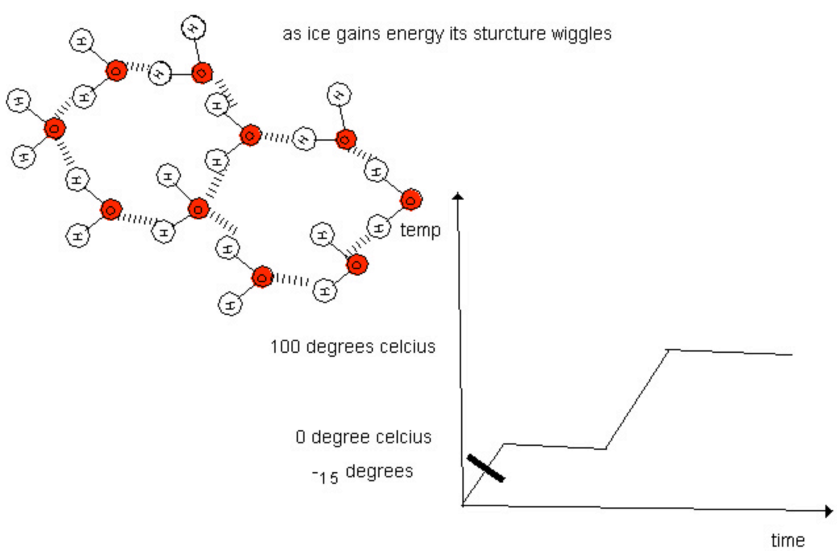


Figure 3.
This is a screenshot of a frame produced by a pair of students.

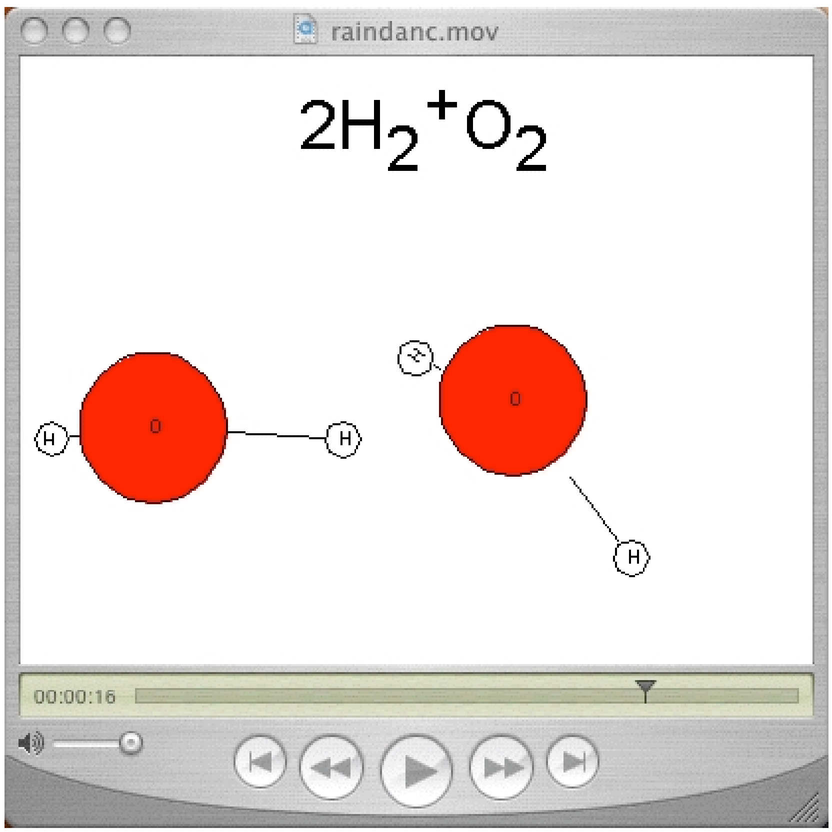
The animation may be viewed:
http://www.chemsense.org/classroom/inaction.html
Scroll to: Miramonte HS
Select: Water phase change (Group 11)

Creativity expressed in an animation

Students sometimes expressed their understanding of chemical concepts creatively. This sample of student work was produced in response to the assignment to animate the chemical reaction: $2H_2 + O_2 \rightarrow 2H_2O$. Figure 4 is a screenshot of one of the frames of the animation.

The animation may be viewed at:
http://www.chemsense.org/classroom/inaction.html
Scroll: Antioch High School
Select: $2H_2 + O_2$ "Rain dance"

Figure 4: Screenshot of one of the frames of a student animation.



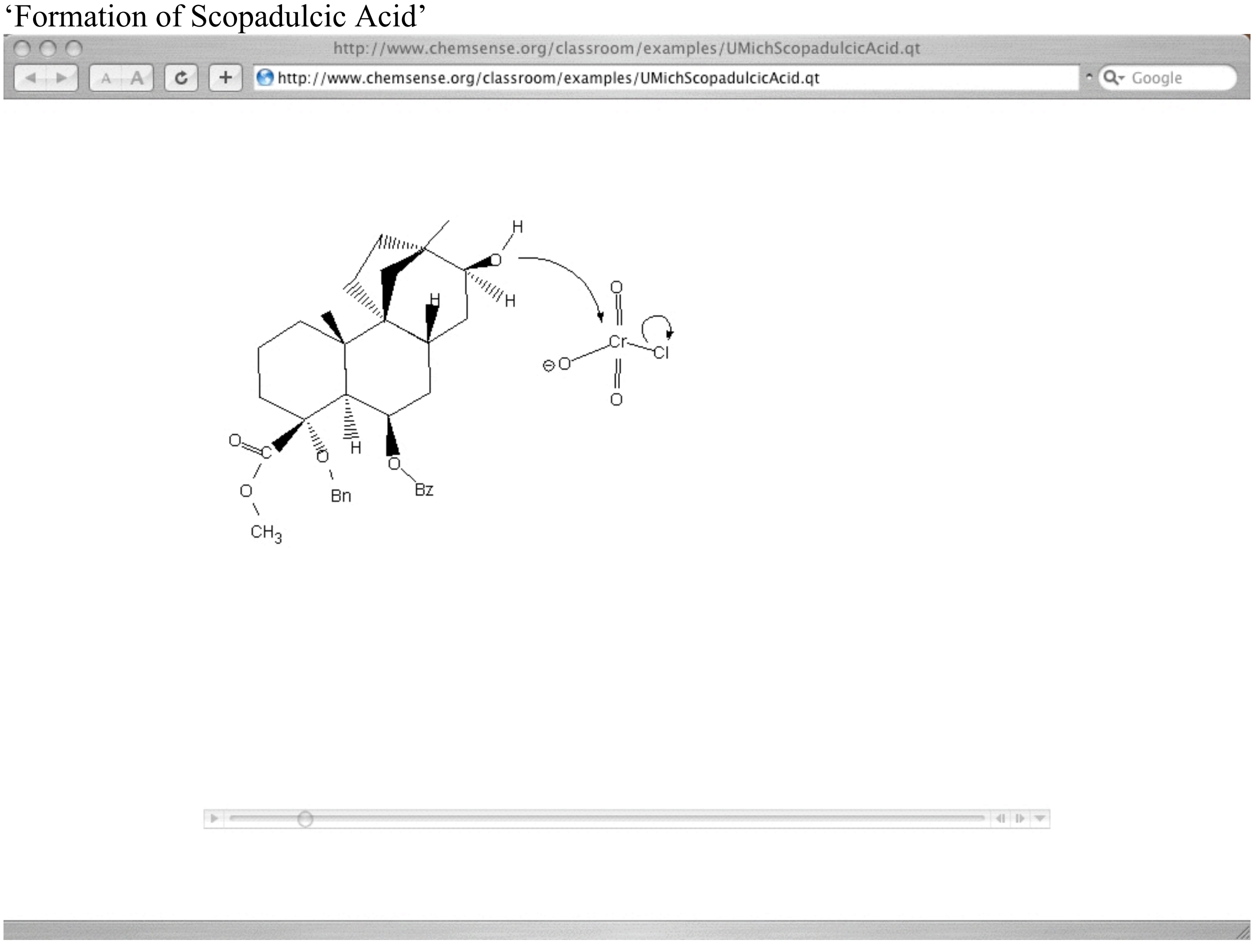
This animation produced by a pair of high school students from Britt Hammon's college preparatory chemistry class in Antioch, California has a very whimsical character.

University general chemistry students can use ChemSense

A few college professors have integrated student use of ChemSense into their teaching strategies for general chemistry students. Vickie Williamson, Texas A & M chemistry education professor, assigns ChemSense activities to her general chemistry students. She believes that students can understand dynamic chemical phenomena better if they have to construct a representational animation at the particle level. She also has the students in her teacher training classes working with ChemSense. Brian Coppola, co-PI of the ChemSense project and professor of chemistry at the University of Michigan, gave each group of students in his freshman chemistry class different reaction types to investigate and represent. One group produced the following animation:

To view the animation go to:
http://www.chemsense.org/classroom/inaction.html
Scroll to: University of Michigan
Select: Formation of Scopadulcic Acid

Figure 5: Screenshot of one frame of an animation created by a group of students entitled ‘Formation of Scopadulcic Acid’

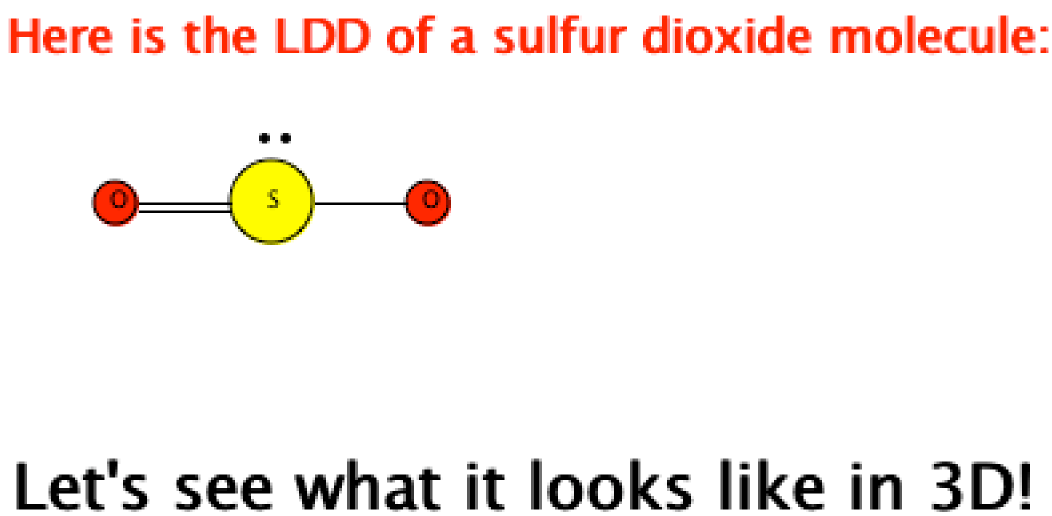


This animation was produced by a group a group of general chemistry students in Brian Coppola’s class from the University of Michigan.

Teachers can use ChemSense to demonstrate chemical dynamics
Some chemical concepts are difficult to describe for teachers and to visualize for students. Valence Shell Electron Pair Repulsion (VSEPR) is one that is easier to understand if one could see the dynamic interactions between the electron bonding and nonbonding pairs surrounding a central atom. One of our partner high school teachers, Irene Hahn, wanted give students a visual representation of VSEPR theory. This is a screenshot of the animation that she created to illustrate the bent geometry, using the molecule $SO_2(g)$ as an example.

To run the movie, select the little movie icon to the bottom left of the initial screenshot.

Figure 6: Screenshot of an Animation of VSEPR bent shape constructed by Irene.
To view animation: http://chemsense.org/classroom/examples/VSEPRbent.qt



Section II: Our Research

Our research activities included the collection and analysis of videotape of students engaged in performing various ChemSense activities. Videotapes were examined for evidence of multiple representational use and discourse about chemical concepts. We collected journals from teachers regarding their use of ChemSense in their classrooms and the effectiveness of the activity for helping students to better understand chemical phenomenon. In Study 1, we compared student learning in chemistry between two sets of students with the same teacher. One set of students does ChemSense learning activities, while the other set of students is engaged in a different, but comparable activity. We employed pretests and posttests given to students before and after each activity to assess student understanding of the targeted concept. Student surveys were administered to ascertain the student's reaction to using ChemSense as a learning tool. I will report details from 'Study 1' and summarize what we found by examining our other artifacts. If you don't find research reports interesting, you might want to skip this Section II and go on to Section III. Section III includes a short set of instructions on how to download ChemSense for your and your students' use. It will also highlight resources available to you on our website.

Study 1. ***Phase Change Activity (Water Wiggles)***

In this particular study, students used a computer-based representational tool, ChemSense, to animate the phase change of H_2O on the molecular level. The student animations were scored on the structure and relative position of the water molecules as they increased in kinetic and potential energy from the ice phase, -25 $^{\circ}$C, to the boiling phase, 100 $^{\circ}$C. Our intent was to require students to create a representation of the phenomena that helped them think about the spatial and temporal dimensions of the phase changes of water at the molecular level.

Study 1 involved a total of 156 students across nine high school classrooms taught by two different teachers who participated in the treatment group that used ChemSense for this particular activity. Thirty of these students did not actually use ChemSense because they were away taking the high school exit exam, but did participate in the pretest, posttest, and whole-class discussion of animations that students generate with ChemSense. (The students who left for the exit exam were all tenth graders who were in academically accelerated programs.) A total of 151 students across nine classrooms taught by two different teachers comprised a control group that did an alternative, traditional activity instead of ChemSense. The treatment group and the control groups had similar API scores on California's general standardized test, which is administered to high school students in California annually. Both groups also had similar scores on California's standardized end-of-year test for high school college preparatory chemistry. Both groups used the same textbook and spent roughly the same amount of time on task during the study. Both groups of students were taught by fully credentialed, veteran teachers with more than five years experience teaching college-preparatory chemistry. ChemSense students were given a pretest worth 16 points, which consisted of both standard questions (identifying sections of the water phase-change curve; 5 points) and conceptual questions (including drawing molecular representations of water molecules in different states of matter; 11 points). The next day, ChemSense students were taught the concepts of phase change in a more "traditional" lecture manner – the teacher lectured about phase change while the student took notes and asked questions. Students were assigned reading homework and a set of written questions. Control students were given a similar lecture and the same assignments. After the lecture, students in the control group conducted a more traditional hands-on, wet-laboratory activity, while students in the treatment group (except the 30 who left to take the high school exit exam) completed a ChemSense-based assignment called "Water Wiggles" (see handout, Appendix A). In the ChemSense assignment, students worked in pairs to animate a group of H_2O molecules as they changed from –25 °C (ice phase) through increasingly higher temperatures until 100 °C (boiling) was reached. Along with the molecule drawings, ChemSense students drew a phase-change diagram in their animation, and indicated in each frame the corresponding location on the phase change graph. Many students also chose to annotate their frames with text describing what was happening. Students in the treatment group engaged in a whole-class discussion, led by their teacher, using a subset of ChemSense animations created by the students. Finally, students in the treatment and control groups took a posttest the day following the web-lab or ChemSense assignment and discussion.

Findings

An analysis of the pre- and post-test data for the ChemSense group indicates a significant change in score from pre-test to post-test. ChemSense students particularly showed marked improvement on the conceptual questions, which measured their ability to create detailed and accurate representations of H_2O molecules in the solid, liquid, and gaseous phases. Control students did not take the pre-test, so a comparison from pre- to post-test cannot be made for this group. Although treatment and control groups had similar background knowledge and similarly experienced teachers, scores for ChemSense students on the post-test were significantly higher than post-test scores for the control group. ChemSense students had higher scores than the control group on the conceptual questions on the post-test, but difference was observed on the standard questions, at least in part, due to a ceiling effect on the scores for the standard questions.

Exhibit 4. Descriptive statistics for pre- and post-test scores, by group.

	Mean scores					
	Pre-test (max=16)	Post-Test (max=16)	Pre-test Standard Questions (max=5)	Post-test Standard Questions (max=5)	Pre-test Conceptual Questions (max=11)	Post-Test Conceptual Questions (max=11)
ChemSense Group (N=156)	10.80	14.17	4.75	4.91	6.05	9.26
ChemSense students who missed activity but joined discussion (N=30)	11.69	13.53	4.77	4.97	6.92	8.57
Control Group (N=151)	N/A	11.5	N/A	4.8	N/A	6.7

Within the ChemSense treatment group, scores were also compared between students who constructed the animation assignment within three classes and those who did not construct animations but participated in the culminating whole-class discussion of a subset of animations generated by the students. There was no significant difference between these two subgroups, but the "accelerated" students who missed the activity (because they were away taking the high school exit exam) showed slightly higher pre-test scores particularly, for the conceptual questions (as might be expected from accelerated students), and slightly smaller gains from pre- to post-test (as might be expected from missing the activity). However, the fact that they had gains at all could be attributed to their participation in the whole-class discussion.

Discussion

Based upon the analysis of our data, it appears that students who participated in the ChemSense activities, learned to better visualize changes at the particle level during the phase changes of H_2O than those students who did not participate in the ChemSense animation activity. It is interesting to note, however, that in the classroom in which some students constructed the animations and some students simply viewed and discussed the animations constructed by others, there was no significant difference in achievement between the two groups. It suggests that viewing animations that other students construct, within the context of a whole class discussion directed toward knowledge building, may be as effective as constructing the animation. It would be very interesting to further explore this comparison.

Wrap-Up of Study 1

This study suggests that the student construction of an animation of a group of molecules during phase changes helps students to understand the particle level interactions better than traditional reading, lecture and laboratory methods of pedagogy. It further suggests that viewing and analyzing student-constructed animations within a whole-class-knowledge-building discussion context may also be an effective at teaching strategy.

Further research needs to be conducted in this area to make the findings conclusive. Teacher effect needs to be eliminated, as does treatment and comparison groups' curricular activities. Time-on-task also needs to be exactly matched. Additional studies could compare the relative effectiveness of different visualization strategies in enhancing student conceptual learning in about phase changes. Students constructing animations of chemical processes on other chemical topics, such as equilibrium and LeChatelier's principle, gas laws, reaction mechanisms and others could also be explored as a technique to promote deeper student understanding of particle interactions in chemistry.

Other artifacts examined…..

We looked at teacher journals. These journals were for the purpose of reflecting about the how the ChemSense learning activity supported student learning for the purpose it was designed and used. They also wrote about ways that the activity could be improved. With one exception, teachers reported that though they often had improvements to suggest, middle and lower academic students increased their understanding of the particle interactions as a result of creating animations illustrating them. The higher academic students seemed impatient with the time that it took to create an animation. They often felt like they knew the material well enough, so did not benefit from the added focus on the topic. Teachers indicated that they plan to continue to use ChemSense in their classrooms. Upon examination of how many teachers, in fact, did continue to create accounts for their students and assign activities, it was noted that all but one of the teachers continued to use ChemSense.

We administered surveys to the students who used ChemSense. Students indicated overwhelmingly that they enjoyed creating animations with ChemSense. They reported that they preferred to learn a concept by engaging in these collaborative activities than by listening to their teachers lecture. There were exceptions expressed. The exceptions involved the higher academic end students as before mentioned.

We have examined videos of students while they were constructing the assigned animations of chemical phenomena. The students' discourse indicated more discussion about chemical phenomena as they interacted to create their representations. We conducted video analysis of the wrap-ups after parallel activities were assigned to students; one using ChemSense and one engaged in some other activity. The other activity was usually a paper and pencil equivalent of the ChemSense activity. We found that during the ChemSense wrap-ups, fewer verbal descriptions and explanations were used than with the nonChemSense students. The teacher pointed to the animations around which to center the class discussion. In the wrap-ups with the paper and pencil activities, many more words and gestures were used by the teacher in an attempt to explain the same chemical phenomena as in the ChemSense classes.

We are currently looking at student produced animations over time. We would like to see whether there is an increase in the accuracy and complexity of the representations that the students produce. University of Michigan Ph.D. candidate, Alan Kiste, analyzed the representations produced by students in two parallel classrooms of general chemistry students. One of the classes created animations using ChemSense and the students in the other classroom used storyboarding to illustrate their ideas. Alan compared both groups of drawings with those of expert chemists. He found that the representations created by the students who had used ChemSense were closer to those of expert chemists than were the drawings made by students who had only storyboarded their thinking.

We will post these, and other reports to our website when completed. Overall, the data indicate that students enjoy the ChemSense activities, teachers feel like the software is an effective teaching tool and in some cases constructing animations and/or viewing them in a teacher led debrief yields better student understanding of particulate level chemical interactions.

Part III: Get Free ChemSense Software and Related Resources

As we have a web page, http://www.chemsense.org/, that makes available information about the ChemSense project, our participants, the research, curriculum activities, download information and related references. By accessing the home page you are able to go all other related information. I will provide a brief listing and description to direct you to the download page and some of the other key resources to help you to use ChemSense Studio in your classroom. Lastly, I will suggest an easy way for you and your students to learn how to use ChemSense.

ChemSense urls and descriptions of key resources

Download ChemSense Studio: http://chemsense.org/chemsense/do/DownloadAction

This page will take you to a registration page, tell you about the different options that you have for using ChemSense and give download instructions.

Curriculum Activities: http://www.chemsense.org/classroom/activities.html

This page will give you access to teacher produced curriculum activities. Teachers have submitted their work to be shared by following a template which describes the activity, aligns it with standards, identifies prerequisite knowledge and includes a scoring rubric with which to assess student work. The lessons are available in word or in a pdf format. If you create a ChemSense lesson that has worked well, you may share it with others. This page links to instructions on how to submit your lesson.

Five time dependent chemistry themes: http://www.chemsense.org/classroom/index.html

The five themes described here were developed by Dr. Brian Coppola to describe essential features of chemical interactions that are best captured by time dependency. These were the foundational ideas upon which the ChemSense Studio was designed to help students

Getting started

It is important that you try using ChemSense to learn about its features before introducing the software to your students. A quick method is to download the lesson ‘Getting to Know You’ from the curriculum page and follow those instructions. This lesson is designed as the introductory lesson to students with instructions on how to use ChemSense. Simply follow these directions. There are two quick start guides that explain about the affordances of the software more comprehensively than does the lesson intended for students. These are available for download at http://chemsense.org/guide/.

After learning how to use ChemSense yourself, you will be ready to introduce it to your students. We hope that you find that using this additional tool to your arsenal of teaching techniques is gratifying for you and your students.